# Historical Review of Sandalwood (*Santalum spicatum*) Research in Western Australia

by O.W. LONERAGAN

Research Bulletin No 4 December 1990

Department of Conservation and Land Management

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**Research Bulletin No 4**
**December 1990**

Published by the
Department of Conservation and Land Management
Como Western Australia

ISSN 1032-8106

Marianne Lewis ........ Editor
Glenda Godfrey ........ Page Preparation
E.M. Mattiske & Associates ........ Illustrations
CALM Mapping ........ Maps
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# Abstract

This paper presents a synthesis of the research information and results collected over the last century on Sandalwood in Western Australia. The information presented is based on a range of experiments and observations undertaken by a large number of individuals in the Forests Department and its successor, the Department of Conservation and Land Management.

The Western Australian Sandalwood industry is restricted by the slow growth of the *Santalum spicatum*, the low rate of natural regeneration, the low germination rate and the previously unregulated exploitation of the resource.

The Western Australian Sandalwood tree takes from 50 to 90 years to grow to a commercial size in the more arid areas of Western Australia. Flowering is sporadic as a result of irregular rainfall in the majority of areas where it still remains. The seed germinates after extremes in temperature and rainfall. Observations in the field have indicated that only 1 to 5 per cent of the seeds germinate. The rate of germination and survival is higher in reserves, protected research and plantation areas, but still below 20 per cent. This low germination and survival is further discouraged by the susceptibility of Western Australian Sandalwood to damage by fires and grazing.

Providing regeneration areas can be protected from grazing, successful regeneration of Sandalwood on an operational and plantation scale can be achieved by sowing four Sandalwood seeds per spot in appropriate well drained sites, 50-70 mm below the soil and mulched in a small depression at the drip line of the south side of a suitable host plant.

# Introduction

The purpose of this Bulletin is to collate and summarize what is currently known about the life history, ecology and silviculture of Sandalwood (*Santalum spicatum*, (R.Br.) A.DC.) in Western Australia. Given the historical commercial importance to the State of the aromatic wood from the Western Australian (W.A.) Sandalwood and the recognised need to conserve this natural resource, very little has been published on this species.

Research on Sandalwood in Western Australia has been associated with the historical development of forestry research in the State and the awareness of the need to conserve W.A. Sandalwood (*Santalum spicatum*) and maintain the Sandalwood industry.

The majority of research information on W.A. Sandalwood has been accumulated from long-term observations and experimentation undertaken by officers of the former Forests Department of Western Australia. The critical aspects for the Sandalwood industry relate to the relevance of this past effort to the long-term survival of Sandalwood and therefore the Sandalwood industry in Western Australia.

In the early days of settlement, W.A. Sandalwood occurred in the Wheatbelt Region and pastoral and arid lands south of latitude 24° in Western Australia (Fig. 1).

Western Australian Sandalwood is a stoutly-branched tree or shrub, growing to a height of 8 m, with a canopy diameter of 2 m (Plate 1). Unlike other commercial tree species, W.A. Sandalwood is not sawn or chopped down: the trees are pulled out of the ground, because the root, butt, stem and branches are all valuable for commercial products and coppice is an insignificant proportion of regeneration. The following plates illustrate the cutting of roots (Plate 2), a pulling tractor which is used to extract Sandalwood (Plate 3), the loading of wood (Plate 4) and a Sandalwood pullers' camp (Plate 5). Dead W.A. Sandalwood is also salvageable. The heartwood is highly valued for its aromatic oils (Kealley 1989).

The East Indian Sandalwood (*Santalum album*) was once harvested from various resource areas in the Asian countries, notably Indonesia and the Spice Islands in the second century A.D., and from Timor to Calicut in about 1550. It was imported into India and China. The occurrence of disease and exploitation in the East Indian Sandalwood reduced this resource. At the time of European settlement in Western Australia (1829) India and China were obtaining the wood from the diminishing Asian resource. By 1843 the value of the Western Australian Sandalwood, through its aromatic wood for religious and artistic uses by the Chinese, was rapidly recognized by the early settlers and the Western Australian commercial industry for *Santalum spicatum* rapidly expanded.

The W.A. Sandalwood trade was one of the original industrial activities of the early Swan River Colony in Western Australia. The first four tons of Western Australian Sandalwood was shipped from Fremantle to Ceylon in 1845 (Talbot 1983). By 1848, Sandalwood had become Western Australia's primary industry, for example, the export trade of 3048 tons in 1868 was forty times more valuable than all the other timber exports combined from Western Australia. Historical summaries of the Sandalwood industry in Western Australia are also provided by Underwood (1954), Drake-Brockman (1960), Donovan (1975), Ware (1975), Williams (1979), and Talbot (1983).

Tambellup and other Western Australian 'Wheatbelt' towns owe their origin to Sandalwood, which proved a reliable source of income for struggling primary producers, although the Sandalwood industry was initially restricted by the need to cart the wood over long distances to the ports at Geraldton, Bunbury, Fremantle, Albany and Hopetoun. As transport facilities improved the commercial Sandalwood industry spread eastwards to Southern Cross and Kalgoorlie. Initially this spread followed the railway line in 1894 to Southern Cross and then later in 1900 to Kalgoorlie. The commercial extraction of W.A. Sandalwood in the south-west of Western Australia expanded further in the period 1904 to 1919 with the development of other railway systems.

Sandalwood also enabled many farmers to retain agricultural holdings along the Great Southern Railway (Fall 1972). Funds from Sandalwood sales assisted land-owners through the difficult periods of drought, depression and market shortages for other farm produce, as well as helping many gold prospectors survive the periods between gold finds. However, the Sandalwood trade was itself subject to similar produce and market fluctuations. During

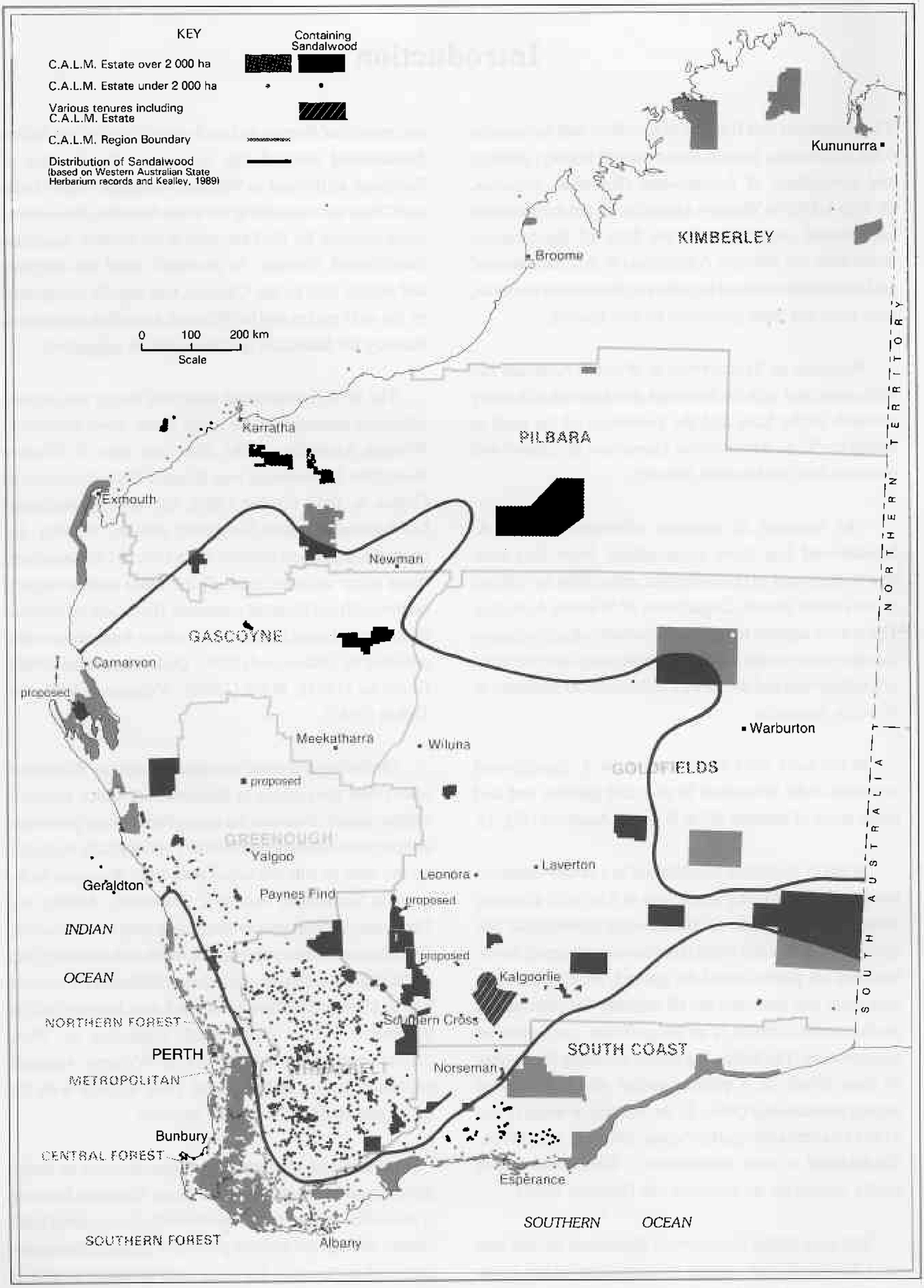


**Figure 1**
Distribution of W.A. Sandalwood (*Santalum spicatum*)

the slumps in the Sandalwood trade the local workforce had to turn to alternative employment (McMahon 1972) and many settlers were subjected to great hardships (Bolton 1972).

Slumps and gluts resulted from uncontrolled competitive marketing in the hundred years prior to the State Government's Sandalwood Act of 1929. Exploitation was destructive during the early days of settlement, when a quantity three times as large as the present residual Sandalwood resource was harvested. As a result of heavy buying, harvesting and stockpiling, China had four years' supply on hand, thereby enabling buyers from Shanghai and Hong Kong to manipulate the market; demand was subject to fluctuations. Huge stocks of Sandalwood accumulated at Fremantle and in China between 1919 and 1921. Consequently it became imperative that export be limited under Government monopoly, and a single permit was issued authorizing four firms to operate collectively from November 1923. (These amalgamated subsequently to form the Australian Sandalwood Company in 1930.) Western Australia agreed to restrict export from 1926 to 1930, because accumulated stocks continued to cause concern in the industry. Legislation in 1929 improved the management of the W.A. Sandalwood industry through an agreement between the Sandalwood Merchants' Association, formed in 1928, and the Sandalwood Export Committee which was chaired by the Conservator of Forests, Western Australia.

Unfortunately, by the time the industry was regulated for continuous employment and trade, the resource had been seriously depleted. The only significant resources remaining today are located in the eastern 'Goldfields' areas surrounding Kalgoorlie, Southern Cross, Lake Plumridge, the north-eastern Goldfields and areas surrounding Leonora, Laverton, Wiluna and the Gascoyne and Greenough Regions and areas surrounding Payne's Find, Meekatharra, Yalgoo (Fig. 1 and Appendix I). A few localized remnants still remain on previously harvested areas. These trees were left as some areas were inaccessible to the horse and dray, while others were immature at the time of earlier harvesting.

The establishment and growth of the W.A. Sandalwood (*Santalum spicatum*) is restricted by a low rate of natural regeneration and low germination and establishment rates of the seedlings. The Western Australian Sandalwood tree takes from 50 to 90 years to grow to a commercial size (127 mm diameter at 150 mm above the ground) in the more arid areas of Western Australia. Flowering and seed germination is spasmodic as a result of irregular rainfall and extremes in temperatures in the majority of areas where it still remains. The rate of germination and survival is higher in protected reserves, research and plantation areas, but still below 20 per cent (Kealley 1989). The low germination and survival rate is further diminished by the susceptibility of W.A. Sandalwood to damage by fires and grazing. These factors, combined with the early exploitation of the resource, made it inevitable that there would be a recognition of the need to improve research on Sandalwood and management of the industry.

These needs were recognized as early as 1895 by the first Conservator of Forests, Mr J. Ednie-Brown, who established an experimental Sandalwood farm at Pingelly and a reserve for seed production at Meckering. Unfortunately, it was not known until 1921 that Sandalwood is a root parasite, and there were extremely heavy losses, especially in the first summer months. Eventually, neither area survived agricultural clearing, grass fires and rabbit infestations. In 1921, the Conservator of Forests, Mr C.E. Lane-Poole, stated that it was urgent to commence a large-scale Sandalwood plantation in order to provide for future production before supplies became exhausted. A total of 1630 ha of land in Kalgoorlie, Southern Cross, Kondinin, Narrogin and Busselton areas were sown with Sandalwood seeds in the 1920s, but this work was discontinued during the 1930s depression. Although very little of the regeneration was successful, the few survivors have provided information on Sandalwood growth rates under different climatic conditions, which is invaluable for planning the future of Sandalwood in W.A.

As current Sandalwood exports from Western Australia exceed $10 million, it is economically important to improve our understanding of Western Australian Sandalwood. This species also warrants a significant place in the conservation arena as it has been, and still is, an integral part of the history and ecology of the State. Specific research topics covered in this Bulletin include seed production, germination and seedling trials, regeneration, cultivation and growth rates.

## NOMENCLATURE AND TAXONOMY

The taxonomy of the Western Australian Sandalwood (*Santalum spicatum*) has recently been summarized in Flora of Australia (George 1984).

> Shrub to 4 m tall. Bark rough, grey. Branchlets stiff, spreading. Leaves lanceolate to narrowly elliptic, flat, obtuse; lamina 2-7 cm long, 3-15 mm wide, concolorous, grey-green;petiole 3-5 mm long. Flowers numerous in panicles, scented; peduncle 3-5 mm long; pedicels 1 mm long. Receptacle 1-1.5 mm long. Tepals triangular-ovate, 1.5-2 mm long, scurfy inside, red-green, persistent in fruit; hair tufts small. Disc shortly lobed. Style 0.5 mm long; stigma bilobed. Drupe 1.5-2 cm diam.; epicarp green or brown; mesocarp firm, usually adhering to endocarp when ripe; endocarp smooth. *Sandalwood.*

Four species of the genus *Santalum* occur in Western Australia. Western Australian Sandalwood (*Santalum spicatum*, (R.Br.) A. DC.) is found only in Western Australia and South Australia, but the other three species - *S. lanceolatum* R.Br. (Plumbush), *S. acuminatum* (R.Br.)A. DC. (also called Quandong or Candle Nut) and *S. murrayanum* (Mitch.) C. Gardner (Bitter Quandong) are widely distributed throughout Australia. All three lack aromatic fragrance, but Plumbush contains oil. Plumbush has an ovoid, dark plum-like fruit and is widespread in tropical Australia and the Northern Territory, and extends south through the interior areas of most mainland States. Quandong fruit has a red outer covering, a deeply pitted stone and an oily, edible kernel; Bitter Quandong has a bitter brownish-red outer covering and a finely pitted stone. The Sandalwood fruit is illustrated in Plate 6. Quandong and Bitter Quandong are widespread throughout the warmer parts of temperate Australia. As *Santalum spicatum* has been exploited commercially in Western Australia, the research on this species has been more extensive. The research findings by the former Forests Department and the current Department of Conservation and Land Management are summarized in this Bulletin. Unless specified otherwise, Sandalwood, or W.A. Sandalwood in this Bulletin refers to the species *Santalum spicatum.*

# Distribution and Habitat

Prior to the development of agriculture in Western Australia Sandalwood was distributed mainly from latitude 24°S (approximately 80 km north of Carnarvon), eastwards along the lake system around the Nullarbor Plain into South Australia, south to a latitude of 35° and west as far as the drier fringe of the main forest area on the Darling Ranges (Fig. 1). Additional plants have been recorded in localized areas to the north of the main distribution (George 1984; Western Australian State Herbarium records) (Fig. 1).

Clearing for agricultural development in the 'Wheatbelt' (Fig. 1) has reduced the main distribution of Sandalwood from 90 million ha by 13 million ha to about 77 million ha. The main area of Sandalwood and the area available for harvesting is around 52 million ha. This loss of Sandalwood in the Wheatbelt areas was noted in the early 1920s by Lane-Poole (1921). Most of the remaining areas of Sandalwood are under lease for sheep grazing, with exceptions on Sandalwood Reserves, State Forests, National Parks, Nature Reserves and Timber Reserves (Appendix I).

Between 1980 and 1984 an assessment of Sandalwood was undertaken to determine the location and total Sandalwood resource. The assessment used aerial photography, landsat imagery and ground verification via available access roads and tracks. The assessment greatly improved the knowledge on distribution, habitat and size class distribution and quantified the total Sandalwood resource throughout its range (Kealley and Caporn[1], personal communication).

### LANDFORM AND SOILS

A framework for mapping the broad distribution of Western Australian Sandalwood is provided by the palaeo-drainage system of Beard (1973). Usually, Western Australian Sandalwood is present in the valley slopes of seasonal water-courses in the Greenough and Gascoyne Regions (Fig. 1), and around the main drainage systems of inland salt lakes. It is absent from the continental watershed and the interfluves of the Western Australian Pre-Cambrian Shield.

### VEGETATION

Western Australian Sandalwood occurs predominantly in low shrublands of *Acacia* species on the alluvial lower slopes of the main drainage lines in the Greenough and Gascoyne Regions and on the fringes of the adjacent woodlands of *Eucalyptus* on the clay soils. Other occurrences are irregular and scattered through the species range. *Santalum spicatum* avoids the woodlands of almost pure species of one genus - for example, *Eucalyptus dundasii* (Maiden), *E. longicornis* (F.Muell.) F.Muell. ex Maiden), *E. salmonophloia* (F.Muell.) and *E. salubris* (F.Muell.) and the Chenopod communities on the more saline areas. The previous patterns can be correlated with particular vegetation systems on Beard's vegetation maps (Beard 1972a, 1972b, 1972c, 1974, 1975a, 1975b, 1976a, 1976b and 1981; Beard and Webb 1974).

### CLIMATE

Western Australian Sandalwood occurs over a range of climatic conditions from Narrogin through Kalgoorlie to the semi-arid and arid areas. Early trials also included some plantings at Busselton, so the climatic conditions for Bunbury are also discussed. The climatic records for Kalgoorlie, Narrogin and Bunbury are summarized in Table 1. The climatic conditions are critical in determining its initial occurrence, its growth rates and also its ability to regenerate.

The critical differences for Sandalwood establishment and growth appear to relate to the regularity of rainfall, the length of the growing season and the regularity of frosts. The effects of recent rains on the crown foliage of Sandalwood near Kalgoorlie are illustrated in Plate 7.

The mean rainfall at Kalgoorlie is 257 mm, with the month of June averaging 31 mm. Dry spells at Kalgoorlie may occur for 5,7 and 9 consecutive months. These dry spells appear to have a marked effect on the ability of native species to germinate and survive. On average the growing seasons vary between 4.5 months from mid-March to the end of July, and 3.5 months from mid-May to the end of August (May-July being the most reliable months for rainfall).

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[1] Department of Conservation and Land Management, Kalgoorlie W.A.

The mean annual maximum temperature for Kalgoorlie is 25.1°C, while the mean annual minimum temperature is 11.5°C. Based on screen temperatures in Kalgoorlie , there are 10 frosts per year under 2.2°C and the frost-free period over 2.2°C is 297 days per year.

The climatic extremes are less severe in the Wheatbelt and coastal areas where trial plantings of Sandalwood have been carried out.

Narrogin, Perth and Bunbury all have a mediterranean climate with 75-85 per cent of the annual rainfall predominantly in the winter months (May to October for Narrogin - 78 per cent of the total rainfall, Table 1). The mean annual rainfall at Narrogin is 504 mm. Dry periods of seven consecutive months may occur in Narrogin once in 2.5 years. The length of the growing season is 5.6 months at Narrogin. The mean annual maximum temperature at Narrogin is 22.2°C, while the mean annual minimum temperature is 9.9°C. Based on screen temperatures, there are 7 frosts per year under 2.2°C.

The mean annual rainfall at Bunbury is 871 mm. Dry periods of six consecutive months may occur in Bunbury once in three years. The length of the growing season is seven months at Bunbury. The mean annual maximum temperature at Bunbury is 21.9°C, while the mean annual minimum temperature is 12.4°C. Based on screen temperatures, there are two frosts per year under 2.2°C.

**Table 1**

SUMMARY OF CLIMATIC CONDITIONS FOR KALGOORLIE, NARROGIN AND BUNBURY
(Extracted from records of Bureau of Meteorology - Perth)

| | *Jan* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sep* | *Oct* | *Nov* | *Dec* | *Year* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *KALGOORLIE* | | | | | | | | | | | | | |
| *Temperature (°C) - 48 years of Records* | | | | | | | | | | | | | |
| Mean Maximum | 33.6 | 31.9 | 29.7 | 25.1 | 20.4 | 17.5 | 16.5 | 18.3 | 22.1 | 25.6 | 28.9 | 32.0 | 25.1 |
| Mean Minimum | 18.2 | 17.6 | 15.9 | 12.4 | 8.3 | 6.2 | 4.8 | 5.4 | 7.8 | 10.8 | 13.9 | 16.5 | 11.5 |
| *Rainfall (mm) - 50 Years of Records* | | | | | | | | | | | | | |
| Mean Rainfall | 22 | 28 | 19 | 19 | 28 | 31 | 26 | 20 | 15 | 16 | 18 | 15 | 257 |
| Mean Raindays | 3 | 4 | 4 | 5 | 7 | 8 | 9 | 7 | 5 | 4 | 4 | 3 | 63 |
| *NARROGIN* | | | | | | | | | | | | | |
| *Temperature (°C) - 22 Years of Records* | | | | | | | | | | | | | |
| Mean Maximum | 30.8 | 29.9 | 27.1 | 22.5 | 18.3 | 15.3 | 14.6 | 15.1 | 17.3 | 21.2 | 24.9 | 28.9 | 22.2 |
| *Temperature (°C) - 21 Years of Records* | | | | | | | | | | | | | |
| Mean Minimum | 14.7 | 14.9 | 13.5 | 10.9 | 8.2 | 7.0 | 5.8 | 5.6 | 6.3 | 8.1 | 10.7 | 12.8 | 9.9 |
| *Rainfall (mm) - 98 Years of Records* | | | | | | | | | | | | | |
| Mean Rainfall | 10 | 17 | 21 | 30 | 65 | 92 | 89 | 68 | 47 | 34 | 18 | 13 | 504 |
| Mean Raindays | 2 | 3 | 4 | 6 | 11 | 15 | 15 | 14 | 11 | 9 | 5 | 3 | 98 |
| *BUNBURY* | | | | | | | | | | | | | |
| *Temperature (°C) - 21 Years of Records* | | | | | | | | | | | | | |
| Mean Maximum | 27.8 | 28.2 | 26.0 | 22.5 | 19.9 | 17.8 | 16.9 | 17.0 | 18.0 | 20.2 | 22.5 | 25.5 | 21.9 |
| *Temperature (°C) - 20 Years of Records* | | | | | | | | | | | | | |
| Mean Minimum | 16.4 | 17.0 | 15.4 | 13.2 | 11.1 | 9.7 | 9.0 | 8.8 | 9.7 | 11.0 | 12.9 | 14.9 | 12.4 |
| *Rainfall (mm) - 108 Years of Records* | | | | | | | | | | | | | |
| Mean Rainfall | 11 | 12 | 22 | 46 | 128 | 183 | 171 | 124 | 80 | 54 | 26 | 14 | 871 |
| Mean Raindays | 2 | 2 | 4 | 7 | 14 | 18 | 20 | 17 | 14 | 11 | 6 | 4 | 119 |

# Descriptive Features of Sandalwood

## PHENOLOGY

The species of *Santalum* are distinguished by their variability in height, form, leaf shape, colour and fruiting patterns (Sedgley 1982).

In the Perth metropolitan area, Western Australian Sandalwood produces flower buds at the age of three or four years, and the first seedcrop sets at six or seven years. Panicles of flower buds, terminal and axillary, appear from mid-summer (about February) to autumn, and the main blossoms are fully developed by about May. The fruits mature usually between October and January, and fall to the ground during January and February. The ripe fruit has a leathery tan-brown outer epicarp and a smooth round, inner nut or endocarp.

## WOOD

The wood includes sapwood (pale yellow) and heartwood (usually dark brown). The heartwood and the roots contain the strongly aromatic Sandalwood oil. Density at 12 per cent moisture content (air dry) is 810 kg. $m^{-3}$.

## ROOTS

The lateral roots of Western Australian Sandalwood may run for 25-30 m, but rarely extend more than 200 mm deep, even in deep sandy soils (Plate 8). The root butts can regenerate shoots after injury to the parent tree, but rarely do so in the field. Generally, along the whole length of the lateral roots, fine feeder roots renew the search for suitable host roots during the growing season.

## PARASITISM

The root parasitism in the *Santalum* genus has been summarized by Herbert (1925). The fine roots, which develop on the extensive lateral roots of the Sandalwood, produce a lateral haustorium with roots of other species. The range of hosts which one plant may be living on may vary in number and variety (Herbert 1925; Western Australian Forests Department 1925). The haustoria are produced in large numbers, although the haustoria have only a limited functional existence.

Therefore, *Santalum spicatum*, although capable of photosynthesis, is an obligate parasite, which can survive only by parasitising through the development of haustoria on a wide range of host species (Table 2), usually of the genera *Eucalyptus* and *Acacia* (Herbert 1925; Gardner 1928; Kuijt 1969).

**Table 2**
HOST SPECIES RECORDED FOR
*SANTALUM SPICATUM*

| |
|---|
| *Acacia acuminata* (Benth.) |
| *Acacia aneura* (F.Muell. ex Benth.) |
| *Acacia colletioides* (Benth.) |
| *Acacia hemiteles* (Benth.) |
| *Acacia linophylla* (W.Fitzg.) |
| *Acacia tetragonophylla* (F.Muell.) |
| *Cassia chatelainiana* (W.Fitzg.) |
| *Cassia nemophila* (Cunn. ex Vogel) |
| *Casuarina cristata* (Miq.) |
| *Dodonaea lobulata* (F.Muell.) |
| *Eremophila alternifolia* (R.Br.) |
| *Eremophila dempsteri* (F.Muell.) |
| *Eremophila ionantha* (Diels in Diels and E. Pritzel) |
| *Eremophila oldfieldii* (F.Muell.) |
| *Eremophila oppositifolia* (R.Br.) |
| *Eucalyptus loxophleba* (Benth.) |
| *Eucalyptus wandoo* (Blakely) |

## ADAPTATION TO DROUGHT

Western Australian Sandalwood is well-adapted to drought conditions. The radicle of the germinating seed is long and brittle and buries rapidly into the soil, given sufficient moisture and warmth. Development independent of a host plant is able to continue while the nutrient of the endosperm of the seed is available for the growth of the shoot above ground and the root system. Although Western Australian Sandalwood has a shallow root system, its parasitic habit allows it to draw nourishment from the extensive and deeper root systems of host plants. By means of this adaptation, Western Australian Sandalwood not only withstands drought, but may maintain growth during a dry spell. Observations have indicated that under extreme drought stress the parasite will die before the host.

## SANDALWOOD OIL

The British Pharmacopoeia describes Sandalwood oil as:

> a colourless or pale yellow oily liquid with a characteristic odour and unpleasant taste, containing not less than 90 per cent W/W of free alcohols. Mass per millilitre is 0.964 to 0.974 grams, soluble 1 in 3 to 6 of 70 per cent alcohol.

Western Australian Sandalwood oil, has an optical rotation of -8° to -3°. East Indian Sandalwood oil has an optical rotation of -15 ° to -21°, has more odour and is more bitter. The optical rotation of the oil of *S. lanceolatum* (Plumbush) is from -30° to -40°. The oils from these two W.A. *Santalum* species could be blended to produce the same optical properties as the East Indian Sandalwood oil.

The oil has a specific gravity of 0.975 at 15.5°C,a refractive index of 1.507 at 20°C, and total alcohols over 90 per cent as santalol. These are principally alcohols of the sesquiterpene group. Anomalous properties of Western Australian Sandalwood oil have been explained by the content of farnesol, an acrylic primary alcohol (Birch *et al*. 1953).

The commercial yield of oil varies from 2.4 to 2.9 per cent for roots and butts. Trees from semi-arid areas have been recorded as producing the highest quality oil (Western Australian Forests Department 1925). Relatively fast grown plantation trees in the Dryandra Forest, near Narrogin, at 22 and 47 years have yielded 49 and 74 per cent of the yield of mature trees (i.e. 1 per cent - 2 per cent oil). Extracts from the sapwood at 22 and 47 years have yielded 13 and 19 per cent respectively of the extracts of the heartwood (i.e. percentages of oil in the sapwood of 0.2 and 0.4). Extracts from the sapwood of mature trees at Narrogin have yielded 22 per cent of the extracts of heartwood (0.6 per cent of oil in the sapwood). Mature trees at the southern limits of distribution (Ravensthorpe) yielded about 1.5 per cent oil or half of the yield of trees from the arid region. Oil yield from heartwood at 15 years of age on coastal sand near Perth was 0.5-1.0 per cent, or about quarter of that of inland mature trees.

A unique method was used to extract the Sandalwood oil. This involved subjecting the finely ground wood to extraction with a volatile solvent, then the extract was vacuum distilled (Rock 1967). The medicinal values of the oils of the *Santalum* spp. were recognized by the Australian aborigines and early settlers (Aboriginal Communities of the Northern Territory of Australia 1988).

Since the discovery of penicillin and the development of modern antibiotics, the medicinal importance of sandalwood oil has declined. In recent years the sandalwood oil has been substituted as a fixative in cosmetics, soaps and perfumes. Despite this decline the commercial operations have been maintained for the unique aroma of sandalwood joss-sticks. Prior to June 1950, sandalwood oil sales exceeded the value of the wood sales by $1 195 460. The export value of the oil was similar to that of the raw wood until 1971, when these supplies ceased.

# History of Research on Sandalwood

**EARLY REGENERATION STUDIES - 1895**

Planting of Sandalwood in Western Australia commenced after the formation of the Woods and Forests Department (as a branch of the Lands Department) in 1895-1896. Initially, an area of 2 ha near Pingelly was ploughed, fenced and planted with Sandalwood nuts in August 1895. Both the native W.A. Sandalwood (*Santalum spicatum*) and the East Indian species (*Santalum album*) were sown.

The W.A. Sandalwood germinated freely. In contrast the East Indian species did not germinate freely. The seeds of the latter are smaller than the W.A. Sandalwood (George 1984) and observations have indicated that the seeds of the East Indian species lose their viability with time.

**REGENERATION STUDIES - 1920 TO MID 1950s**

A further 192 ha were sown with W.A. Sandalwood during the 1920s, using seeds obtained locally by contract Sandalwood pullers. The total area sown was increased to 1630 ha by 1930. In 1931, a decision was made to cease further widespread sowing until results from the areas already established could be evaluated.

During the Depression years (1929 - 1933), a series of experimental plots were established on a range of soil types, from sandy-loams at Kalgoorlie to yellow sands at Busselton (formerly growing stands of tuart (*Eucalyptus gomphocephala* (DC.)) (Table 3).

The seed was usually sown without pre-treatment. In some tests, however, the seed was cracked and soaked overnight. The soil was loosened with a hoe at 3 to 4 m intervals, and the seed sown to a depth of 20 to 50 mm (Kalgoorlie) or 50 to 100 mm (Dryandra-Narrogin).

Following the discovery, in 1921, that Sandalwood is parasitic, seeds were sown immediately beneath host plants; the density of sowing depending on the density of potential host species. In experimental areas where host plants were few or absent, seeds of *Acacia hemiteles* (Benth.) and *Cassia nemophila* (Cunn. ex Vogel) were sown either before or simultaneously with the Sandalwood sowing.

**Table 3**

SUMMARY OF SANDALWOOD SOWINGS IN 1920 TO MID 1950s

(Based on Departmental Files and Western Australian Forests Department Annual Reports)

| *Date* | *Area (ha)* | *Location* |
|---|---|---|
| *KALGOORLIE* | | |
| 1927 | 160 | Cowine, near Southern Cross |
| 1928 | 383 | Lakeside Sandalwood Reserve |
| 1925-30 | 781.65 | Karramindie State Forest |
| 1928-30 | 1-8 | Calooli, Coonana and Scahill Sandalwood Reserves |
| *NARROGIN* | | |
| 1921 | 15 | Bendering Reserve 25081 |
| 1922-23 | 90 | Bendering Reserve 25081 |
| 1925 | 93 | Bendering Reserve 25801 |
| 1931 | 5-10 | Dryandra Reserve 8324 |
| 1956 | 0.1-1 | Lol Gray, Bald Rock, Corakin,Peters, Smith and Stokes Blocks Dryandra State Forest |
| *BUSSELTON* | | |
| 1931-35 | NA | State Forest. Young plantations of *Pinus pinaster* and *Pinus radiata* |

The seeds were often graded for size. The larger seeds (over 18 mm) were sown because it was thought they gave the young seedlings a better chance of surviving the period prior to host attachment.

Most areas were fenced to exclude kangaroos, rabbits and domestic stock. In rabbit-infested areas, sowings were often protected using galvanized iron tubes or wire netting guards.

**Germination**

On the basis of observations summarized in Forests Department records and the Western Australian Forests Department Annual Reports (1920-1950), the higher germination of Sandalwood was obtained from fresh seed, treated by soaking overnight. Although some buried seed germinated four years after sowing, two years was recognized as the useful limit of viability (Western Australian Forests Department 1927).

Germination rates were invariably low, and higher germination rates occurred only after one or more years of rainfall, usually exceeding 100 mm or more, or 25 mm per month for three months from the time of sowing.

Observations indicated that sowing in January favoured seed germination. Germination of the seeds appeared to be favoured by the higher temperatures in the summer months (Table 1). Other observations indicated that the pattern of sowing in late summer or early autumn, with opening rains in autumn, followed by winter rains, produced higher seed germination results. Therefore, the combination of temperatures and prevailing soil moisture levels appeared to be the main determinants of favourable seed germination.

**Establishment and Survival**

On the basis of observations summarized in Forests Department records and the Western Australian Forests Department Annual Reports (1920-1950), the best overall establishment and survival results were achieved on lower slopes with loam or sandy loam soils. Light soils gave poor results in the dry seasons, while in the wet seasons clay soils gave poor results because seeds were washed away (Western Australian Forests Department 1925, 1927, 1930).

Prior to host attachment, seedlings protected from the direct rays of the sun survived three to five months longer than exposed seedlings.

Grass and shrub growth on the light to medium soils was observed to protect and sometimes to provide temporary host tissue for the Sandalwood seedlings in their establishment growth period (Western Australian Forests Department 1927).

The best establishment and survival rates were in the order of 1 per cent at Kalgoorlie and Dryandra-Narrogin. The growth potential of 28-year-old Sandalwood, that established and survived, is illustrated at Frank Block (Plate 9) and Stokes Block (Plate 10).

**Pests**

In these series of trials, the surviving seedlings of Sandalwood were prone to rabbit attack during the first three to four years. Although the seedlings resprouted, heavy losses were experienced following continuous grazing. In most instances, rabbits browsed the seedlings in late summer when other fodder stocks were very degraded (Western Australian Forests Department 1925).

Insect attacks on regeneration were first noted in June 1930, when new shoots and leaves were destroyed by the larvae of a native Chrysomelid beetle (Western Australian Forests Department 1930). Such attacks appear to be periodic; however, at times diseased Sandalwood was heavily affected by scale insects of *Mytilaspis* and *Eriococcus* species. Damage to Sandalwood by wood borers and defoliators was usually not widespread.

**Summary**

These early regeneration studies indicated that germination and survival of Sandalwood was most successful on water run-on sites, and in areas where there was a range of potential host species. Seeds of 18 mm or more in diameter favoured germination and two to three spot-sown seeds at a depth of 25 to 50 mm directly below the canopy of the host species favoured the establishment of Sandalwood.

## REGENERATION STUDIES - 1973 TO 1979

Fifty years of observations and measurements had provided useful information on Sandalwood establishment, growth rate and yields. Data on regeneration were still lacking and further research programs were developed in the 1970s. In 1973, a new series of plots were designed to examine the management of W.A. Sandalwood regeneration in the inland Mulga (*Acacia aneura*, F.Muell. ex Benth.) and Eucalypt woodlands. The work was carried out in the Kalgoorlie and Narrogin areas. The observations and results are summarized by topic in the following chapters.

## REGENERATION STUDIES - 1981

On the basis of the research carried out from 1895 to 1979 a series of trials were established in the Dryandra forest near Narrogin to investigate the regeneration of Sandalwood with a diversity of seeds, seedlings and germinants on a range of site conditions. The observations and results summarized in the following chapters should assist future regeneration of Sandalwood on an operational and plantation scale.

# Sandalwood Seed

### SEED PRODUCTION

One of the main determinants of seed production is the prevailing climatic conditions. Observations at Kalgoorlie have revealed that in the years of moderate rainfall Western Australian Sandalwood usually flowered and set seed in one year. In contrast, after a drought spanning two years, two consecutive years of reasonably high rainfall are needed to allow full crown recovery, flowering and seed set. For example, in April 1973, the Sandalwood at Kalgoorlie flowered and set seed for the first time since the onset of a four-year drought in 1969 (annual rainfall was 55 per cent of the average during the drought) (Fig. 2). The wet year in 1973 at Kalgoorlie was also followed by a widespread and abundant seed crop in 1974. However, by 1978, seed production had fallen to less than 25 per cent (in some cases less than 10 per cent) of the higher 1974 level.

Davies (1976) recorded that fruit set at Mileura (near the mouth of the Murchison River) was correlated with April rain and cold winters. He concluded that cool conditions favoured the species, as is likely considering its southern distribution. The best years of Sandalwood seed production recorded at Mileura by Davies were 1966, 1968 and 1971. During this period the summer rainfall was average or better than average. In 1971, when there was no rain in April, both summer and winter rainfall were above average.

In 1978, the Lol Gray stand of 46 trees at Dryandra, near Narrogin, produced an average of 150-200 seeds each, with a range from nil to two thousand per tree. The seed was noticeably larger than that of the Kalgoorlie provenances. The average seed number per kilogram was 277. It was picked up in October after lying under the parent trees for ten months. Observations during this experiment indicated that emus, through their digestive processes, may have influenced local seed distributions. Similar findings were made earlier by officers of the Western Australian Forests Department (1925).

The site conditions and resultant vigour of the Western Australian Sandalwood trees can also affect the seed production levels. Observations at Calooli and Bullock

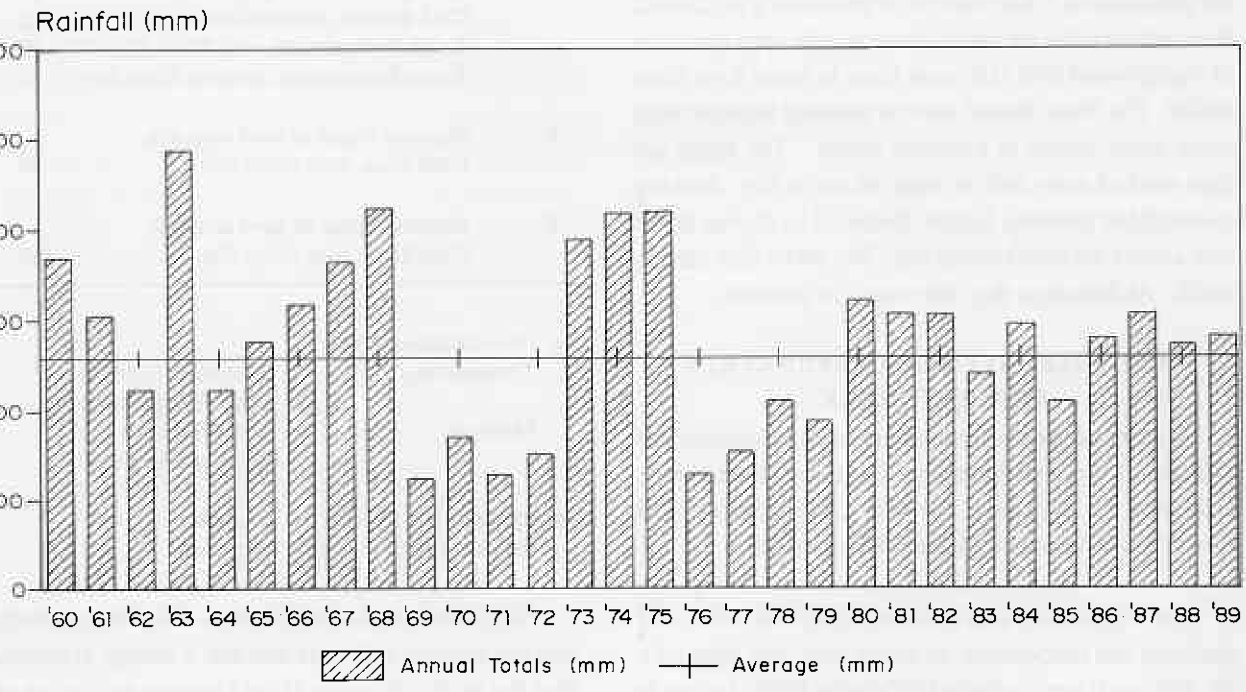


**Figure 2**
Kalgoorlie yearly rainfall (1960 - 1989)

Holes Sandalwood Reserves on different site conditions in 1978 and 1979 reflected budding and flowering of the Sandalwood trees. All the mature fruit dropped from the trees at Bullock Holes, and was collected in January 1979. No fruit matured at the less favourable ridge site at Calooli. Trees under stress did not flower, and further incipient budding and flowering in March 1979 failed to set seed in both reserves. At Bullock Holes, the average production in 1978 was 28 mature fruit per tree ( and five undeveloped fruit which was not collected). The mature seed number per kilogram was 460 with the endocarp retained and the epicarp removed.

The vigour of the trees was also affected by the scale insects. The scale was particularly evident in the below-average rainfall years. It was most noticeable in August 1979. In the preceding January to March, incipient flush with some new leaves appeared in about half of the trees. Although black scale was very evident when seed production was absent during the study period in the 1970s, other observations have shown that insect infestations are reduced by adequate rain.

## PRE-SOWING SEED TREATMENT

Several methods for the germination of Sandalwood (*S. spicatum*) and Quondong (*S. acuminatum*) seeds have been tried previously (Grant and Buttrose 1978; Crossland 1981, 1982; Sedgley 1984). All these methods involve detailed preparation of the seed and controlled conditions for germination. Observations on pre-sowing treatments have indicated that the optimum method for large quantities of Sandalwood fruit is to soak them in water for a short period. The fruits should then be tumbled together with some heavy stones in a cement mixer. The husks are then washed away and the nuts set out to dry. Soaking overnight or possibly longer, followed by drying in the sun, allows the shells to dry out. The shells then start to crack. At this stage they are ready for planting.

## SEED VIABILITY AND GERMINATION AFTER STORAGE

A series of tests were undertaken to investigate the viability of Western Australian Sandalwood seed in the field and in storage. Previous investigations had concentrated on seed less than two-years-old.

The experiment was initiated to test the effects of moisture and temperature on stored seed (see Appendix II). The seeds were collected in October 1974. The seeds were soaked overnight and the endocarp (hard coat) of some of the seeds was cracked in a vice. Seed viability tests were carried out initially, after two years, five years, eight years and nine years on varying seed treatments. The findings are summarized in Table 4. The decline in seed viability observed in Sandalwood at five years supports similar findings by Sedgley (1984), where Quandong (*S. acuminatum*) germination rates started to decline after five years.

**Table 4**

SUMMARY OF SEED VIABILITY AND GERMINATION TESTS AFTER STORAGE

| *Time of Seed Viability Tests (Years)* | *Seed Treatment* | *Seed Germination Rate (%)* |
|---|---|---|
| 0 | seeds soaked overnight & endocarp[b] cracked in vice | 84 |
| 2 | 400 seeds with endocarp removed, four treatments[a]. Germination terminated in 6 weeks | |
| | Average for four treatments | 76.5 |
| 5 | 400 seeds with endocarp removed, four treatments [a] Germination terminated in 13 weeks | |
| | Average for four treatments | 34 |
| 9 | 160 seeds with epicarp intact, four treatments [a] | |
| | Cold Storage, with Silica Gel | 50 |
| | Cold Storage, without Silica Gel | 22 |
| | Room Temperature, with Silica Gel | 30 |
| | Room Temperature, without Silica Gel | 15 |
| 8 | Separate Serial of Seed stored in Cold Store, with Silica Gel | 57 |
| 9 | Separate Serial of Seed stored in Cold Store, with Silica Gel | 52 |

(a) Four Treatments were:

| | | |
|---|---|---|
| Temperature | - | Cold Store (4-5°C) |
| | - | Room Temperature |
| Moisture | - | With Silica Gel |
| | - | Without Silica Gel |

(b)

| | | |
|---|---|---|
| Epicarp | - | outer coat |
| Endocarp | - | hard coat |

The Sandalwood results indicate that the germination rate deteriorates with time and that if storage is required then the preferred option is cold storage with silica gel. In addition, a continuing regeneration program would require storing twice the annual requirements for a period of up to eight years. The need to maintain the store of seed from the seed production years becomes critical, particularly for areas such as Kalgoorlie (see previous discussion on Seed Production).

## SEED GERMINATION AT NARROGIN

A series of tests were undertaken to investigate the effects of shelling the seeds (removing the endocarp) on the germination of 25 000 Sandalwood seeds (see Appendix III).

The results indicated that the maximum germination was attained for seed without shells in 16 days, and for intact seed in 36 days. Sixty-two per cent of the unshelled seed and over 80 per cent of the shelled seed germinated. The initial germination advantages of shelling were also observed by Sedgley (1984) for Quandong (*S. acuminatum*). Later observations on Sandalwood indicated that although shelling the seeds appeared to favour germination, leaving the endocarp intact appeared better for seedling survival.

# Germination and Seedling Establishment of Sandalwood

A series of experiments were designed to investigate the germination of Western Australian Sandalwood seedlings with different host species at Narrogin and Kalgoorlie in both nursery and field situations (see Appendix IV and Appendix V).

### NARROGIN TRIALS

Host species included Mulga (*Acacia aneura*), Jam (*Acacia acuminata*, Benth.), *Acacia hemiteles*, *Cratystylis subspinescens* (F.Muell. & Tate), *Maireana polypterygia* ((Diels) Paul G. Wilson) and *Atriplex amnicola* (Paul G. Wilson).

Results are summarized in Appendix IV and Table 5. Survival was initially favourable, however, survival decreased over the first summer. The low survival of Sandalwood (2 per cent irrespective of experiment) and the better survival of the host species of Mulga (22 per cent) and Jam (17 per cent) in the field, suggested that Sandalwood failed to make satisfactory union with the roots of nurse plants while in the nursery, as well as with the roots of the natural hosts in the native vegetation near Narrogin. The latter failure of the development of haustoria was confirmed by inspection of washed roots.

**Table 5**

PERCENTAGE SURVIVAL OF SEEDLINGS BEFORE AND AFTER THE FIRST SUMMER (1978-1979) AND TOTAL SURVIVAL AFTER THE SECOND SUMMER (1979-1980)

| | *Percentage of Seedlings* | | |
|---|---|---|---|
| *Date* | *Seedling 1.11.78* | *Survival 22.3.79* | *Survival 23.5.80* |
| Period Since Planting(Months) | 4 | 9 | 23 |
| *Acacia aneura* (Mulga) | 92 | 71 | 22 |
| *Atriplex amnicola* | 92 | 47 | 5 |
| *Cratystylis subspinescens* | 35 | 5 | 0 |
| *Maireana polysterygia* | 88 | 48 | 3 |
| *Santalum spicatum* | 49 | 5 | 2 |

### KALGOORLIE TRIALS

A series of experiments were established in fenced plots in the Kalgoorlie Arboretum, Jeedamya Pastoral Station, and Bullock Holes Sandalwood Reserve to test the effects of a range of sites and techniques on the germination and establishment of Sandalwood seedlings. These experiments are summarized in Appendix V and the results are summarized in the following text and Table 6 and Table 7.

**Table 6**

CHEMICAL ANALYSES OF THE SURFACE SOIL IN THE KALGOORLIE ARBORETUM

| *Treatment Type* | *Soil Depth (mm)* | *pH* | *Electrical Con-ductivity* | *Total soluble Salts (%)* | *NaCl (%)* |
|---|---|---|---|---|---|
| Control | 0-10 | 8.20 | 140 | 0.030 | 0.005 |
| Irrigated | 0-10 | 8.65 | 142 | 0.030 | 0.006 |
| Control | 10-20 | 8.80 | 142 | 0.030 | 0.004 |
| Irrigated | 10-20 | 8.55 | 122 | 0.026 | 0.003 |
| Control | 20-30 | 8.70 | 857 | 0.220 | 0.103 |

**Table 7**

GERMINATION OF SANDALWOOD FROM 200 SEEDS PER TREATMENT AT KALGOORLIE

| *Locality* | *Treatment* | *Soaked (in water)* | *Not soaked* | *Total* | *Signi-ficance* |
|---|---|---|---|---|---|
| Kalgoorlie | Irrigated | 20 | 11 | 31 | * |
| Kalgoorlie | Not Irrigated | 13 | 8 | 21 | N.S. |
| Bullock Holes | Not Irrigated | 66 | 53 | 119 | N.S. |
| Jeedamya | Not Irrigated | 18 | 30 | 48 | * |
| *Locality* | *Treatment* | *Peat* | *No Peat* | *Total* | *Signi-ficance* |
| Kalgoorlie | Irrigated | 8 | 23 | 31 | ** |
| Kalgoorlie | Not Irrigated | 6 | 15 | 21 | ** |
| Bullock Holes | Not Irrigated | 65 | 54 | 119 | N.S. |
| Jeedamya | Not Irrigated | 30 | 18 | 48 | N.S. |
| *Locality* | *Treatment* | *With Coat* | *Coat Removed* | *Total* | *Signi-ficance* |
| Kalgoorlie | Irrigated | - | 31 | 31 | ** |
| Kalgoorlie | Not Irrigated | - | 21 | 21 | ** |
| Bullock Holes | Not Irrigated | 62 | 57 | 119 | N.S. |
| Jeedamya | Not Irrigated | 35 | 13 | 48 | * |

Significance by Binomial Proportion Test

| | |
|---|---|
| ** | $P<0.05$ |
| * | $P<0.10$ |
| N.S. | $P>0.10$ |

The germination of Western Australian Sandalwood at the Kalgoorlie Arboretum improved initially with irrigation, but germination rates were low when compared with the results of the field plots (Table 7). For similar treatments and rainfall, germination from seed sown in plots in May 1975 was:

| | |
|---|---|
| Bullock Holes | 30.5 per cent |
| Kalgoorlie (control) | 4.0 per cent |
| Kalgoorlie (irrigated) | 7.8 per cent |

To review the possible effects of salinity and pH levels in the interpretation of results at the Kalgoorlie Arboretum, the surface soils were analysed for pH and salt content (Table 6).

The results illustrate only slight differences in the pH and salt content of the surface soils for the control and irrigated treatment sites at the Kalgoorlie Arboretum. Therefore the surface soil differences are insufficient to influence the germination rates in the various treatments.

Percentage germination results for the Kalgoorlie Arboretum suggest that germination improves with overnight soaking of seed and with irrigation (Table 7).

In field trials, results for treatments to encourage germination were somewhat inconsistent and no better than the controls, pooling all sites (Table 7 and Appendix V - Experiment V-2). Removing the endocarps of the seeds decreased survival in the Jeedamya plot. This coincided with a reported mice plague at the Jeedamya homestead. Some of the Sandalwood seeds lying exposed on the ground under mature Sandalwood trees were eaten by rodents at Jeedamya. What appeared to be a better germination in retaining the endocarps of the seeds was probably caused by the plague of mice eating more of the seeds that already had the endocarp removed. At the Bullock Holes Sandalwood Reserve, there was no difference between these treatments, and no evidence of field mice.

The increase in the population of rodents (mice) and rabbits in the pastoral areas coincided with above-average rainfall during 1973-1975.

Concurrently, seed treatments to improve moisture relationships for seed (soaking, peat, seed coat removal) in the non-irrigated and irrigated plots were tested in the Kalgoorlie Arboretum. These results were inconclusive.

In general, an adequate supply of water seems to favour Sandalwood germination, but survival is determined mainly by the availability of host roots. In the field trials, survivals were significantly closer to the nearest host, within 2.5 m in open woodland and within 1.25 m in open low woodland.

In other tests, cultivation was found to assist germination but not survival. The latter was probably a result of the destruction of the host roots during cultivation. Mortality of seedlings and deficiency of host plants were most pronounced in the Kalgoorlie Arboretum. Germination was also most deficient in this area. It was decided that follow-up work on these techniques should be re-located to the more favourable nursery conditions at Narrogin.

# Sandalwood Regeneration

### EFFECTS OF SITE CULTIVATION ON ARTIFICIAL AND NATURAL REGENERATION

A series of trials were established, in May 1974, to test the effects on Sandalwood germination and survival of site, natural seed supply and artificial sowing, and cultivating the seedbed. Four sites were selected for the studies, in relation to their representation of plant communities and their location from Kalgoorlie and Coolgardie, on two Pastoral Stations (Gindalbie and Jeedamya, located 60 km north-east and 160 km north of Kalgoorlie) and two Reserves (Bullock Holes and Calooli, located 40 km north-east of Kalgoorlie and 15 km south-west of Coolgardie respectively (Appendix VI). The sites differed in their location, soil types and dominant plant communities (Appendix VI).

A good year of seed production in 1973 at Kalgoorlie was followed by two wet years, both favourable for germination and establishment of Sandalwood seedlings. Although seedlings of six and seven months old were observed to establish haustoria on host roots at Kalgoorlie in 1975, observers have also noted that seedlings when dug up at twelve months (Western Australian Forests Department Annual Report 1924) had not always parasitised a host plant. Therefore the older seedlings cannot be assumed to have established haustoria at 12 months. Results are summarized in Figure 3 and Table 8.

A series of illustrations in Plates 11, 12, 13 and 14 reflect the range of regeneration and germination of seedlings at Bullock Holes and Gindalbie.

Results illustrate that far more seedlings established in the cultivated than the uncultivated soil. Nevertheless the plants on the cultivated soils were far less stable than those on the uncultivated soils, as the higher germination was followed by a greater mortality in the following summer months. Improved germination was probably a result of the burying of seeds by the rotary hoe (Fig. 3).

The severe drought that occurred at Kalgoorlie in 1976 and 1977 resulted in significant Sandalwood seedling mortality in the field trials (Table 8, Fig. 3).

Drought of this severity is rare, as only one other drought of a similar severity has been recorded since 1895. This suggests that the germination and survival rates recorded in these experiments are a benchmark in that they represent likely patterns under the worst germination and establishment conditions. The 1976-77 drought continued to cause high mortality in both the experimental seedling population of Sandalwood and in the mature Sandalwoods and host shrubs well into 1978 and 1979.

The seedlings, given equal initial germination from spot sowing, were favoured by uncultivated soils during 1975 and 1976 (Fig. 3). These differences appeared to be affected by the occurrence of two years of severe drought. As droughts occur at relatively frequent intervals in the semi-arid areas of Western Australia, the results in October 1977 (Fig. 3) reflect the earlier comments about the low establishment rate of Sandalwood. The effectiveness of cultivation must then be questioned in areas which are subject to periods of drought.

The seedlings in cultivated soil suffered greater mortality, both relative and absolute, than did the seedlings in uncultivated soil (Fig. 3). This mortality may be related to the parasitic nature of Sandalwood. The new seedling has little chance of surviving its first summer unless it develops a haustorial link with the root systems of the host species for a supply of water and nutrients. Cultivation appears to have destroyed the fine surface roots of potential hosts, leaving the Sandalwood seedlings to perish.

Other factors may have contributed to seedling mortality. One possibility is that the cultivated soil dries out more rapidly. Another is the potential competition between seedlings.

A sequence of three wet years appears to be necessary for the succession of flowering, seed set, germination and establishment of Sandalwood seedlings in the field. Such a sequence occurs infrequently in the inland areas. The results from the field trials in the more favourable years of 1973 to 1975 assisted in evaluating germination and establishment needs of Sandalwood, however, little is known on a regional scale of the impacts of the changes in climatic conditions on natural regeneration of this species.

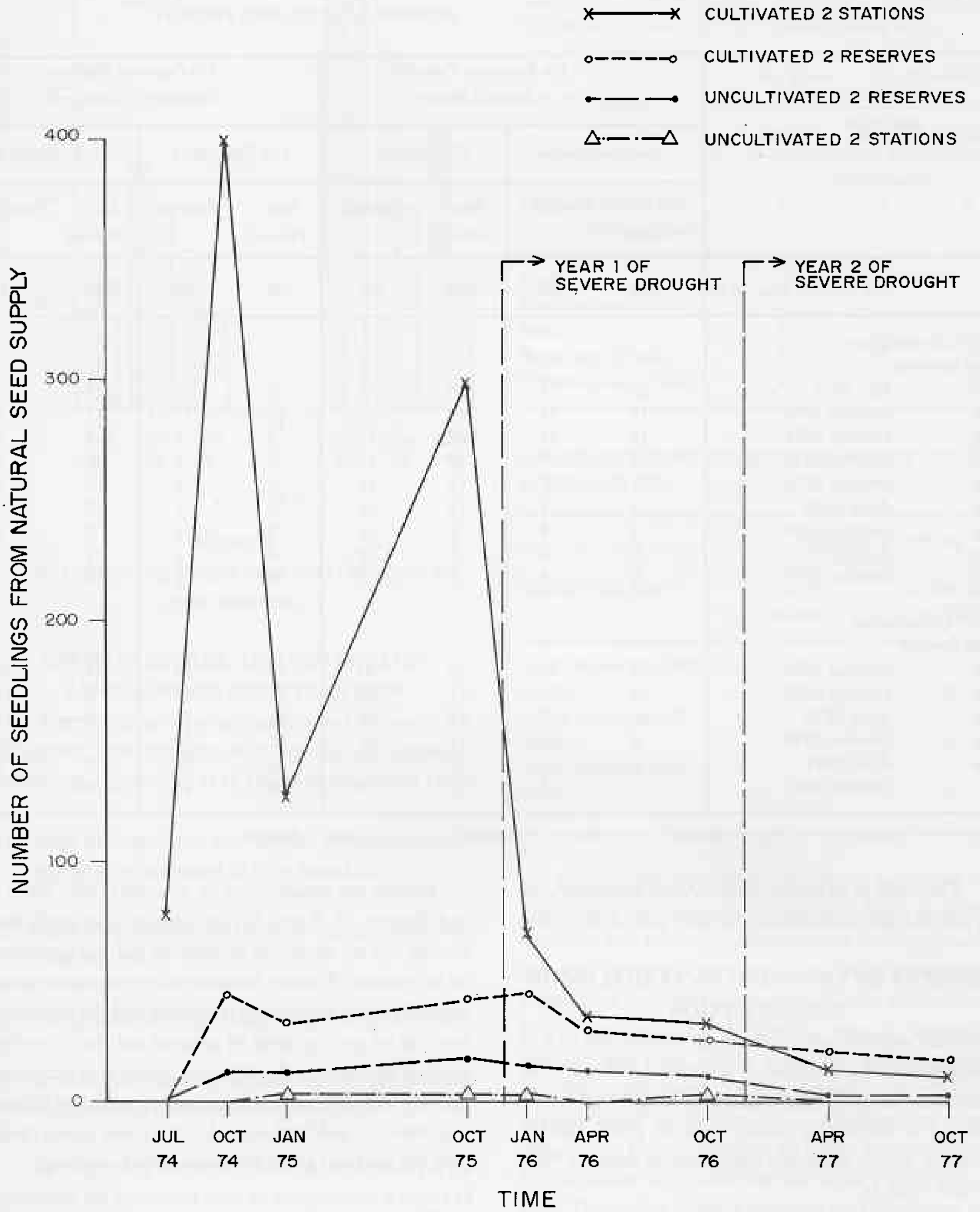


**Figure 3**
Effect of cultivation on germination and seedling survival from natural seed supply

**Table 8**

GERMINATION AND SEEDLING SURVIVAL FROM SPOT SOWING OF 100 SANDALWOOD SEED PER PLOT TREATMENT

*NUMBER OF SEEDLINGS PRESENT*

| Season and Date of observation | | On Reserves, Calooli + Bullock Holes | | | | On Pastoral Stations, Gindalbie + Jeedamya | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Not Cultivated | | Cultivated | | Not Cultivated | | Cultivated | |
| | | Not Fenced | Fenced | Not Fenced | Fenced | Not Fenced | Fenced | Not Fenced | Fenced |
| | No. sown in May 1974 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| *1974 Germination and Survival* | | | | | | | | | |
| Wi | July 1974 | 23 | 28 | 38 | 15 | 0 | 2 | 1 | 0 |
| Sp | October 1974 | 19 | 51 | 44 | 43 | 13 | 15 | 12 | 8 |
| Su | January 1975 | 10 | 29 | 30 | 33 | 3 | 6 | 2 | 6 |
| Sp | October 1975 | 1 | 9 | 19 | 17 | 0 | 1 | 0 | 2 |
| Su | January 1976 | 1 | 8 | 15 | 18 | 0 | 1 | 0 | 2 |
| Au | April 1976 | 1 | 8 | 14 | 16 | 0 | 1 | 0 | 2 |
| Sp | October 1976 | 1 | 8 | 9 | 16 | 0 | 1 | 0 | 2 |
| Au | April 1977 | 0 | 6 | 8 | 9 | 0 | 1 | 1 | 2 |
| Sp | October 1977 | 0 | 4 | 3 | 5 | 0 | 1 | 0 | 2 |
| *1975 Germination and Survial* | | | | | | | | | |
| Sp | October 1975 | 33 | 35 | 33 | 30 | 79 | 74 | 24 | 36 |
| Su | January 1976 | 15 | 24 | 21 | 28 | 36 | 66 | 6 | 17 |
| Au | April 1976 | 10 | 17 | 14 | 18 | 23 | 55 | 3 | 11 |
| Sp | October 1976 | 8 | 14 | 11 | 17 | 10 | 54 | 2 | 10 |
| Au | April 1977 | 3 | 7 | 7 | 7 | 0 | 29 | 0 | 7 |
| Sp | October 1977 | 1 | 3 | 5 | 4 | 0 | 14 | 0 | 5 |

Wi = Winter, Sp = Spring, Su = Summer, Au = Autumn

The findings on longer-term survival were restricted by the drought conditions in the latter part of the 1970s.

## EFFECTS OF BROWSING ON SANDALWOOD REGENERATION

Previous workers and observers have noted the lack of Sandalwood regeneration in Western Australia. The fate of seedlings is often thought to be affected by the grazing of herbivores (sheep, rabbits, goats, camels, donkeys, horses, cattle and kangaroos) as shown in Plate 15 and Plate 16.

A series of fencing trials were established to investigate the impact of grazing on Sandalwood regeneration on a range of sites in the Kalgoorlie area.

Results are summarized in Appendix VII, Table 8 and Figures. 4, 5 and 6. The results confirmed that fencing was not significant on reserves, but was significant on the stations. Whether Sandalwood regeneration occurs naturally, or is artificial, it is evident that the chance of survival on grazing areas of pastoral stations (covering most of the residual Sandalwood country) is very low. Hot dry seasons reduce the amount of succulent foliage and domestic and feral animals (sheep and goats) range over the land and graze the Sandalwood seedlings.

The impact of rabbits and native herbivores was evident on the reserves, however, the impact was markedly less than on the stations with the larger numbers of introduced herbivores (sheep and goats).

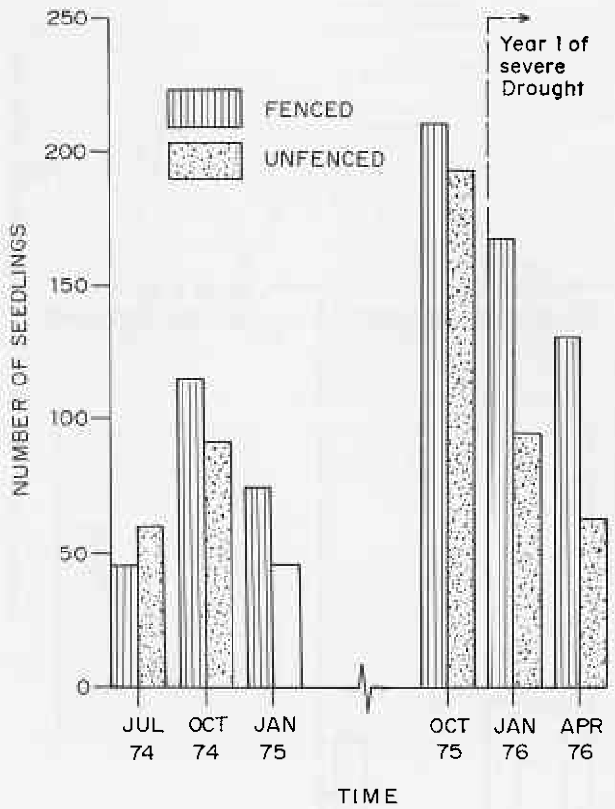


**Figure 4**

Effect of Fencing on spot sown seed (800 seeds in each treatment)

## EFFECTS OF FIRE AND CUTTING ON SANDALWOOD REGENERATION

Observers have reported Sandalwood coppice in the Wheatbelt, with coppicing after fire, and after cutting at Bendering reported by G.H. Drake-Brockman in 1921:

(1) Large trees sprouted after a grass fire had passed and the trees appeared to have been killed;

(2) Other severely scorched trees frequently suckered from the base;

(3) Young trees were generally killed outright by fire;

(4) Trees cut at ground level have frequently suckered and produced marketable timber.

As coppicing might be a more positive method for replacing the harvested crop of Sandalwood a series of experiments were established in 1974-75 to investigate recovery after cutting and from wildfires on reserves. Results are summarized in Appendix VIII and Table 9.

**Table 9**

EFFECTS OF FIRE AND CUTTING ON SANDALWOOD REGENERATION

*LAKESIDE SANDALWOOD RESERVE - EFFECTS OF WILDFIRE IN JANUARY 1975* (see Appendix VIII)

| *Fire Impact* | *No. Burnt* | *No. Surviving* | |
|---|---|---|---|
| | *Jan 75* | *Oct 75* | *Oct 77* |
| Lightly scorched trees (only 2 produced fresh growth in the crown and stem) | 11 | 8 | 8 |
| Moderate to severely burnt | 33 | 20 | 1 |
| Burnt trees (Total) | 44 | 28 | 9 |
| Unburnt trees (Total) | 12 | 12 | 12 |

*CALOOLI SANDALWOOD RESERVE - EFFECTS OF CUTTING IN 1975 AND 1976*

| *Cutting Treatment* | *Numbers Coppicing* | |
|---|---|---|
| | *After 4 Months* | *At the end of 1976* |
| 16 cut in summer 1975 (moist) | 4 | 0 |
| 16 cut in winter 1975 (moist) | 0 | 0 |
| 32 cut in winter 1976 (dry) | 0 | 0 |

The practice of pulling the whole tree from the ground and harvesting the runner roots down to 40 mm diameter was historically accepted in the Sandalwood industry (current licence conditions include harvesting roots down to 25 mm heartwood). Yields are increased by between one-and-a-half and two times by harvesting the butt and roots of the tree. The early observers recognized the potential for coppicing, if the effects of grazing could be minimized. Although the initial observations looked promising the results from the detailed investigations suggested that the coppice survival was low. The studies in the Kalgoorlie area confirmed that 10 to 15 per cent of stumps coppiced when the soil was moist, but then completely failed within two years, probably when the soil dried out.

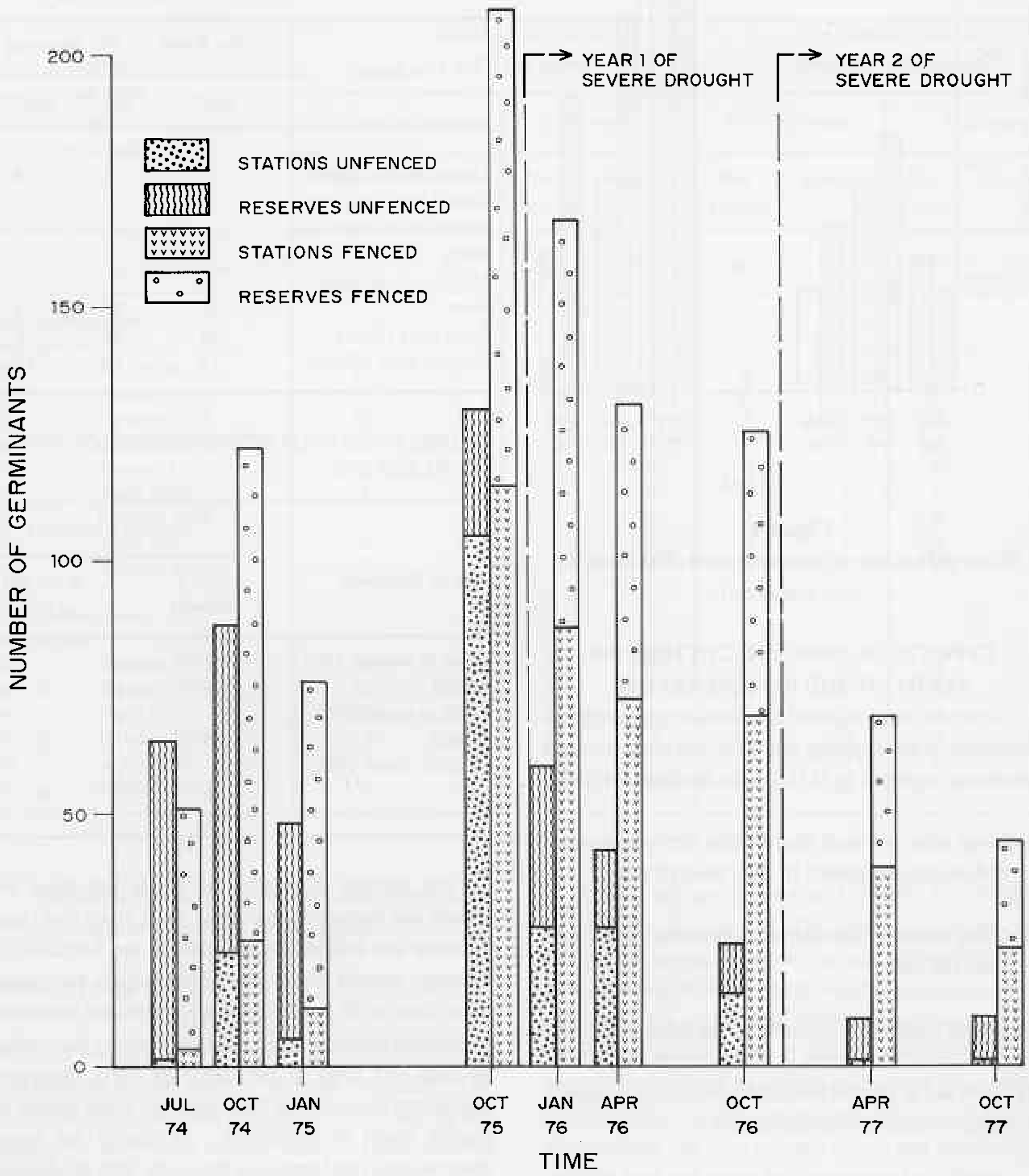


**Figure 5**
Effect of fencing on geminants of spot sown seed (400 seeds in each treatment)

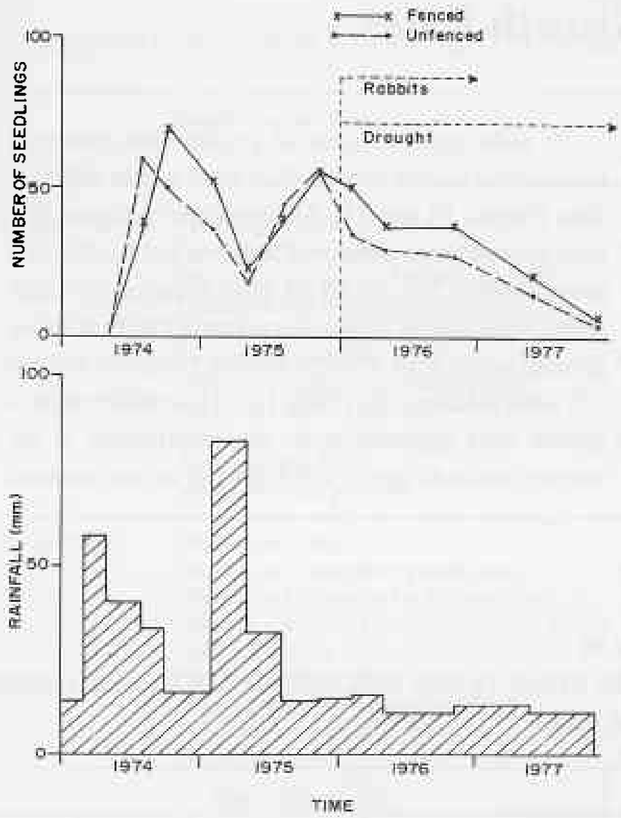


**Figure 6**
Effect of rainfall, drought, rabbit and fencing on germination for spot sown seed
(200 seeds per treatment - Calooli Sandalwood Reserve plot)

Twenty-eight of the study population coppiced from roots and butts after fire, but only 9 of those burnt survived (Table 9, Appendix VIII).

A preliminary study in another Sandalwood area (Hampton Hill Station, 75 km north-east of Kalgoorlie) burnt in November 1974 and harvested in January 1975, started with promising regeneration from coppice growth, but showed similar failure with time. In this area, most of the burnt Sandalwood trees were snapped off by the operators. The residual stumps and roots coppiced during a very wet period in early 1975. In one stand of 82 stems, 60 (73 per cent) coppiced. Mortality in 1976 reduced survivors to 40 trees: 47.5 per cent of the original population. By 1978, the survival rate was less than 10 per cent.

The cutting trials at Calooli showed a low number of plants coppicing (4 plants or 6 per cent) and all coppice growth did not persist (Table 9, Appendix VIII).

All the studies confirmed that coppicing could not be relied upon as a source of Sandalwood regeneration in the Kalgoorlie area. These findings appear to differ from recent observations at Shark Bay where coppicing of roots appears to be a possible option for regeneration of *Santalum spicatum* (Plate 17). The latter differences in coppicing capability may relate to genetic variations in the populations at Shark Bay or the different climatic and site conditions.

## REGENERATION STUDIES AT NARROGIN

In 1981, a series of trials were carried out at Dryandra State Forest to research operational requirements for planting Sandalwood. Research into provenance, planting methods, planting stock and site factors was undertaken. Trials were established in an area of Jam (*Acacia acuminata*). Results are summarized below and in Appendix IX. The regeneration trials at Gura Road in Dryandra State Forest are illustrated in Plates 18, 19, 20 and 21. Examples of 1-year and 3-year-old seedlings are illustrated.

The results indicated that sowing germinated seeds at four per spot produced one surviving germinant per spot (Appendix IX). In the niches where W.A. Sandalwood established and grew most successfully it was observed that a clump of three or four Sandalwood trees can be grown to maturity. In an operational regeneration program the potential number of failed spots can be offset by increasing the number of plants at each spot.

Planting of germinated seed under full shade on a well drained, brown sandy loam slope will produce twice as many survivals as any other method (Appendix IX).

Successful artificial regeneration of Sandalwood can therefore be achieved by sowing four germinated Sandalwood seeds per spot in appropriate well drained sites, 50 mm below the soil and mulched in a small depression at the drip line of the south side of a host plant, protected from grazing.

# Sandalwood Growth Rates

During 1974 and 1978 studies were undertaken to determine the range in size of Sandalwood trees and the rate of growth. The natural variation in plant size and rates of growth are predictably related to factors such as site conditions, climate and soils. Results were extrapolated to determine the length of time Sandalwood needs in the different regions to attain commercial size. Results are presented in Tables 10, 11, 12 and 13; Figures 7, 8 and 9; and Appendix X.

A wide range in rates of growth were observed between the largest and smallest trees within different sites (Tables 10 and 11). Observations indicated that local site conditions influenced both host and Sandalwood growth rates. The length of time required to attain commercial size (127 mm diameter at 150 mm above ground) varied from 32 to 59 years at Dryandra to 59 to 115 years at Kalgoorlie (Table 12). These differences in growth rates appeared to be related primarily to the varying site and climatic conditions in the two regions.

**Table 10**

SUMMARY OF HEIGHT AND STEM DIAMETER GROWTH RESULTS FOR SANDALWOOD AT KARRAMINDIE AND SCAHILL

| | | *Height (m)* | | | | | *Stem Diameter (mm)* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Total height* | | | | | *Stem at 75 mm above ground* | | | *At 150 mm above ground* | | | |
| | *Year Sown* | *1940* | *1974* | *Incr. 34 years* | *To 38 mm heartwood* | *To 55 mm overbark* | *1940* | *1974* | *Incr. 34 years* | *Over bark* | *Under bark* | *Overbark for 38 mm heartwood* | *Bark (twice thickness) at 300 mm* |
| *KARRAMINDIE* | *1930* | | | | | | | | | | | | |
| Plot 1 | | 1.50 | 3.80 | 2.30 | 0.62 | 1.12 | 16 | 107 | 91 | 100 | 78 | 72 | 22 |
| (6 trees) | | 1.25 | 3.60 | 2.35 | | | 13 | 107 | 94 | | | | |
| | | 1.25 | 3.65 | 2.40 | | | 19 | 70 | 51 | | | | |
| | | 0.97 | 4.10 | 3.13 | | | 13 | 107 | 94 | | | | |
| | | 0.84 | 3.20 | 2.36 | | | 6 | 80 | 74 | | | | |
| | | 1.07 | 3.78 | 2.71 | 0.66 | 1.31 | 10 | 105 | 95 | 102 | 81 | | 21 |
| Mean tree | | 1.15 | 3.68 | 2.53 | | | 13 | 96 | 83 | | | | 21 |
| Annual increment | | | | 0.074 | | | | | 2.44 | | | | |
| Sample tree | | | | | 0.45 | 0.92 | | 91 | | 90 | 69 | 87 | 21 |
| *KARRAMINDIE* | *1925* | | | | | | | | | | | | |
| Plot E (12 trees) | | 1.50 | 2.95 | | | 0.55 | 24 | 70 | 46 | 65 | 47 | | 18 |
| Mean tree | | 1.50 | 2.50 | 1.00 | | 0.66 | 24 | 70 | 46 | 70 | 54 | | 14 |
| Annual increment | | | | 0.030 | | | | | 1.35 | | | | |
| *SCAHILL* | *1930* | *1941* | | | | | *1941* | | | | | | |
| Mean (14 trees) | | 1.08 | 1.93 | 0.85 | | | 18 | 57 | 39 | 56 | 38 | | 16 |
| Annual increment | | | | 0.025 | | | | | 1.18 | | | | 10 |
| Mean (12 trees) | | 0.91 | 1.23 | 0.32 | | | 15 | 38 | 23 | 37 | 22 | | 11 |
| Annual increment | | | | 0.010 | | | | | 0.70 | | | | |

**Table 11**

SUMMARY OF SANDALWOOD YIELD IN TREES AGED 44 YEARS NEXT TO KARRAMINDIE (PLOT 1)

| | *Sample Trees and Parameters of Sections* | *Wood & Bark* | *Bark* | *Total Wood* | *Heart-wood* | *Sapwood* |
|---|---|---|---|---|---|---|
| *Largest Tree* | Total height 3.86 m | | | | | |
| | Diameter at 75 mm above ground (mm) | 104 | 25 | 79 | | |
| | Diameter at 150 mm (and at 300 mm) (mm) | 98 | (20) | 78 | 56 | 22 |
| | Diameter at 650 mm for heartwood to 40 mm | 78 | 18 | 60 | 40 | 20 |
| | Volume for above ($m^3 \times 10^{-3}$) [a] | 4.2 | | 2.5 | 1.3 | 1.2 |
| | Per cent by volume (%) | 100 | 40 | 60 | 30 | 30 |
| | Diameter at 1250 mm for stem to 55 mm | 55 | 16 | 39 | 18 | 21 |
| | Volume for above ($m^3 \times 10^{-3}$) [a] | 6.2 | | 2.8 | 1.5 | 1.3 |
| | Per cent by volume (%) | 100 | 55 | 45 | 25 | 20 |
| | Weight by stem [b] (kg) | | | 2.5 | 1.3 | |
| | Number of stems per tonne | | | 400 | 770 | |
| *Large Class* | Mean height 3.54 m | | | | | |
| | Diameter at 75 mm above ground (mm) | 91 | 21 | 70 | | |
| | Diameter at 150 mm (and at 300 mm) (mm) | 90 | (21) | 69 | 46 | 23 |
| | Diameter at 450 mm fork for heartwood to 40 mm | 83 | 18 | 65 | 43 | 20 |
| | Volume for above ($m^3 \times 10^{-3}$) [a] | 2.7 | | 1.6 | 0.7 | 0.9 |
| | Per cent by volume (%) | 100 | 40 | 60 | 25 | 35 |
| | Diameter at 920 mm for stem to 55 mm | 55 | 16 | 39 | 16 | 23 |
| | Volume for above ($m^3 \times 10^{-3}$) [a] | 4.5 | | 2.2 | 0.8 | 1.4 |
| | Per cent by volume (%) | 100 | 50 | 50 | 20 | 30 |
| | Weight by stem [b] (kg) | | | 1.9 | 0.7 | |
| | Number of stems per tonne | | | 525 | | |
| *Small Class* | Mean height 2.76 m | | | | | |
| | Diameter at 75 mm above ground (mm) | 71 | 18 | 53 | | |
| | Diameter at 150 mm (and at 300 mm) (mm) | 70 | (16) | 54 | 33 | 21 |
| | Diameter at 660 mm for heartwood to 55 mm | 55 | 15 | 40 | 18 | 22 |
| | Volume for above ($m^3 \times 10^{-3}$) [a] | 2.2 | | 1.3 | 0.4 | 0.9 |
| | Per cent by volume (%) | 100 | 40 | 60 | 20 | 40 |
| | Weight by stem [b] (kg) | | | 1.1 | 0.35 | |
| | Number of stems per tonne | | | 910 | | |

[a] Volume ($m^3 \times 10^{-3}$) - 0.0785 x $d^2$ (cm) x L (m) (Avery 1975)

[b] Weight converted from 880 kg/$m^3$ (Tables 8, 9, Figs 2, 3).

A range of measurements were also undertaken in 1974 and 1978 on Sandalwood trees in the Narrogin and Swan Coastal Plain areas. The length of time required to attain a commercial size (stem diameter of 127 mm) varied with climatic and soil conditions, in different plant community types within the three regional areas (Appendix X):

**Narrogin** (500 mm annual rainfall)
PLANT COMMUNITY TYPES
*Acacia acuminata* (Benth.) - *Eucalyptus wandoo* (Blakely): 23 - 50 years
*Eucalyptus wandoo* - *Allocasuarina huegeliana* (Miq.)L. Johnson: 50 years

**Narrogin** (335-385 mm annual rainfall)
PLANT COMMUNITY TYPES
Ploughed Broombush -*Acacia acuminata*: 45 - 50 years
Unploughed Broombush -*Acacia acuminata*: 80 - 130 years

**Swan Coastal Plain** (875-890 mm annual rainfall)
PLANT COMMUNITY TYPES
*Banksia* spp. on Bassendean Sand Dune System: 35 years
*Eucalyptus gomphocephala* (DC.): 35-70 years

**Table 12**

GROWTH RATE OF SANDALWOOD AT NARROGIN AND KALGOORLIE AND NUMBER OF YEARS NEEDED TO REACH COMMERCIAL DIAMETER OF 127 MM (DIAMETER OVER BARK AT 150 MM ABOVE GROUND LEVEL - D.O.B.)

| *Locality* | *State Forests and Reserves* | *Age* | *Number of Trees* | *Mean d.o.b.* | *Annual d.o.b. increment* | *Age to reach d.o.b. 27 mm* |
|---|---|---|---|---|---|---|
| | | *(yrs)* | *(n)* | *(mm)* | *(mm)* | *(yrs)* |
| Narrogin | Dryandra S.F. | 22 | 337 | 88.0 | 4.0 | 32 |
| | Reserve 8324 | 47 | 106 | 101.5 | 2.16 | 59 |
| Kalgoorlie | Karramindie S.F. | 52 | 288 | 91.4 | 1.76 | 72 |
| | Plot 1 as above | 44 | 10 | 95.0 | 2.16 | 59 |
| | Plot E as above | 49 | 12 | 70.0 | 1.43 | 89 |
| | Scahill Reserve | 44 | 26 | 48.2 | 1.10 | 115 |

**Table 13**

LINEAR REGRESSIONS OF VARIOUS COMPONENTS OF SANDALWOOD TREES FOR DIAMETER OVER BARK UNDER COMMERCIAL SIZE (1,2) AND ALL TREES (3-9) IN THE EASTERN GOLDFIELDS AND GREENOUGH/GASCOYNE REGIONS.

| | *Y (kg)* | *N* | *y* | *S.D.* | *a* | *b* | *r* |
|---|---|---|---|---|---|---|---|
| 1 | Total weight | 15 | 15.8 | 7.2 | -7.728 | 0.2750 | 0.70 |
| 2 | Twigs (<10 mm d.o.b. + leaves) | 15 | 4.93 | 2.15 | -2.922 | 0.0917 | 0.78 |

*based on 15 trees with d.o.b. under 127 mm*

| | *Y (kg)* | *N* | *y* | *S.D.* | *a* | *b* | *r* |
|---|---|---|---|---|---|---|---|
| 3 | Total weight | 22 | 28.5 | 20.8 | -29.32 | 0.5441 | 0.94 |
| 4 | Sound roots | 13 | 3.0 | 1.7 | -1.35 | 0.0370 | 0.82 |
| 5 | Commercial logs | 22 | 10.2 | 7.4 | -10.53 | 0.1952 | 0.95 |
| 6 | Butt log section - 9 broken butts | 22 | 3.6 | 2.1 | -0.91 | 0.0428 | 0.74 |
| 7 | Stem log sections | 22 | 7.0 | 7.2 | -12.01 | 0.1790 | 0.90 |
| 8 | Total branchwood | 22 | 8.4 | 5.7 | -6.11 | 0.1366 | 0.87 |
| 9 | Twigs (<10 mm d.o.b. + leaves) | 22 | 8.3 | 5.7 | -6.10 | 0.1360 | 0.87 |

*based on 22 trees including 7 with d.o.b. <127 mm (ranging 55 - 180 mm)*

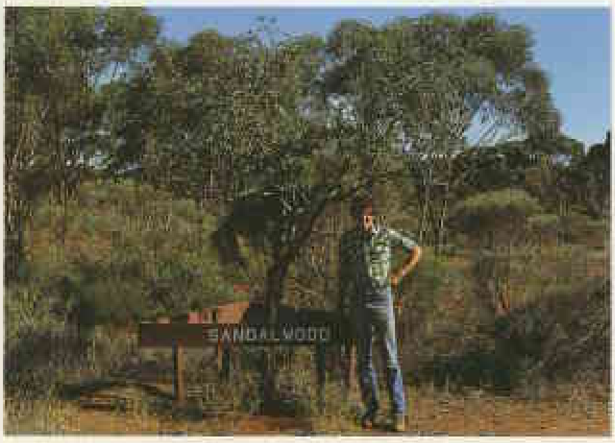


Plate 1 : Sandalwood tree (3 m) at Kalgoorlie

Plate 2: A puller cutting roots

Plate 3: Tractor in use for pulling Sandalwood

Plate 4: Loading Sandalwood Binneringie Station

Plate 5: Sandalwood stacked at Pinner's camp, Gindalbie Station, ready for shipment.

Plate 6: Sandalwood fruit
(size range - 1.5-2 cm diameter).

Plate 7: Healthy crown growth, February1987 in responce to recent rains, West Kalgoorlie.

Plate 8: Lateral root development of Sandalwood.

Plate 9: 28-year-old Sandalwood plant in Frank Block, Dryandra State Forest.

Plate 10: 28-year-old Sandalwood plants at Siding Road, Stokes Block,Dryandra State Forest.

Plate 11: Sandalwood seedlings at Bullock Holes Sandalwood Reserve.

Plate 12: 8-year-old Sandalwood plants at Bullock Holes Sandalwood reserve.

Plate 13: Gindalbie Station trial plot area; fencing trials.

Plate 14: Gindalbie Station trial plot area, germination of seedling inside fence, April 1982.

Plate 15: In absence of grazing, Sandalwood can grow to ground level, September1982.

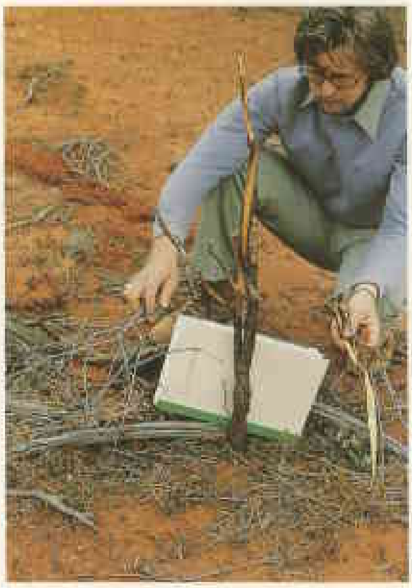

Plate 16: Goat damage to Sandalwood on Yerilla Station Plots 1980.

Plate 17: Coppicing of Sandalwood on Nanga Station.

Plate 18: Regeneration studies at Gura Road, Dryandra State Forest. 1-year-old Sandalwood seedling.

Plate 19: Regeneration and provenance studies at Gura Road, Dryandra State Forest.
3-year-old Sandalwood seedling.

Plate 20: Regeneration and Provenance studies at Gura Road, Dryandra State Forest.
3-year-old Sandalwood seedlings.

Plate 21: Regeneration and provenance studies at Gura Road, Dryandra State Forest. 3-year-old Sandalwood seedlings.

Plate 22: Natural Sandalwood regeneration at Curries Road, Dryandra State Forest.

Plate 23: Sandalwood, Kalannie, Rabbit Proof Fence Road.

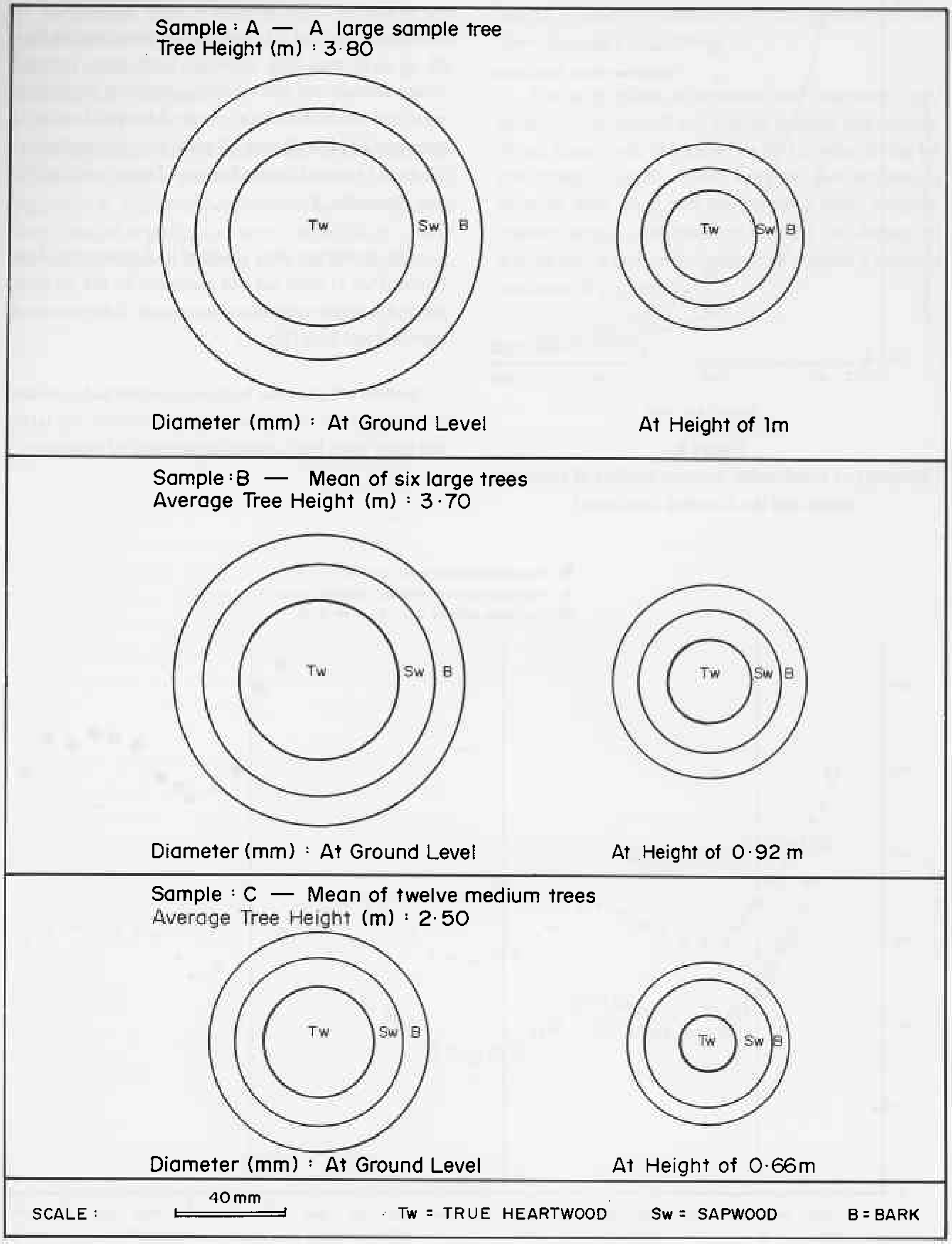


**Figure 7**

Sectional analysis of Sandalwood trees next to Karramindie plot 1

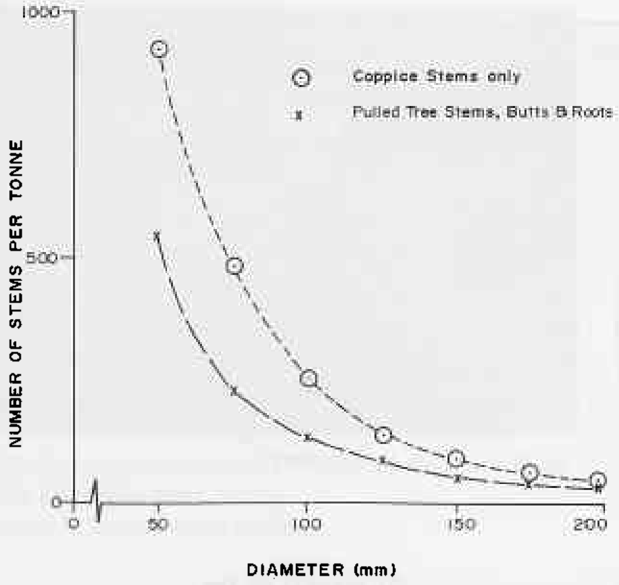


**Figure 8**

Summary of relationship between number of stems per tonne and the diameter class (mm)

Additional measurements were undertaken on constituent parts of 22 Sandalwood trees ranging from 87 to >138 mm stem diameter from three localities where Sandalwood pulling operations were in progress, north and north-east of Kalgoorlie (Morapoi Station - 8 trees; and Edjudina Station - 7 trees) and between Payne's Find and Morawa (Karara Station - 7 trees) see Table 13 and Appendix X.

The plantation trees sampled at Karramindie State Forest (Plot 1) were cut and measured by the sectional method to derive volume and increment of the truewood, sapwood and bark (Fig. 7).

Results indicated that bark and sapwood had a constant thickness of 21- 22 mm and that predictably the larger and taller trees had a higher component of heartwood.

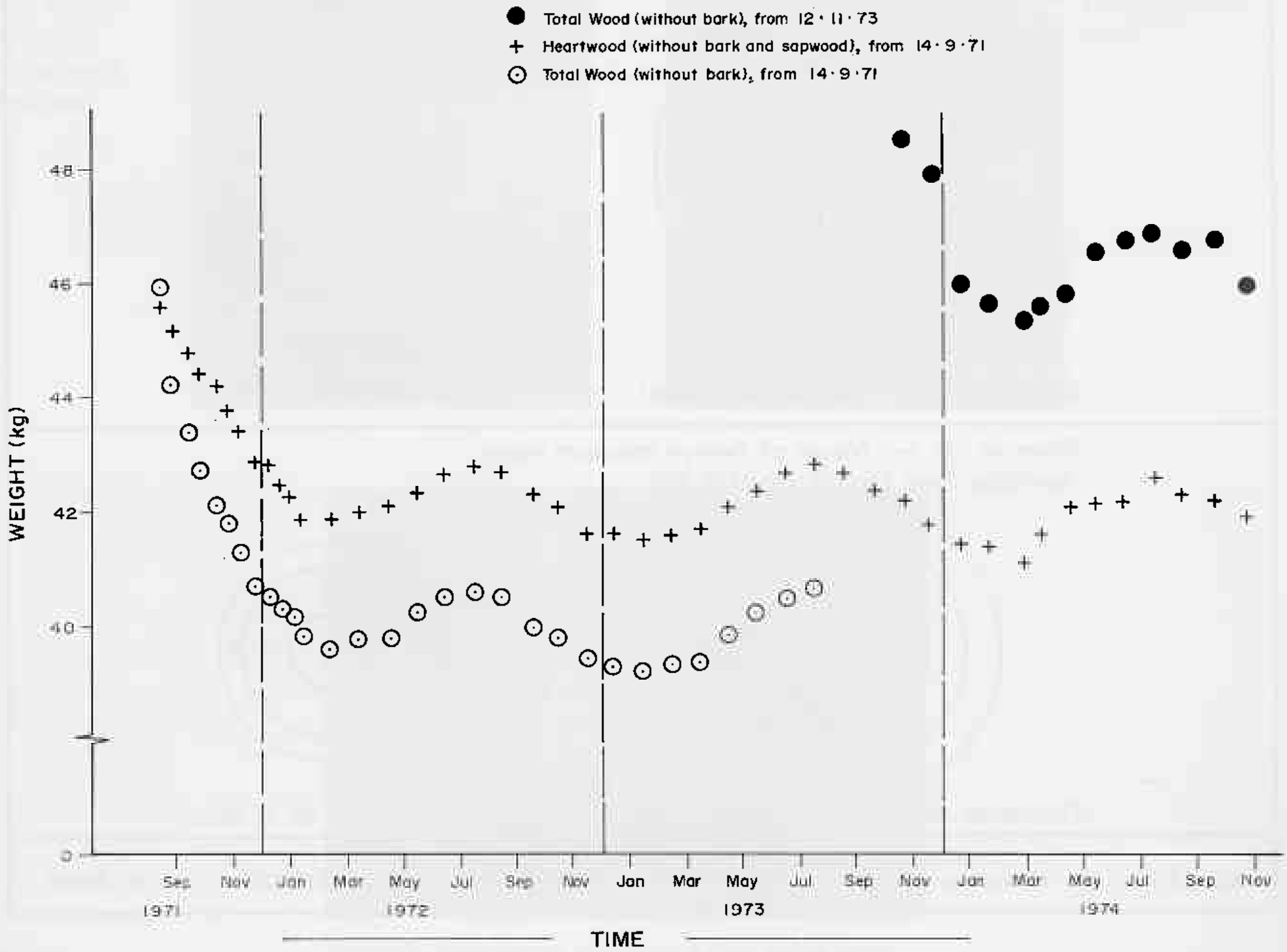


**Figure 9**

Air dry weight of Sandalwood, showing loss of moisture content of fresh green wood and variation in relation to seasonal conditions, 1971 to 1974

In addition, on the basis of these figures it was possible to calculate that the proportion of heartwood exceeds sapwood in trees with a stem diameter greater than 102 mm (over bark).

Relationships between stem diameters and numbers of stems per tonne are summarized in Figure 10 and Appendix X. In general the number of harvested (pulled) stems needed to produce a tonne is about 60 per cent of the number required if stems were cut at ground level, almost 90 and 150 respectively at the commercial size stem diameter of 127 mm.

The proportions of sapwood and heartwood vary inversely with overall tree size, as do most tree species. Wood density was 880 $kg.m^{-3}$ ($\pm$ 50 kg) after drying for one month (Fig. 8). There were no real differences between total wood and heartwood in these samples. Further drying over summer reduced the density to 810 $kg.m^{-3}$, which over 3 years had showed a seasonal variation of $\pm$ 13 kg.

# Conclusions

Conclusions from the W.A. Sandalwood research program from 1895 to 1981 are:

1. The viability of the nuts decreases rapidly after two years and best germination is obtained from fresh mature seed.

2. A series of consecutive wet years are required for the trees to flower and set seed. A following wet year is needed for germination and establishment of the seedlings. This sequence of favourable years must be extended following drought. Such a sequence is less predictable in the drier inland areas near Kalgoorlie than in the Wheatbelt.

3. Cultivation improves germination, probably owing to the burying of the seeds.

4. The significance of cultivation is reduced during periods of drought.

5. Spot-sowing seeds, about 50-70 mm deep, without cultivation improves survival of seedlings over spot-sowing in cultivated soil.

6. Seedling survival improves if grazing animals are excluded by fences, especially on the pastoral stations.

7. Sandalwood regeneration cannot be reliably obtained from coppice, following either fire or cutting.

8. From the experiments with seedlings of Western Australian Sandalwood and host species, a high mortality of Sandalwood and the better survival of the Mulga and Jam seedlings indicated that the Sandalwood may have failed to make satisfactory union with the roots of the host plants, either in the field or in the nursery.

9. The direct seeding trials confirmed that establishment by this method was very uncertain under the harsh conditions prevailing in the field.

10. Germination and survival of Sandalwood seedlings in the field is favoured by proximity to the host and semi-shade.

11. Successful artificial regeneration of Sandalwood on a plantation scale can be achieved by sowing four germinated Sandalwood seeds per spot in appropriate well drained sites, 50 - 70 mm below the soil surface and mulched in a small depression at the drip line of the south side of a host plant, and protected from grazing.

In conclusion the potential for widescale regeneration and establishment of Sandalwood in Western Australia is feasible if the natural limitations on this species are recognized. The possibility of re-establishing Sandalwood in the Goldfields and the Wheatbelt similar to those illustrated (Plates 22 and 23) should be encouraged for the future of Sandalwood in Western Australia.

# Acknowledgements

Special thanks are due to the Conservator of Forests and the Australian Sandalwood Company for encouragement and funding.

The author would like to thank the many individuals and organizations involved in Sandalwood research within the State of Western Australia over the last century. In particular:

Officers and staff of the former Forests Department and the Department of Conservation and Land Management; P.C. Richmond, N.C. Caporn , M.J. Tagliaferri, B. Brennan for field work on research plots; J. Humphries, R. McAlinden for nursery and field trials at Narrogin; I. Kealley, R. Underwood, J.J. Havel, F.H. McKinnell, P.N. Hewett for critical reviews of the research;

Officers of the Department of Agriculture for assistance in field studies at Kalgoorlie;

E.M.Mattiske, M. Lewis, I. Kealley for their critical editing and advice in the preparation of this document. In addition the helpful comments by the referees M. Sedgley, J. Noble, I. Abbott and J. McGrath;

The Sandalwood Conservation and Regeneration Project (SCARP) for funding the rewriting and publishing costs.

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APPENDIX I

## Statutory Reserves containing Sandalwood in Western Australia at 1990.

| *No.* | *Locality Index* | *Number* | *Vesting* | *Area (ha)* |
|---|---|---|---|---|
| | *GOLDFIELDS* | | | |
| | *National Parks* | | | |
| 1 | Goongarrie | A35637 | NPNCA | 60335 |
| | *State Forests and Timber Reserves* | | | |
| 2 | Majestic | 195/25 | LFC | 2226 |
| 3 | Randalls | 194/25 | LFC | 16350 |
| 4 | Kambalda | 199/25 | LFC | 3342 |
| 5 | Kangaroo Hills | 198/25 | LFC | 6600 |
| 6 | Karramindie SF No. 8 | | LFC | 781 |
| | *Sandalwood Reserves* | | | |
| 7 | Emu Rock | C19645 | L ACT (NV) | 8186 |
| 8 | Wallaby Rock | C19764 | L ACT (NV) | 4556 |
| 9 | Coonana | C19640 | L ACT (NV) | 37061 |
| 10 | Bullock Holes | C19825 | L ACT (NV) | 13313 |
| 11 | Lakeside | C19214 | L ACT (NV) | 3787 |
| 12 | Calooli | C19211 | L ACT (NV) | 3121 |
| 13 | Yellari | C19212 | L ACT (NV) | 6102 |
| 14 | Scahill | C19621 | L ACT (NV) | 6916 |
| | *Other Reserves* | | | |
| 15 | Kalgoorlie Green Belt (20 km radius) | | VCL (NV) | 83000 |
| 16 | Reserve land between Kalgoorlie and Widgiemooltha (excluding other reserves and Hampton areas) Reg. 95(b) | | Various (NV) | 260240 |
| | *Nature Reserves* | | | |
| 17 | Rowles Lagoon | C4274 | NPNCA | 404 |
| 18 | Clear & Muddy Lakes | C7634 | NPNCA | 1926 |
| 19 | Kurrawang | C35453 | NPNCA | 621 |
| 20 | Kambalda | C33300 | NPNCA | 3650 |
| 21 | Binaronca Rock | C32552 | NPNCA | 185 |
| 22 | Victoria Rock | C8480 | NPNCA | 258 |
| 23 | Dordie Rock | C3211 | WSSD | 121 |
| 24 | Cave Hill | C17804 | WSSD | 202 |
| 25 | Burra Rock | C7038 | WSSD | 809 |
| 26 | Cardunia Rock | A39148 | NPNCA | 38 |
| | *N.E. GOLDFIELDS* | | | |
| 27 | Wanjarri Nature Reserve | A30897 | NPNCA | 53248 |

APPENDIX I (*continued*)

| No. | Locality Index | Number | Vesting | Area (ha) |
|---|---|---|---|---|
| | *GASCOYNE RIVER AREA* | | | |
| 28 | Collier Range National Park | A35104 | NPNCA | 277841 |
| | *MURCHISON DISTRICT* | | | |
| 29 | Karroun Hill Nature Reserve | A36936 | NPNCA | 309000 |
| 30 | Kadji Kadji Timber Reserves | 1/10 | LFC | 6355 |
| | | 2/10 | LFC | 19983 |
| | *YILGARN DISTRICT & N.E. WHEATBELT* | | | |
| | *National Parks* | | | |
| 31 | Boorabin | A35004 | NPNCA | 26000 |
| | *Sandalwood Reserves* | | | |
| 32 | Kangaroo Rocks | C30445 | Lands (NV) | 8814 |
| | *Nature Reserves* | | | |
| 33 | Duladgin Rock | C2179 | NPNCA | 1363 |
| | | C2112 | MWS | 259 |
| 34 | Wedwarie Rock | C3112 | MWS | 259 |
| 35 | Deborah East | A36918 | NPNCA | 13750 |
| 36 | Mt Manning | C36208 | NPNCA | 153293 |
| 37 | Jilbadgi | A24049 | NPNCA | 208863 |
| 38 | Biljahnie Rock | C29920 | NPNCA | 1036 |
| 39 | Condarnin Rock | C29823 | NPNCA | 323 |
| 40 | Walyahmoning Rock | A35752 | NPNCA | 20925 |
| | *Other Reserves* | | | |
| 41 | Jaurdi Station | 3114/1072 | PL (CALM) | 321399 |
| | *CENTRAL DESERT AREAS* | | | |
| | *Nature Reserves* | | | |
| 42 | Queen Victoria Spring | A30491 | NPNCA | 272607 |
| 43 | Great Victoria Desert | A30490 | NPNCA | 2495777 |
| 44 | Plumridge Lake | A34605 | NPNCA | 308990 |
| 45 | Yeo Lake | A36271 | NPNCA | 321946 |
| 46 | Mangkili Clay Pan | A34604 | NPNCA | 3635 |
| 47 | Gibson Desert | A34606 | NPNCA | 1859286 |
| | *SOUTH COAST* | | | |
| | *Timber Reserve* | | | |
| 48 | Coconarup | C30795 | (NV) | 8553 |
| | *WHEATBELT* | | | |
| | *State Forest and Timber Reserve* | | | |
| 49 | Dryandra | 51/52 | LFC | 26680 |
| | | C16201 | MWS | 1270 |
| 50 | Other Reserves * | | | |

Vesting Codes -

L Act - Land Act
LFC - Lands and Forests Commission
NPNCA - National Parks and Nature Conservation Authority
WSSD - Water Supply, Sewerage and Drainage
NV - Not Vested
VCL - Vacant Crown Land
MWS - Metropolitan Water Supply

*There are numerous small and large wheatbelt conservation reserves that contain remnant Sandalwood stands. There are too many to list here.

APPENDIX II

# Seed Viability and Germination after Storage

## HYPOTHESES

H1: The age of seed affects the long term viability of Sandalwood seed.

H2: The storage of seed affects the long term viability of Sandalwood seed.

## BACKGROUND

Previous investigations on the viability of Sandalwood seed had concentrated on seed less than two years old. In view of the irregularity of seed production in the field in response to the infrequent occurrence of conditions suitable for seed production, the concepts of long term viability of seed in the field and in storage required testing. To this end a series of tests were undertaken to investigate the viability of Sandalwood seed in the field and in storage.

## METHODS

1. In October 1974 seeds were collected from the Kalgoorlie area.

2. In December 1974 the seeds were subsampled.

3. 800 seeds were soaked overnight. The endocarp of the seeds were then removed using a vice on the following day. These seeds were then subdivided into 2 sets of 100 seeds for each of the following 4 treatments:

| | | |
|---|---|---|
| Temperature | - | Cold Store (4-5°C) |
| | - | Room Temperature |
| Moisture | - | With Silica Gel |
| | - | Without Silica Gel |

The 2 sets were then stored for 2 and 5 years prior to the testing of the viability of the seeds.

4. The remaining seed was then stored in 20-L hard plastic containers with screw-top lids.

5. After eight years a separate serial batch of seed which had been stored in the cold with silica gel was tested. This was repeated at nine years. The first viability test was done at 25°C, the second at 20°C.

6. After nine years the viability of 160 medium-sized seeds with their epicarp intact was tested (40 seeds for each of the four treatments defined above).

## RESULTS

The results indicate that the germination rate deteriorates with time (Table 4, p. 12). Irrespective of treatment the seed germination percentages fall from 84 (0 Years) to 76.5 (2 years) to 34 (5 years). After five years the type of storage affects the germination rate, with the combination of cold storage with silica gel being the favoured combination.

Therefore the results support the Hypotheses that the age and storage of the seed affects the long term viability of the Sandalwood seed.

In addition the germination trials eventually became standardized as follows:

15 cm diameter petri-dishes are partly filled with vermiculite;

Sandalwood seed is placed in the vermiculite;

Fungicide is then dusted over seed;

Water is added to the vermiculite;

A piece of hessian (large enough to cover seeds) is moistened in a solution containing fungicide;

This is placed over the seed and the lid is replaced;

Seed is placed in germination cabinet (operating at 22°C-25°C);

Hessian is periodically re-moistened and replaced.

APPENDIX III

# Germination of Seed at Narrogin

## HYPOTHESES

H1: The endocarp of the Sandalwood seed restricts the rate of seed germination.

H2: The endocarp of the Sandalwood seed restricts the survival of seedlings.

## BACKGROUND

In view of the limited natural germination of Sandalwood seeds in the environment, tests were undertaken to investigate the likelihood of the endocarp affecting the germination of seed and survival of seedlings.

## METHODS

1. 25 000 Sandalwood seeds were collected in October 1977.

2. All seed trials were undertaken at the Narrogin nursery.

3. The seeds were divided into two equal sets; one set with endocarps intact and one with endocarp removed. All seeds were sown on 11 October 1977. All seeds were half-buried in the surface of a 50:50 mixture of peat moss and coarse sand. This was placed out in trays 50 mm deep on an electrically heated, thermostatically controlled hot bed at 22°C, under a polythene plastic tent.

4. Inspections were made every morning and germinations recorded. When fine white hyphae of mycellium appeared on the fourth day, a fungicide (Captan) mist was applied by hand spray, and then repeated 8 days later.

5. When the radicle of a seed appeared it was transferred to a standard pot (100 mm) or veneer tube (Plate 12) with or without host plants. The seedlings were raised in the nursery for subsequent planting in a field trial. Some seed was allowed to continue to grow in the sand-peat moss medium. These germination studies were terminated on 22 December 1977, when a final count was made of germinants and remaining seed.

## RESULTS

Maximum germination was attained for seed without shells in 16 days (27 October 77) and for intact seed in 36 days (16 November 77). The last of the germinants from the shelled seed was set out in containers five days before the first of the unshelled seed (16 November 77). Therefore the results support the hypothesis that the endocarp of the Sandalwood seed restricts the rate of seed germination.

Sixty-two per cent of the unshelled seed and over 80 per cent of the shelled seed germinated. However, later observations showed seedlings from the intact seeds survived better. Therefore the results do not support the second hypothesis that the endocarp of the Sandalwood seed restricts the survival of seedlings.

The radicles of the germinating seed left in the sand-peat or vermiculite medium were white and brittle, and rapidly grew 40-80 mm long before incipient branching.

In summary, although shelling the seeds appeared to favour germination, leaving the endocarp intact appeared better for seedling survival.

# Germination and Seedling Establishment of Sandalwood - Narrogin

### HYPOTHESIS

H1: The presence of host species increases the germination rate of Western Australian Sandalwood.

### BACKGROUND

A series of tests were undertaken to investigate the germination of Sandalwood with host seedlings at Narrogin.

### *Experiment IV-1*

### METHODS

1. Both seed-germinants and seedlings of Sandalwood were tested with *Acacia aneura* seedlings, with and without three other possible nurse seedlings (namely - *Maireana polysterygia*, *Atriplex rhagodioides* and *Cratystylis subspinescens*).

2. This experiment was repeated three times on ten units within a fenced area of State Forest near Narrogin.

3. Initial seed viability was 82 per cent in April 1978.

4. To protect the brittle roots, seed-germinants were transferred to veneer tubes immediately following emergence of the white tip or swelling of the radicle.

5. Germination was timed to enable planting out of 4- to 5-month-old seedlings in mid-winter on 27 June 1978.

6. Inspections were recorded before and after summer, at 4 months after planting (1 November 1978), 9 months after planting (23 March 1979) and 23 months after planting (23 May 1980).

### RESULTS

The results for seed-germinants and seedlings of Sandalwood were 51 per cent and 48 per cent survival respectively before summer. As these percentages were similar for seed-germinants and seedlings of Sandalwood after planting, the results were pooled and are presented in Table 5. Survival percentages dropped over the first summer to 5 per cent for both and then to 2 per cent two years after planting (Table 5, p. 14).

For the 1-year-old host seedlings, mortality was also high after planting. *Acacia aneura* survived the best, from 92 per cent before summer to 71 per cent after summer and then to 22 per cent, two years after planting among the natural vegetation of the Wandoo woodland at Narrogin.

### *Experiment IV-2*

### METHODS

A second experiment was designed to test the establishment and survival of 1200 Sandalwood (*Santalum spicatum*) with the host species of Jam (*Acacia acuminata*).

1. 1200 Sandalwood seeds were sown together with 1200 *Acacia acuminata* seeds in sets of 30 cells (5 x 6) in polystyrene trays. The cells in the trays were 5 cm square and 8 cm deep.

2. The resulting germinants were planted out, at four and a half months, in the first week of August 1979 into five sites (240 at each site). Individual cells were cut or broken out of the trays on two sides, leaving two sides intact. Each was planted without further disturbance to the roots, into holes dug with a mattock.

### RESULTS

Three and a half months after planting in the 1979 trials, there was a significant difference (P=0.05) between species. Sandalwood survived better (P=0.53 ± 0.02) than Jam (P=0.25 ± 0.02). However, after summer Jam (*Acacia acuminata*) (17 per cent) was surviving significantly better than Sandalwood (2 per cent).General observations indicated that survival was better in the fenced than on the unfenced areas. No other differences were found.

APPENDIX IV (*continued*)


## SUMMARY

The high mortality of Sandalwood and the better survival of Mulga (*Acacia aneura*) and of Jam (*Acacia acuminata*) in the field indicated that Sandalwood failed to make satisfactory union with the roots of nurse plants while in the nursery, as well as with roots of the natural hosts in the native vegetation. This was confirmed in the nursery by inspection of washed root systems of surplus plants.

In summary, insufficient seedlings established for conclusive results. The failure of Sandalwood to make haustorial connections may have affected the testing of this hypothesis. Therefore the results did not conclusively support the Hypothesis.

# Germination and Seedling Establishment of Sandalwood - Kalgoorlie

## INTRODUCTION

A series of experiments were undertaken between 1974 and 1977 to investigate the effects of a range of sites and techniques on the germination and establishment of Sandalwood seedlings at Kalgoorlie. The experiments were undertaken in fenced plots in the Kalgoorlie Arboretum, Jeedamya Pastoral Station and Bullock Holes Sandalwood Reserve.

## HYPOTHESES

H1: Watering seed beds increases the germination and establishment rates of Sandalwood seedlings.

H2: Cultivation of seed beds increases the germination and establishment rates of Sandalwood seedlings.

H3: The strategic placement of buried seed affects the germination and establishment rates of Sandalwood seedlings.

H4: The germination and establishment rates of Sandalwood seedlings is increased if seed is placed close to potential host plant.

### *Experiment V-1*
### METHODS

The first experiment was established in May 1974 at the Kalgoorlie Arboretum in a typical open woodland of Salmon Gum - Redwood(*Eucalyptus salmonophloia-Eucalyptus transcontinentalis*) , dominated by *Acacia hemiteles* in the understorey on red loam soils, to test the following factors:

1. Watering, to simulate better than average rainfall, and unwatered.

| | *Watering Rates (mm)* | | | | |
|---|---|---|---|---|---|
| *Month* | *May* | *June* | *July* | *Aug* | *Sept* |
| Rainfall | | | | | |
| (Average-mm) | 26 | 33 | 27 | 30 | 15 |
| 1974 Unwatered | 29 | 20 | 27 | 13 | 59 |
| 1974 Watered * | | 25 | | | |

(* 25 L $m^{-2}$ = 25 mm)

2. Seedbed cultivation.

3. Seed placement, on soil surface and buried; all seed dusted with protectant before sowing - Ceresan (1.5 per cent w/w Hg as mercuric acetate; not to exceed 1.5 g/L of dust to seed).

4. Distance of the seed from the base of the *Acacia* host plant, systematically distributed in four radial lines of 25 Sandalwood seeds for optimum seedling establishment between 0 to 5 m from the host stem.

## RESULTS

From 1600 seeds sown in 10 treatments in May 1974, only one germinant emerged in 1974. A further 13 emerged in 1975, in the uncultivated block which had not been watered.

Insufficient germinations occurred to test the four hypotheses.

## HYPOTHESES

H1: The watering of seed beds increases the germination and establishment rates of Sandalwood seedlings.

H2: The removal of the endocarp increases germination of Sandalwood.

H3: The soaking of seed overnight increases the germination of Sandalwood.

H4: The use of peat increases seed germination and seedling survival of Sandalwood.

### *Experiment V-2*
### METHODS

The second experiment included trials at the Kalgoorlie Arboretum and field trials at Bullock Holes Sandalwood Reserve and Jeedamya Pastoral Station.

An experiment at the Kalgoorlie Arboretum was established in May 1975 to test the following four factors. Two replicates of 25 seeds at 1-m spacing between spots in block treatments were used in the experiment.

1. Endocarp, retained and removed.

2. Seed soaked overnight and not soaked.

3. Seed spot sown, with peat in peat pots and without peat; all seed dusted with Ceresan (as in first experiment) - half of these placed in bottom of peat pots, three-quarters filled with peat.

4. Irrigated and not irrigated.

Trickle irrigation, to supplement the natural rainfall was adjusted to 4.5 L $m^{-2}$ per week (20 mm per month) - this was exceeded by 93 mm rainfall in the three months of May (45 mm), July (38 mm) and October (70 mm).

Two replicates of the unwatered treatments were established concurrently in two fenced field plots, at Bullock Holes Sandalwood Reserve and Jeedamya Pastoral Station. The fenced plots were 18 m x 20 m. Treatments at random were marked with numbered metal tags along the fence, 1 m apart between lines and 25 seeds within lines were sown in spots 0.8 m apart for each treatment and replicated (x2). Individual spots were marked with coloured wire markers.

The soil was moist below 75 mm in all plots at the time of sowing. Seeds without peat pots were sown 100 mm deep and covered with 50 mm of soil. Seeds with peat pots were sown 125 mm deep and covered with 30 mm of moist soil.

A survey was made of mortality and survival of Sandalwood seedlings, in relation to distance to the nearest host.

## RESULTS

**Kalgoorlie Arboretum**

From 2400 seeds sown in 96 units of 25 seeds for 8 treatments replicated (x 2), in 3 irrigated plus 3 non-irrigated plots, 335 germinants (14 per cent) and 55 (2 per cent) seedlings survived. Results were significant, at the 95 per cent level of confidence.

The results support the first hypothesis, that the irrigation and watering increases germination of Sandalwood.

For all sites pooled, out of 200 seeds given no treatment, 14 survived (7 per cent). No other treatment exceeded this result (peat, soaking or seed coat removed).

In the Kalgoorlie Arboretum, the nearest hosts were further away (outside the plot) and no seedlings survived.

**Field Trials - Bullock Holes Sandalwood Reserve and Jeedamya Pastoral Station**

In field trials, results for treatments to encourage germination were somewhat inconsistent and no better than no treatment, pooling all sites (Table 7 - p. 14). Removing the endocarp decreased survival in the Jeedamya plot. This coincided with a reported mice plague at the Jeedamya homestead. The apparent higher germination rates in the seeds which retained the hard coats was probably caused by the plague of mice eating more of the seeds which already had the endocarps removed. At the Bullock Holes Reserve, there was no difference between these treatments, and no evidence of field mice. Therefore the results are not consistent and the second hypothesis was not validated.

In other tests, cultivation was found to assist germination but not survival. The latter was probably a consequence of the destruction of the host roots during cultivation. Mortality of seedlings and deficiency of host plants were most pronounced in the Kalgoorlie Arboretum. Germination was also most deficient in this area.

The results supported the third hypothesis as soaking the seed increased the germination in most instances.

The results for the peat applications were not consistent, so the fourth hypothesis was not validated.

Survivors in the field trials, compared with germinants which died, were significantly closer to the nearest host: within $1.3 \pm 0.6$ m at Jeedamya Station and within $2.6 \pm 0.3$ m at Bullock Holes.

### *Experiment V-3 and V-4*

### METHODS

The third experiment, established in August 1976, repeated the previous treatments in two irrigated blocks in the Kalgoorlie Arboretum, one at 5 L/ spot (0.25 $m^2$) per week (or 1000 mm/year) and another, twice weekly (i.e. at 10 L/wet spot diameter of 56 mm per week, or eight times the average annual rainfall). Quantities were measured from a surplus trickle point in each system and timing of 5 L according to the time required to fill 0.5 L container at each watering.

The fourth experiment was established in May 1977 to test four factors:

1. Endocarp, retained and removed.
2. Peat in the pot mixture (with peat and without peat).
3. With seedling host of Mulga (*Acacia aneura*) and without; irrigated plot replicated with *Cratystylis subspinescens*, non-irrigated plot replicated with *Atriplex rhagodioides*.
4. Irrigated and not irrigated.

Twelve treatments by random numbers in each block were located 2.5 m apart between lines; and 30 spots, at two seeds per spot were sown 1.5 m apart between spots. All seeds were dusted with Ceresan before sowing. The seedling host plants were raised in 120-mm pots at Narrogin nursery.

Trickle irrigation was established at 8 L/spot, twice weekly in June, July and August (that is four to six times the monthly average) and thereafter three times weekly. Owing to the drought, sprinkler irrigation during summer was prohibited by law. Irrigation of the plot was terminated in December 1977 and the Kalgoorlie trials were suspended.

### RESULTS

From 720 seeds sown in the irrigated plot, germination commenced in August. There were 20 randomly distributed germinants in September, four months after sowing. Owing to lack of response Experiment 4 was suspended in December 1972.

### *Experiment V-5*

### METHODS

The fifth experiment was established to review the effects of early uniform pre-treatment of seed with endocarp retained and sown in irrigated and non-irrigated blocks (as for Experiment 4). Pre- treatments were applied to two sets of three factors with 16 treatments in the first set and 8 in the second:

The first set of factors were:

1. Soaked in water, starting hot and cold.
2. Four periods of soaking - 1, 3, 9 and 27 days.
3. Sowing in moist peat, in peat pot and without peat.

The second set of factors were:

1. Soaked in sulphuric acid, full and half strength (acid slowly added to water). The seeds were then washed in lime water.
2. Four periods of soaking of 2, 15, 20 and 40 minutes.
3. Sowing in moist peat in peat pot, with and without permanganate of potash ($KMnO_4$, 1:400).

The 1440 seeds were dusted with Ceresan before sowing. The seeds were sown in units of 30 seeds with six host Mulga (*Acacia aneura*) seedlings per treatment, five seeds sown in spots regularly distributed around each seedling host, planted at 1.5 m apart. This required 288 hosts for a total of 48 treatments, 144 for each block of 24 treatments.

### RESULTS

From 720 seeds sown in 24 treatments in the irrigated plot, there were three germinants in October, three months after sowing.

Owing to lack of response this Experiment was suspended in December 1977. Viability of the seed was 82 per cent (tested at the Forests Department Headquarters, Como).

APPENDIX VI

# Effects of Site Cultivation on Artificial and Natural Regeneration

## HYPOTHESES

H1: The cultivation of the site and seed bed increases the germination of Sandalwood seed.

H2: The cultivation of the site and seed bed increases the survival of Sandalwood seedlings.

## INTRODUCTION

A series of trials were established, in May 1974, to test the effects of site, of natural seed supply (or seed *in situ*) and artificial sowing, and of cultivating the seedbed on Sandalwood germination and survival. Four sites were selected for the studies in relation to their representation of plant communities and their distance and direction from Kalgoorlie (in parentheses), namely:

*Pastoral Stations*

Gindalbie Station in open woodland (70 km north north-east),

Jeedamya Station in low open woodland (145 km north);

*Reserves*

Bullock Holes Sandalwood Reserve in open woodland (42 km north- east),

Calooli Sandalwood Reserve in low open woodland (48 km south-west).

The open woodland is mainly Salmon Gum (*Eucalyptus salmonophloia*, F. Muell.) and Mulga (*Acacia aneura*, F. Muell. Ex Benth.), with *Acacia hemiteles* (Benth.), *Acacia tetragonophylla* (F. Muell.), *Casuarina cristata* (Miq.) and *Cassia nemophila* (Cunn. Ex Vogel) dominating the understorey. Gindalbie trial area occurs on a wide drainage course of alluvial red clay loams, and Bullock Holes trial area occurs on a narrow shallow course of alluvial gravelly silty-loam over red clay.

The low open woodland is mainly Jam (*Acacia acuminata*, Benth.) at Calooli Sandalwood Reserve and Mulga (*Acacia aneura*) at Jeedamya Station. The understorey species at both sites include *Eremophila* species. Jeedamya trial area occurs on a hard red sandy clay loam over calcrete at 150-300 mm and Calooli trial area occurs on a ridge of iron-oxidised, stony fragments over heavy red (crab-hole) clay.

The rainfall for Kalgoorlie in 1973 was 388 mm. This was evenly distributed with 270 mm falling in the months from April to August and 118 mm in the remaining seven drier months. In 1974, an autumn rainfall of 198 mm preceded sowing in May. After sowing, the average rainfall for the field areas was 84 mm in August, 30 mm in September and 49 mm in October - December. Ephemeral flooding, with 210 mm in April was followed by winter rainfalls of 113 mm to July, and a further 82 mm to October. Drought conditions followed at Kalgoorlie, with annual rainfalls of 127 mm in 1976, 153 mm in 1977 and 212 mm in 1978.

## METHODS

Eight treatments were established at the four sites in May 1974. The three factors tested were:

1. Natural seeding on soil surface compared with artificial spot sowing (75 mm deep).

2. Seedbed cultivated with rotary hoe and not cultivated.

3. Rabbit-proof netting was used in an enclosure (20 m x 80 m) and an unfenced block (20 m x 80 m) (See Appendix VII).

### Natural Seed Supply

The trial areas were selected near a minimum of two Sandalwood seed trees, which were fruiting in October 1973. The natural seed supply was abundant at Gindalbie with about 15 000 seeds per plot, frequent at Bullock Holes with about 5000 seeds per plot and moderate at Calooli and Jeedamya with about 1500 seeds per plot. All seed dropped to the ground early in the summer of 1974.

Cultivation was carried out with a rotary hoe to a depth of 150 mm. The cultivation was carried out beyond the tree crown canopies to avoid damage to the established trees. Most of the fallen seed was buried. There was no cultivation under the crowns, and seed in these areas remained on the surface. In addition to natural seed fall for each of the four treatments (cultivated and not cultivated on reserves and pastoral leases) 100 seeds were placed on the soil surface and marked to test surface germination and survival.

**Artificial sowing**

At each of the four sites 100 seeds were used for the two artificial spot sowing treatments (with and without cultivation). These were sown 75 mm below the soil surface and covered with 25 mm of soil. Spots were prepared by mattock to the width and the depth of the blade. After sowing, the soil was pressed firmly over the seed. All spot-sown and surface seed treatments were marked with painted wire markers.

Two units of 200 hard-coated seeds were tested for viability in the laboratory. Germination in one month was 35 per cent and the capacity increased subsequently to 82 per cent.

## RESULTS

**Natural Seed Supply**

Seeds of the germinants were found by careful, random inspection to be located at a depth of 70-100 mm below the soil surface.

Germination from natural seed was highest in the cultivated Gindalbie plots; there were 388 germinants in 1974 and 271 in 1975. The results presented in Figure 3 (p. 17) for the two reserves (Calooli and Bullock Holes) and the two stations (Gindalbie and Jeedamya) reflected a marked decrease in numbers on all areas by October 1977. The survival of natural seedfall germinants for all plots in October 1977 was less than 1 per cent (27 seedlings) (Fig. 3).

The results show germination of natural seed fall increased in the cultivated plots supporting Hypothesis 1. In cultivated areas, the survival of seedlings was higher (at October 1977) thereby supporting Hypothesis 2.

For the marked seed on the surface, germination occurred only at Gindalbie, two germinated in 1974 and two in 1975, all on cultivated ground (i.e. germination of 2 per cent on cultivated ground and 0 per cent on uncultivated ground at Gindalbie). Surface sowing was unsuccessful.

**Artificial Sowing**

In 1974, the best germination from the spot sown seeds occurred on the reserves where 20 per cent of seeds germinated, however, there was no difference between germination on the cultivated plots (22 per cent) and uncultivated plots (18 per cent).

In 1975, the best germination of seed occurred on the stations (27 per cent) where there was a significant difference ($P<0.05$ level) in germination on cultivated plots (15 per cent) and uncultivated plots (38 per cent) (Table 8, p 18). During continued observations until October 1977, of the 1975 station germination results indicated that seedlings in the uncultivated soil were surviving better than those in the cultivated soils (significant at $P>0.05$ level) (Table 8, p 18). This was not the case with 1974 germination on reserves or stations and 1975 germination on reserves.

The results from the spot sown seeds were too inconsistent to prove either Hypotheses 1 or 2 for artificial sowing.

APPENDIX VI *(continued)*

SUMMARY OF SANDALWOOD GERMINATION
(Natural Seed Supply)

| *Month and Year of Observation* | *Germinants from Natural Seedfall plus 100 surface seeds per treatment* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *2 Stations* | | | | *2 Reserves* | | | | *Total Surviving* |
| | *Not Cultivated* | | *Cultivated* | | *Not Cultivated* | | *Cultivated* | | |
| | *1* | *2* | *1* | *2* | *1* | *2* | *1* | *2* | |
| July 1974 | 0 | | 75 | | 0 | | 2 | | 77 |
| October 1974 | 3 | | 401 | | 13 | | 42 | | 459 |
| January 1975 | 0 | | 126 | | 12 | | 31 | | 169 |
| October 1975 | 1 | 0 | 16 | 27 | 75 | 14 | 11 | 27 | 351 |
| January 1976 | 0 | 1 | 8 | 58 | 4 | 9 | 14 | 26 | 120 |
| April 1976 | 0 | 1 | 7 | 26 | 4 | 9 | 4 | 24 | 75 |
| October 1976 | 0 | 0 | 6 | 22 | 2 | 8 | 4 | 23 | 65 |
| April 1977 | 0 | 0 | 4 | 6 | 0 | 0 | 4 | 14 | 28 |
| October 1977 | 0 | 0 | 4 | 6 | 2 | 0 | 1 | 14 | 27 |

1 - Number of seedlings present from the 1974 germination event.

# Effects of Browsing on Regeneration

## HYPOTHESIS

H1: The fencing of areas increases the germination and survival of Sandalwood seedlings.

## INTRODUCTION

Many observations in the past have noted the lack of Sandalwood regeneration. The fate of seedlings is often thought to be affected by the grazing pressures of herbivores (sheep, rabbits, goats, camels, donkeys, horses, cattle and kangaroos).

To test the impact of grazing on Sandalwood regeneration a series of fencing trials were established on a range of sites in the Kalgoorlie area.

## METHODS

A series of trials were established, in May 1974, to test the effects of grazing on Sandalwood germination and survival. A series of fenced and unfenced areas were designated on the four sites, (see further methods for these treatments in Appendix VI), namely:

*Pastoral Stations*
Gindalbie Station
Jeedamya Station

*Reserves*
Bullock Holes Sandalwood Reserve
Calooli Sandalwood Reserve

At each of the four sites, half of each block (40 m x 80 m) was enclosed (20 m x 80 m) with stock-proof and rabbit-netting fences and half was left unfenced (20 m x 80 m) (Plate 9).

Movements of animals were noted from time to time.

## RESULTS

Rabbits were present throughout the Goldfields in the period 1974 to 1976. Colonies were located near one of the four plots (Calooli Sandalwood Reserve) for a relatively short period in 1976. Rabbit droppings were seen, but no other activity was recorded at the Jeedamya plot in 1976 and Gindalbie plot in 1977. Kangaroo droppings were recorded at the Gindalbie Station and Bullock Holes Sandalwood Reserve plots in 1975 and 1976. Kangaroos were sighted at Jeedamya in 1977. Rodents, field mice in particular, were active at Jeedamya early during observations. Sheep grazing was heavy on the station plots at Gindalbie and Jeedamya. Twenty sheep were counted at the plot on one occasion.

From the 1600 seeded spots, 553 germinants were recorded with germination occurring in winter/spring 1974 and 1975 (Table 8, p. 18). By January 1976, 164 seedlings still survived inside the fenced plots and 94 seedlings outside.

Notwithstanding the continuous drought from mid 1975 until 1978, overall survival to October 1977 of 38 seedlings (4.7 per cent of seeds planted) in fenced areas was significantly greater ($P<0.05$ level) than survival of 9 seedlings (1.1 per cent of seeds planted) in unfenced areas for all plots pooled (Table 8, p. 18).

Results for pooled survival of germinants for unfenced (grazed) plots on stations and reserves in October 1977, revealed that survival of 9 seedlings (6.8 per cent of germinants) on reserves was significantly better ($P<0.05$ level) than on stations where no germinants survived. In the fenced plots there was no significant difference between survival on the station plots where 22 seedlings (16.5 per cent of germinants) survived and on the reserves where 16 seedlings (10.1 per cent of germinants) survived.

By October 1977 of the total of 292 germinants on reserves, 16 (10.1 per cent) in fenced areas and 9 (6.8 per cent) in unfenced were surviving. On the stations from 261 germinants in fenced areas the survival was 22 (15 per cent) and in the unfenced was nil. Fencing was a significant factor on stations but not on reserves ($P< 0.05$).

APPENDIX VII (*continued*)

**Germination and seedling survival from spot sowing at 200 Sandalwood seed per plot treatment - summary**

| | *2 Stations (Gindalbie + Jeedamya)* | | | | *2 Reserves (Calooli + Bullock Holes)* | | | | *Total* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *No. Sown* | *No. germ-inants* | *Survival at Oct 1977* | | *No. sown* | *No. germ-inants* | *Survival at Oct 1977* | | *No. Sown* | *No. germ-inants* | *Survival at Oct 1977* | |
| | | | *No.* | *%* | | | *No.* | *%* | | | *No.* | *%* |
| Fenced | 400 | 133 | 22 | 16.5 | 400 | 133 | 16 | 10.1 | 800 | 266 | 38 | 14.3 |
| Unfenced | 400 | 128 | 0 | 0 | 400 | 159 | 9 | 6.8 | 800 | 287 | 9 | 3.1 |
| Total | 800 | 261 | 22 | 8.4 | 800 | 292 | 25 | 8.6 | 1600 | 553 | 47 | 8.5 |

Grazing by sheep at the Gindalbie plot commenced with the dry season in October 1975 and coincided with seedling mortality owing to drought.

Sheep ranged more actively for green feed and grazing pressure increased with drought. Mortality during the first year was 61 per cent inside the fence and 94 per cent outside the fence. During the second year of the study the drought developed, and by the third year many mature plants had died.

At the Jeedamya plot, rabbits were observed in October 1974 and sheep in February 1975. Feed was abundant early in 1976 and only the tops of the plants were grazed at this stage. Heavy grazing commenced in May 1976. The effects of fencing at Jeedamya were similar to those at Gindalbie. An initial advantage by chance of germinants in the unfenced plot was subsequently lost owing to grazing.

In the unfenced plot in the Calooli Reserve rabbits nipped off some seedlings in October 1974. On the basis of observations the activity of rabbits appeared to decrease temporarily for a short period in early 1975, allowing some recovery of seedlings. However, the rabbits increased their grazing activities again in the months of April to October 1975, when 88 per cent of deaths occurred in the cultivated, unfenced area owing to rabbit browsing. Little damage occurred among seedlings in the uncultivated plots. The rabbit population was evidently limited and the rabbits preferred to graze on the soft, cultivated ground, where initially there were more seedlings. Rabbit activity ceased during the 1976-77 summer. With continuation of the drought, by October 1977, fencing in the reserve had little effect on survival of seedlings from spot sowing.

At the Bullock Holes Reserve, fencing had little effect on survival of Sandalwood seedlings. Slight rabbit damage occurred in October 1975. Kangaroos and emus frequented the areas throughout the observations, without evidence of grazing.

In summary, fencing increases the germination and survival of Sandalwood seedlings, therefore the results support the Hypothesis. The differences between fenced and unfenced are clearer on the pastoral stations.

APPENDIX VIII

# Effects of Fire and Cutting on Sandalwood Regeneration

***Experiment VIII-1: Coppice after the 1975 Wildfire, Lakeside Reserve***

### HYPOTHESIS

H1: The occurrence of fire increases regeneration in Sandalwood.

### INTRODUCTION

Many observations in the past have noted the lack of Sandalwood regeneration. Early observations on coppice growth of Sandalwood in the Wheatbelt suggested that coppice regeneration may be an option for the harvesting of Sandalwood.

To evaluate the productivity of recovery from burning and cutting a series of experiments were established in 1974-75 on fenced areas protected from grazing on a reserve and on a pastoral station.

### METHODS

An area of approximately 40 ha of typical Salmon Gum - Gimlet (*Eucalyptus salmonophloia* F.Muell. - *Eucalyptus salubris* F.Muell.) and Mirret (*Eucalyptus celastroides* Turcz.) woodland, 10 km east of Kalgoorlie, was burnt in wildfire on the 9-10 January 1975. Within this burnt area 56 Sandalwood trees were selected and graded into scorch categories, 12 trees were selected in the same size-class range in adjacent unburnt areas. All trees were numbered and their positions mapped to assist in future relocation.

Periodic assessments of recovery or deterioration in crowns, stems and roots, and of flowering and fruiting, were carried out at intervals of three months for the first 15 months and half-yearly for the next two years.

### RESULTS

The results of the 56 burnt and 12 control trees are summarized below:

**Wildfire Effects on Sandalwood Trees in Lakeside Sandalwood Reserve**

| *Description of Fire Effects* | *No. of Trees* | *% of Burnt Trees* |
|---|---|---|
| Control (Unburnt Trees) | 12 | - |
| Light scorch of crown, little or no butt scorch | 11 | 20 |
| Light-medium scorch only, butt scorch to 0.5 m, and heavy-medium scorch up to 50% defoliation, bole and branches blackened to 1.5m | 22 | 39 |
| Severe scorch, more than 50% defoliation, total bole blackened and branches scorched | 11 | 20 |
| Destroyed, stems burnt to ground | 9 | 16 |
| Pieces, dead before fire | 3 | 5 |

Of the total of 44 burnt trees, 9 (16 per cent) survived and appeared to have healthy crowns by October 1977, and all others in the burnt areas were killed by the fire. None of the unburnt control trees died during the study (Table 9, p. 19).

The results do not support the Hypothesis that Sandalwood regeneration is increased by the occurrence of fire.

### *Experiment VIII-2: Coppice after Cutting at Ground Level*

#### HYPOTHESIS

H1: The cutting of Sandalwood at ground level increases the regeneration of Sandalwood through coppicing.

#### INTRODUCTION

The potential for coppice regeneration had been noted by Drake-Brockman in 1921, and the possibility of utilizing coppicing as an operational technique for Sandalwood regeneration was explored by a series of trials.

#### METHODS

Four blocks were established, each of about 4000 $m^2$, at Calooli Sandalwood Reserve and Gindalbie Station. These blocks were adjacent to existing regeneration plots. The size of the trees were ranked and matched for grazing treatments within the blocks. The following factors were investigated to review the coppice production:

1. Grazing - fenced (open wire ringlock excluding large animals) and not fenced;
2. Season - summer and winter;
3. Soil - moist and dry;
4. Vermin - guard (1 cm bird netting to exclude small animals) and no guard;
5. Location - Gindalbie and Calooli.

All stems were cut with a chainsaw as prevailing field practices utilized this technique of cutting.

Trees were identified and numbered (1-128) and their position mapped in the four blocks (32 stems in each block). Of these 128 trees:

- 64 were felled with a chainsaw, 16 after summer moist soil treatments (trees were felled in March 1975) and 16 in the winter moist soil treatment (July 1975). Another 32 were cut down in the dry winter treatment (July 1976).

- The other 64 trees were retained for subsequent treatments, which owing to the results obtained were later shown to be unnecessary.

- Of the 64 trees felled, 32 trees were fenced in blocks and 32 were left unfenced. Within the blocks, half of the trees were guarded with netting and half of the trees were left unguarded.

- Stem diameters at 150 mm above ground, ranged from 76 mm to 222 mm. Periodic assessments were carried out quarterly for the first year and then at longer intervals.

#### RESULTS

Of the 16 trees cut down in March 1975, four coppiced after 4 months. No coppice subsequently survived.

There was no coppice from 48 stems cut during the winter treatments and the experiment was terminated.

Therefore the results do not support the Hypothesis that cutting at ground level increases coppicing in Sandalwood.

APPENDIX IX

# Regeneration Studies at Narrogin

## INTRODUCTION

A series of techniques for sowing and germinating Sandalwood seed were investigated at Narrogin. An attempt was made to study the problems of different seed viability and diversity of sites.

## METHODS

Planting was carried out in 1981 in a partially stocked stand (87 m x 207 m) of Jam (*Acacia acuminata*) trees in the Dryandra State Forest. The area was fenced and three treatments were allocated at random in 30-m strips (3 m apart) in three replicates x 10 units per treatment x 3 m between spots, pegged and labelled on site. The following seven factors and a combination of treatments on a suitable site for Sandalwood were investigated with plants raised in the Narrogin nursery:

1. Two seed sources:
   - Narrogin,
   - Kalgoorlie.
2. Three sorts of planting stock:
   - seed sown at 3 and 4 per niche,
   - germinated seed sown at 2 per niche,
   - nursery seedlings planted at 1 per niche.
3. Two planting methods:
   - mattocked spots,
   - ploughed furrows.
4. Two seed treatments:
   - strips sprayed with herbicide,
   - not sprayed.
5. Three degrees of shade:
   - open,
   - half shade,
   - full shade.
6. Two drainage conditions:
   - freely drained slope,
   - a water gaining site on clayey flat.
7. Sandalwood established alone and with a variety of host seedlings, including Jam (*Acacia acuminata*), Mulga(*Acacia aneura*), Sheoak (*Casuarina cristata*) and fragrant grey bush (*Cratystylis subspinescens*).

## RESULTS

### Seed Source and Planting Stock

Results from the direct seeding indicated that all the Kalgoorlie seed failed. Eighteen per cent of the Narrogin seed germinated, however, only 9 per cent of the germinated seed survived the summer.

Results from the planted seedlings indicated a variation in success between the Narrogin and Kalgoorlie provenance, as follows:

33 per cent of seedlings of Narrogin provenance surviving at the end of summer, and
8 per cent of seedlings of Kalgoorlie provenance surviving at the end of summer.

The sowing of germinated seeds indicated similar results initially, as follows:

31 per cent of 360 Narrogin germinated seeds survived as seedlings in spring, and
29 per cent of 520 Kalgoorlie germinated seeds survived as seedlings in spring.

Results had altered after summer, as follows:

34 per cent of 360 Narrogin germinated seeds survived as seedlings, and
23 per cent of 520 Kalgoorlie germinated seeds survived as seedlings.

These results are similar to those for the planted seedlings.

Sowing germinated seeds at four per spot produced one surviving germinant per spot, as follows:

23 per cent of spots for Kalgoorlie seed, and
27 per cent of spots when pooled with Narrogin provenance seed.

**Site Preparation**

Chemical spraying of weeds before sowing or planting had no effect on Sandalwood germination or survival. Sandalwood germination and survival was higher on spot sown areas compared with seed sown in furrows. In contrast there appeared to be no differences in planting seedlings in furrows or spots.

**Site Conditions**

Germination and survival on the well-drained slope was consistently better than on the water gaining clayey flat (winter flooded).

The influence of shade was evident from a comparison of the survival of germinated seedlings, where:

55 per cent survived under full shade, compared with

43 per cent survival in the open.

**Seedling Host Species**

Survival of host species were:

72 per cent Jam (*Acacia acuminata*),
69 per cent Mulga (*Acacia aneura*),
32 per cent Sheoak (*Allocasuarina huegeliana*),
8 per cent *Cratystylis subspinescens*.

# Sandalwood Growth Rates

### HYPOTHESES

H1: The natural variation in plant size and rates of growth are affected by site conditions.

H2: The site conditions, climate and soils affect the plant sizes of Sandalwood.

H3: The site conditions, climate and soils affect the growth rates of Sandalwood.

### INTRODUCTION

During 1974 a number of studies were undertaken to determine the range in size of Sandalwood trees and the rate of growth.

The natural variation in plant size and rates of growth are predictably related to factors such as site conditions, climate and soils.

### *Experiment X-1: Growth Rates - Kalgoorlie*

### METHODS

In 1974, numbered trees were sampled from two locations sown between 1925 and 1930 at Karramindie State Forest and Scahill Sandalwood Reserve, both near Kalgoorlie:

Karramindie - 530 ha of gently sloping sites with heavy loam soils
Scahill - 91 ha of sandy flats

A total of 22 trees were measured at Karramindie and 26 at Scahill. All 48 trees had previously had measurements taken at 1-3 month intervals for the first two years following sowing, then at 3-6 months for five years, and next in 1939 and 1940 (Table 10, p. 22).

In 1974, individual trees were grouped into 1.5 m height classes and data were summarized for measurements at 44 and 49 years of age, representing the period over which establishment occurred. Measurements were pooled and adjusted to one age of 44 years. A sample tree of mean height was chosen to represent each height class.

At Karramindie five sample trees were each matched with a tree in the surrounding plantation. These plantation trees were cut and measured by the sectional method to derive volume and increment of the truewood, sapwood and bark.

Volume was calculated from the formula (Avery 1975):

$$V = 0.0785 \times D^2 \times L$$

where: V = volume in cubic metres X $10^2$
D - mid-diameter in centimetres
L - length in metres

Height and diameter relationships for all plot trees were used to derive information on growth rate, production of timber and age at which Sandalwood reaches commercial size. Sandalwood weight was determined using a density figure of 880 $kg.m^{-3}$, established in concurrent studies of wood density (surface-air-dry for one month, so that this figure is essentially wood density of green Sandalwood).

### RESULTS

For the largest sample tree, commercial heartwood of 1.15 kg grew in 44 years. Eight hundred and seventy trees of this size would be required to produce 1 tonne of heartwood. The relative volumes of the material in the commercial section of the Sandalwood consisted of 30 per cent heartwood, 30 per cent sapwood and 40 per cent bark. Bark and sapwood had a combined consistent thickness of 21-22 mm.

Comparable trees in the largest group (98 mm diameter) have 2.5 kg of total wood and 1.3 kg of heartwood equivalent to 400 trees per tonne and 770 trees per tonne of heartwood respectively (Table 11, p. 23).

### *Experiment X-2: Growth Rates - Kalgoorlie, Narrogin*

### METHODS

In 1978, 731 trees were measured (height and stem diameter); 228 trees in 16 ha of 8 km x 20 m transects through Karramindie State Forest (Kalgoorlie) and all

443 trees in the plots at Dryandra State Forest (Narrogin).

The age required to attain the commercial size limit of 127 mm stem diameter was extrapolated from the mean diameter for the age at 1978.

**RESULTS**

A wide range in rates of growth were observed between the largest and smallest trees within different sites. At Dryandra, observations of adjacent groups of 47-year-old Sandalwood trees in woodlands dominated by *Eucalyptus wandoo* and *Acacia acuminata* demonstrated the effect of site conditions on Sandalwood and host survival and growth rates. At one site, hosts had died and Sandalwood growth was slow compared with a water-gaining site adjacent to farmland regularly dressed with fertilizers where vigorous Sandalwood trees were observed up to 3 to 4 m from hosts.

The time required to attain commercial size varied from 32 to 59 years at Dryandra to 59 to 115 years at Kalgoorlie (Table 12, p. 24). The latter differences appeared to relate primarily to differences in site and climatic conditions in the two regions.

***Experiment X-3: Growth Rates - Narrogin and Swan Coastal Plain***

**METHODS**

A range of measurements were also undertaken in 1974 and 1978 on Sandalwood trees in the Narrogin and Swan Coastal Plain areas. The growth rates for known aged trees were extrapolated to determine the time required to attain the commercial size of 127 mm (Table 12, p. 24).

**RESULTS**

**Narrogin District**

1. Twenty three to fifty years was required for growth to commercial size in winter rainfall (500 mm annual rainfall):

   In Jam - Wandoo (*Acacia acuminata - Eucalyptus wandoo*) communities:
   - 23 to 30 years from the 1956 trials at Bald Rock, Corakin, Stokes and Lol Gray Blocks at Dryandra State Forest.
   - 50 years in the adjacent open flat Wandoo-Jam reserve for the 1931 trials and lowland of the Bendering Reserve for the 1928 trials.

   In Wandoo - Jam (*Eucalyptus wandoo - Acacia acuminata*) communities:
   - 30 - 38 years from the 1956 trials in Peters block within the Dryandra State Forest.

   In Wandoo - Rock Sheoak(*Eucalyptus wandoo - Allocasuarina huegeliana*) communities:

   - 50 years in Smith Block within the Dryandra State Forest for the 1931 trials (plus a few replantings in 1962).

2. 50 to 100 years was required for growth to commercial size in winter rainfall (335-385 mm annual rainfall):

   In ploughed broombush flat and lowland Jam communities:
   - 45 - 50 years from 1918-21 trials.

   In unploughed broombush flat (Pikaring Reserve) and granitic ridge Jam (Bendering Reserve) communities:
   - 80 - 130 years from 1918-21 trials. (Recent deaths were observed in 1969 at 50 years (Plate 3)).

**Swan Coastal Plain**

3. 35 to 70 years was required for growth to commercial size in winter rainfall (875-890 mm annual rainfall):

   In coastal Bassendean sand near Perth:
   - 35 years from 1964 records (Plates 6 and 7).

   In Tuart (*Eucalyptus gomphocephala*) forests, Ludlow - between Busselton and Bunbury.

443 trees in the plots at Dryandra State Forest (Narrogin).

The age required to attain the commercial size limit of 127 mm stem diameter was extrapolated from the mean diameter for the age at 1978.

**RESULTS**

A wide range in rates of growth were observed between the largest and smallest trees within different sites. At Dryandra, observations of adjacent groups of 47-year-old Sandalwood trees in woodlands dominated by *Eucalyptus wandoo* and *Acacia acuminata* demonstrated the effect of site conditions on Sandalwood and host survival and growth rates. At one site, hosts had died and Sandalwood growth was slow compared with a water-gaining site adjacent to farmland regularly dressed with fertilizers where vigorous Sandalwood trees were observed up to 3 to 4 m from hosts.

The time required to attain commercial size varied from 32 to 59 years at Dryandra to 59 to 115 years at Kalgoorlie (Table 12, p. 24). The latter differences appeared to relate primarily to differences in site and climatic conditions in the two regions.

***Experiment X-3: Growth Rates - Narrogin and Swan Coastal Plain***

**METHODS**

A range of measurements were also undertaken in 1974 and 1978 on Sandalwood trees in the Narrogin and Swan Coastal Plain areas. The growth rates for known aged trees were extrapolated to determine the time required to attain the commercial size of 127 mm (Table 12, p. 24).

**RESULTS**

**Narrogin District**

1. Twenty three to fifty years was required for growth to commercial size in winter rainfall (500 mm annual rainfall):

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   In Wandoo - Jam (*Eucalyptus wandoo - Acacia acuminata*) communities:

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2. 50 to 100 years was required for growth to commercial size in winter rainfall (335-385 mm annual rainfall):

   In ploughed broombush flat and lowland Jam communities:

   - 45 - 50 years from 1918-21 trials.

   In unploughed broombush flat (Pikaring Reserve) and granitic ridge Jam (Bendering Reserve) communities:

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**Swan Coastal Plain**

3. 35 to 70 years was required for growth to commercial size in winter rainfall (875-890 mm annual rainfall):

   In coastal Bassendean sand near Perth:

   - 35 years from 1964 records (Plates 6 and 7).

   In Tuart (*Eucalyptus gomphocephala*) forests, Ludlow - between Busselton and Bunbury.

- 35 years from plantings in 1931 near Wattles and *Pinus radiata* (2-years-old) near the new alignment of the South Western Highway (picnic site).

- 70 years from 1935 plantings near Wattle (*Acacia pycnantha, Acacia saligna* and *Pinus pinaster* - 8-years-old).

***Experiment X-4: Fibre Mass Assessment of Parts and Whole Trees Eastern Goldfields and Gascoyne and Greenough Regions.***

**METHODS**

Twenty-two trees were pulled from three localities where operations were in progress, north and north-east of Kalgoorlie (Morapoi Station - 8 trees; and Edjudina Station - 7 trees) and between Payne's Find and Morawa (Karara Station - 7 trees). The whole tree and constituent parts were fresh weighed and measured to investigate the relative mass of each component: roots, stems, branches, twigs and leaves. Measurements also included stem diameters over bark at 150 mm above the ground, total height of the tree and crown width. Each tree was pulled out of the ground and the solid roots down to 40 mm wood diameter were harvested.

Trees ranged in size:
9 trees were under 87 mm stem diameter,
4 trees ranged from 88 mm to 112 mm stem diameter,
5 trees ranged from 113 mm to 137 mm stem diameter,
4 trees exceeded 138 mm in stem diameter.

Components of each tree were then segregated and measured, as follows:

1. Root and butt measurements taken were:
   Removed roots and butt at 150 mm;
   Diameters at both ends of bark, sapwood and true hardwood, mid-diameter over bark and length;
   Weighed pieces with and without bark.

2. Logwood and branchwood measurements taken were:

   Delimbed and recorded log and branch dimensions of each piece, i.e. mid and end diameters and length;
   Trimmed logwood and branchwood to 40 mm diameter of heartwood;
   Recorded dimensions, both ends of bark, sapwood, heartwood and mid girth over bark;
   Weighed with and without bark.

3. Branch measurements taken were:

   Weighed individual branches;
   Each branch, total length;
   Estimated point of non-edibility (10 mm considered too large to be browsed);
   Recorded end diameters under bark and length, from 40 mm diameter of heartwood to 40 mm diameter of total wood.

4. Leaf and twig measurements taken were:

   From each branch of each tree, removed approximately ten to twelve leaves with twigs;
   Subsampled 12 to 14 leaves per tree and combined 100 leaves within each locality - separated leaves and twigs, measured area of leaves, fresh and oven dry weights.

The relationships between the various components in various size classes were analysed using linear regressions (Table 13, p. 24).

**RESULTS**

An average tree reaching commercial size will have a total fresh weight of 40 kg of which 45 per cent will be marketable, as follows:

| | *Fresh Weight (kg)* |
|---|---|
| *Total Commercial Tree* | *40* |
| *Marketable* | |
| Stem | 10-11 |
| Butt | 4- 5 |
| Roots | 2- 3 |
| *Non-Marketable* | |
| Foliage and Twigs (<10 mm diameter) (foliage - 5.5 kg green; foliage - 2.5 kg oven dry; twigs - 5.5 kg) | 11 |
| Branchwood (>10 mm diameter) (Sapwood - 4 kg; Heartwood - 2 kg;) | 6 |

The following regressions apply in the small sample of trees below marketable size in the stem diameter ranges 55 mm to 127 mm (Table 13, p. 24):

Small old trees:

Y (Volume) = 0.1132 + 0.0075 X,
r = 0.6

Y1 (Basal Area) = 0.3719 + 0.0039 X,
r = 0.6

Y2 (Healthy Trees) = 0.1327 + 0.0061 X,
r = 0.74

Advanced Regrowth:

Y (Basal Area) = 0.3475 + 0.0082 X,
r = 0.87

On the basis of these figures it was possible to calculate that the proportion of heartwood exceeds sapwood in a stem diameter (over bark) of 102 mm, as follows:

| *Diameter over Bark(mm)* | *% Heartwood in Total Wood* |
|---|---|
| 51 | 7 |
| 76 | 28 |
| 102 | 49 |
| 127 | 69 |

The relationship between stem diameter - d(mm) and stem weight - w(kg) was calculated for air-dried weight at one month from a fresh sample of 22 Sandalwood trees as follows:

Cut Stems: $W = 0.000437\ d^2$ $r = 0.97$ ***
Pulled Stems: $W = 0.000719\ d^2$ $r = 0.97$ ***

From these equations, relationships between stem diameter and number of stems per tonne were derived (diameter in millimetres):

No. Cut Stems per Tonne $= 2288329\ d^{-2}$
No. Pulled Stems per Tonne $= 1390820\ d^{-2}$

In general, the number of pulled stems needed to make a tonne is about 60 per cent of the number required if stems were cut at ground level, almost 90 and 150 respectively at the commercial size of 127 mm stem diameter.

0850 - 0291 - 1300