FINAL REPORT

Gnangara Groundwater System Plantation Species Assessment

Prepared for

Forest Products Commission

695 Gnangara Rd
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Western Australia 6065
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GNANGARA GROUNDWATER SYSTEM PLANTATION SPECIES ASSESSMENT

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<th>Description</th>
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<tr>
<td>DBH</td>
<td>Diameter at breast height</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FPC</td>
<td>Forest Products Commission</td>
</tr>
<tr>
<td>GSS</td>
<td>Gnangara Sustainability Strategy</td>
</tr>
<tr>
<td>Ha</td>
<td>Hectare</td>
</tr>
<tr>
<td>IWP</td>
<td>Integrated wood processing</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf area index</td>
</tr>
<tr>
<td>LVL</td>
<td>Laminated veneer lumber</td>
</tr>
<tr>
<td>MAR</td>
<td>Mean annual rainfall</td>
</tr>
<tr>
<td>MDF</td>
<td>Medium density fibreboard</td>
</tr>
<tr>
<td>MRET</td>
<td>Mandatory Renewable Energy Target</td>
</tr>
<tr>
<td>PCA-LAI</td>
<td>Projected canopy area-leaf area index</td>
</tr>
<tr>
<td>REC</td>
<td>Renewable Energy Certificate</td>
</tr>
<tr>
<td>SLA</td>
<td>Specific leaf area</td>
</tr>
<tr>
<td>WA</td>
<td>Western Australia</td>
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</tbody>
</table>
Executive Summary

The Gnangara groundwater area (referred to hereafter as the Gnangara Groundwater System) is a major natural groundwater resource that is part of the water supply for the Perth region. In response to declining groundwater levels, the Department of Water is developing a long term plan for the management of groundwater called the Gnangara Sustainability Strategy (GSS).

Plantation forestry is a major land use on the Gnangara Groundwater System with the Forest Products Commission (FPC) managing approximately 22,000 hectares (ha) of land on which there is about 17,000 ha of Maritime pine (*Pinus pinaster*) plantations. In response to research that shows *P. pinaster* plantations limit the groundwater recharge, the FPC is exploring alternative plantation options for forestry as an ongoing land use.

The Gnangara Groundwater System area is characterised by the following site attributes:

- Long term mean annual rainfall (MAR) of 782 mm, however annual rainfall has declined by about 11% since the mid 1970s;
- Groundwater system comprised of several different aquifers. The main water source is the superficial aquifer, which exists across the entire Gnangara Groundwater System area. Depth to groundwater varies from less then 3m up to 20m; and
- Major geological landform is the Bassendean dune system. Bassendean sand near the ground surface is typically clean and white, but at depth it can be yellow to brown from higher iron content. Three types of Bassendean sands occur in the area; Jandakot sands, Gavin sands and Joel sands.

URS Forestry (URS) has been engaged by the FPC to undertake a review of available literature and data to identify species other than *P. pinaster* that may be suitable for plantation development on the Gnangara Groundwater System. In reviewing potential alternative species, URS sought information on site-species suitability, silviculture, growth rates, water use and markets. Leaf area index (LAI) is commonly used as a proxy for water uptake and LAI information was reviewed where available.

The following species groups were reviewed:

- *Acacia* species (*A. bartleana*, *A. microbotrya* and *A. saligna*);
- Hardwood plantation species (*C. maculata*, *E. cladocalyx*, *E. saligna* and *E. gomphocephala*);
- Oil mallee species; and
- Sandalwood (*S. spicatum*)

Table ES-1 provides a summary of the findings regarding site-species suitability, market opportunities and limitations for each of the species groups.
Executive Summary

Table ES-1 Summary of opportunities for alternative species on the Gnangara Groundwater System

<table>
<thead>
<tr>
<th>Species</th>
<th>Best product / market prospects</th>
<th>Water use</th>
<th>Opportunities, risks, limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia species</td>
<td>Bioenergy, MDF</td>
<td>Little is known about water use of the species and no LAI data was observed in the literature. Soil moisture will be required to maintain rapid growth and some species appear to have the ability to grow deep roots.</td>
<td>Some Acacia species are expected to grow well on the Gnangara Groundwater System due to preference for sandy soils and acceptable rainfall.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Proposed bioenergy projects present new market opportunities. A. saligna appears to be the best species for bioenergy or MDF as it has fast growth and will coppice, however its poor form will make it difficult to harvest.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plantations grown to produce biomass for bioenergy will normally be planted at high stocking and managed to maximise growth. Alternative plantation regimes with lower stocking or planting only a proportion of the area in block plantings would be necessary on the Gnangara Groundwater System to keep water use within acceptable limits.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Suitability for MDF production needs to be proven.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plantations can be grown over long rotation for specialty sawn timber products, however these markets are not well developed.</td>
</tr>
<tr>
<td>Hardwood plantation species</td>
<td>Sawn timber, Bi-products from sawlog rotation such as posts/poles and biomass</td>
<td>Some LAI data is available. Data is limited but could be used as an indicator for hardwood plantations on the Gnangara Groundwater System.</td>
<td>It is expected to be feasible to manage hardwood sawlog plantations to meet LAI constraints as they can be planted at lower stocking and thinned.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Several species have been grown successfully in trials on sites similar to the Gnangara Groundwater System, although growth rates are low.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tree breeding, silviculture and processing technologies are still being developed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>There may be opportunities to aggregate with existing FPC hardwood plantations in south west WA.</td>
</tr>
<tr>
<td>Oil mallee species</td>
<td>IWP, Dedicated bioenergy plant, Pellets</td>
<td>Some LAI data is available. Data is limited but could be used as an indicator for oil mallee plantings on the Gnangara Groundwater System.</td>
<td>Oil mallee species appear suited to the conditions of the Gnangara Groundwater System.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Proposed bioenergy projects present new market opportunity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Belt or dispersed block plantings would be required to keep within LAI constraints.</td>
</tr>
<tr>
<td>Sandalwood</td>
<td>Timber, oil, nuts</td>
<td>No data identified during the literature review. Water use needs to be considered for a system including sandalwood and host species.</td>
<td>Sandalwood may be suited to some soils on the Gnangara Groundwater System.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Growing interest and investment in sandalwood plantations in south west WA and good market prospects.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High value crop appropriate for small plantings on suitable soils.</td>
</tr>
</tbody>
</table>
1.1 Introduction

The Gnangara groundwater area (referred to hereafter as the Gnangara Groundwater System) is a major natural groundwater resource that is part of the water supply for the Perth region. The Gnangara Groundwater System is located on the Swan Coastal Plain, north of Perth and covers approximately 2,200 km². Groundwater levels have been under increasing pressure since the 1970’s due to a decrease in recharge, as well as increasing public and private demand for water. In response to the decline in groundwater levels, the Department of Water published the draft Gnangara Groundwater Management Plan (the Plan) in February 2008. The Plan sets out how groundwater resources will be managed until a long term plan is developed.

One of the major land uses on the Gnangara Groundwater System is plantation forestry and the Forest Products Commission (FPC) currently manages 22,000 hectares (ha) of land on which there is about 17,000 ha of Maritime pine (Pinus pinaster) plantations on the Gnangara Groundwater System. Much of the plantation resource is reaching maturity and there are concerns that the density of the mature plantation substantially limits the rate of groundwater recharge. In response to these concerns the FPC is currently restricted from replanting harvested areas on the Gnangara Groundwater System. It is expected that the Plan will place limits on the amount of groundwater that can be drawn from the system, but there may be an ongoing opportunity to grow commercial tree plantations at a lower density that enhances the rate of groundwater recharge. Leaf Area Index (LAI) can be used as a proxy for water uptake. LAI is a measure of the total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation is growing.

In order to promote the long term sustainable use of groundwater resources, a Gnangara Sustainability Strategy (GSS) is being developed. Part of the GSS includes the continuation of plantation forestry in recognition of the legislated requirement for the FPC to supply logs from plantations located on the Gnangara Groundwater System. However, a number of studies demonstrate that dense *P. pinaster* plantations limit groundwater recharge on deep sandy soil profiles, and the GSS requires that the FPC consider alternative plantation regimes for forestry as an ongoing land use.

One potential option for future plantation development on the Gnangara Groundwater System is to grow plantations of species other than *P. pinaster* under management regimes that result in a lower level of water use than the current plantations. URS Forestry (URS) has been engaged by the FPC to undertake a review of available literature and data to identify species that may be suitable for plantation development on the Gnangara Groundwater System from a site-species suitability and marketability perspective.

Section 2 of this report provides an assessment of alternative species, which was developed through an extensive literature review. Section 3 summarises the potential market opportunities for alternative species. Section 4 provides a summary of potential species and market opportunities and makes recommendations regarding potential alternative species for the Gnangara Groundwater System. It also outlines the next steps required to further assess the feasibility of different plantation options.

1.2 Site description

The Gnangara Groundwater System area has a Mediterranean climate of warm wet winters and hot dry summers. The long term mean annual rainfall (MAR) of the Gnangara Groundwater System area is 782 mm. However rainfall has varied significantly over different periods, with a shift towards a drier climate since the mid-1970’s. The annual rainfall in south west WA has declined by about 11% since the mid 1970s. Since 1997 annual average rainfall on the Gnangara Groundwater System area has been below 700 mm (DoE 2005).
Section 1  Background

Annual average evaporation\(^1\) in the Gnangara Groundwater System area is around 1,800-2,000 mm (BoM 2008).

The groundwater system is comprised of several different aquifers. These are the superficial aquifer, the semi-confined Mirrabooka aquifer and the confined Leederville and Yarragadee aquifers (Figure 1-1). The superficial aquifer exists across the entire Gnangara Groundwater System area and is the main water source (DoW 2008). The depth to groundwater in the superficial aquifer varies across the Gnangara Groundwater System, from less than 3m up to 20m.

![Figure 1-1  Gnangara system hydrogeological cross-section](image)

Source: DoW, 2008

The major geological landform surface of the Gnangara Groundwater System area is Bassendean sand (quartz sand dunes). The Bassendean dunes are the oldest of three dune systems on the Swan Coastal Plain, and occur about 15 to 40km from the coastline. The Bassendean dune system consists of old, siliceous sands which have been heavily leached by rainfall recharge. Bassendean sand near the ground surface is typically clean and white, but at depth it can be yellow to brown from higher iron content (Bakele et al 2007). Three types of Bassendean sands occur in the area:

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\(^1\) Evaporation is the amount of water which evaporates from an open pan called a Class A evaporation pan. The rate of evaporation depends on factors such as cloudiness, air temperature and wind speed. Measurements are made by the addition or subtraction of a known amount of water, which then tells us how much water has evaporated from the pan (BoM 2008).
Background

Section 1

- Jandakot sands are well drained sands on the crests and upper slopes of the low hills or ridges. In their B horizon they have an iron podzol (contains iron oxide, which appears as a bright orange layer, that can include hardened concretion). The watertable is about 10m below the surface of the Jandakot sands (Bolland 1998). These sands occur in the west of the Gnangara Groundwater System area (Bakele et al 2007).

- Gavin sands occur further down slope from the crest, where the watertable is about 2m below the surface, and in the B horizon, an iron-humus podzol (a bright orange-brown layer which contains iron oxide and organic matter) occurs, which can be partly cemented (Bolland 1998). These sands occur further to the east of Jandakot sands (Bakele et al 2007).

- Joel sands, often a sandy loam (loam texture due to organic matter), occur in the lowest part of the dune system, where the watertable is very close to the surface, and seasonal waterlogging occurs at the wettest time of the year (typically June to mid-August). The B horizon is a humus podzol, comprising a strongly cemented dark brown organic B horizon (Bolland 1998).
Section 2

Assessment of Alternative Plantation Species

This section presents an outline of species that may have potential as alternative plantation tree crops on the Gnangara Groundwater System, including site suitability, potential products, previously observed growth rates, water use and silvicultural options.

2.1 Species suitability

Analysis of potential alternative species is presented in the following species groupings:

- Acacia species;
- Hardwood plantation species;
- Oil mallee species; and
- Western Australian sandalwood (*Santalum spicatum*).

Information has been reviewed with respect to the climatic range and growth performance of the alternative species. The key criteria on which information was sought included:

- **Suitability**: Native environments were assessed for their similarity to the Gnangara Groundwater System site, with particular consideration to water table access for trees;
- **Growth rates**: Species were identified that have demonstrated moderate to high growth rates, under conditions comparable to the Gnangara Groundwater System;
- **Water use**: Information was reviewed relating to expected water use and any available information on species LAI with reference to the maximum allowable LAI under the Plan; and
- **Silvicultural options**: Management requirements and potential silvicultural regimes suitable for the Gnangara Groundwater System were reviewed. The use of herbicide to control pest plants is restricted on the Gnangara Groundwater System to protect the quality of the groundwater as a drinking water supply. Broad acre herbicide application, which is used in most plantation developments, is not permitted. Spot application of some herbicides is permitted. However, FPC advises that weed growth is minimal and can generally be controlled through mechanical techniques if necessary.

Potential products are identified for each species and market opportunities are discussed further in Section 3, including consideration of the plantation scale required for product market viability.
2.2 **Acacia** species

*Acacia* species (genus *Acacia*) are readily adaptable to a wide range of soil types and climates, and have the potential to produce a number of products. *Acacia* species with potential for development as wood crops have been identified under the auspices of the Joint Venture Agroforestry Project (see ‘AcaciaSearch’; Maslin and McDonald, 2004, 2007). The project identified 35 species with potential for crop development in the 250-650 mm/annum rainfall zone of southern Australia, based on particular criteria, including rapid production of commercial wood biomass, and broad soil preferences. Three of the *Acacia* species identified appear to have potential as alternative plantation species on the Gnangara Groundwater System: *A. bartleana*, *A. microbotrya* and *A. saligna*. These species occur naturally in the Swan Coastal Plain region and on similar soil types.

### 2.2.1 Potential products

*Acacia* species have the potential to produce a range of products, including composite wood products; biomass and combustion feedstock; activated carbon; speciality sawn timbers; and secondary chemical products. Uses of *Acacia* species have also included revegetation, fuelwood and fodder (Byrne, 2003).

**Wood products**

Olsen et al (2004) conducted a range of tests on *Acacia* species to assess their suitability as fibre for pulp and paper, for sawn timber and for reconstituted products such as medium density fibreboard (MDF). The key findings were as follows:

- *A. bartleana* had reasonably high yields of quality timber suitable for commercial uses. When boards were dressed and graded, the top two grades made up 88 percent of the sawn timber recovered. It was noted that borer holes were the most common defect, affecting 45 percent of boards. Other potential impediments to its use as sawn timber may include long drying times and poor gluing performance when laminated;

- *A. saligna* was successfully converted to MDF panels with ‘acceptable’ mechanical and physical properties (including thickness, density, internal bond strength, elasticity and rupture); and

- Preliminary testing for pulp and paper properties did not yield promising results for any of the *Acacia* species tested.

**Biomass products**

*A. saligna* and *A. microbotrya* have potential to produce biomass for combustion feedstock and activated carbon (Byrne, 2003). *A. bartleana* has also been observed to have suitable characteristics for combustion feedstock (Olsen et al, 2004).

Preliminary testing of *Acacia* species for charcoal production was undertaken by Olsen et al (2004) and gave promising results. However, it was noted that further testing would be required to clarify the commercial potential of *Acacia* species for this purpose.

**Chemical production**

Seigler (2002) identified a number of potential secondary products that could supplement the primary products from *Acacia* species. These include:

- Phytochemical products (gums) that can be derived from gum exudates;
Section 2

Assessment of Alternative Plantation Species

- Commercial tannins;
- Seed oils and proteins; and
- Terpenes from resins for the production of adhesives.

**Food production**

Short rotation *Acacia* plantations (3-5 years) may produce seed for markets including bush foods, nuts, snack foods and pulses (Olsen et al 2004). While it is premature to judge the potential for *Acacia* species as a food crop, there is acknowledgement in the literature of this potential market (see Olsen et al 2004; Seigler, 2002; Bartle et al 2002).

**Sandalwood plantation host**

*Acacias* are a primary host species for Sandalwood plantations. In particular, *A. acuminata* is commonly used and *A. saligna* has also been identified as a superior host (Byrne, 2003) (see Section 2.5).

2.2.2 Water use

No specific information was noted in the literature with regard to *Acacia* species and their water use physiology. General observations have been made in Bartle et al (2002):

- It has been hypothesised that increased severity of pruning results in increased proportion of roots near the surface, however *Acacia* coppice crops require further research on this aspect; and
- It is likely that some *Acacia* species, particularly those adapted to dry environments, are deep rooted or have the capacity grow deep roots because this is a common characteristic of species with access to groundwater.

2.2.3 Silvicultural regimes

Three silvicultural cropping methods for *Acacia* species have been identified from the literature and referred to in the species profiles below (see Bartle et al 2002; Olsen et al 2004). The three methods are as follows;

- Phase crops (short rotation phase crop) - trees are harvested and removed at 3 to 6 years of age, and usually the land is reverted to another use (e.g. pasture) after harvest;
- Coppice cropping (short rotation coppice crop) – trees are usually planted in large blocks and coppice is harvested every 2-5 years. The coppicing ability of many *Acacia* species is not well known; and
- Long cycle cropping (long rotation crops) - trees are managed over a 10 to 30 year growth period, primarily for solid wood products.

Long cycle crops are most likely to be grown for solid wood products such as fence posts, firewood and sawn timber, while coppice and phase crops would produce material suitable for reconstituted wood products, bioenergy and chemical extracts. Bartle et al (2002) estimates in the 400 mm/annum rainfall area of south west WA, coppice and phase crops will produce 60 to 70 tonnes of biomass per hectare at age 4 to 5, and long cycle crops will produce 90 tonnes of sawlog per hectare at age 25. There is not any similar information available for higher rainfall zones.
Assessment of Alternative Plantation Species

2.2.4 Acacia bartleana

Suitability

A. bartleana occurs on low hill landforms in the 400-600 mm/annum rainfall zone (Maslin and MacDonald 2004). It grows well on sandy soils and is therefore likely to be well suited to the Gnangara Groundwater System (J.Bartle pers comms).

Growth

Maslin and MacDonald (2004) ranked A. bartleana as having a moderate to high growth rate. Its longevity is between 20 and 30 years and it will achieve a height of 4-8m. Coppicing potential is unknown but is considered to be likely. The growth characteristics of A. bartleana are similar to that of A. microbotrya, as the species are closely related.

Silvicultural options

Maslin and McDonald (2004) recommend two forms of cropping regimes for A. bartleana; long cycle and phase cycle cropping. J.Bartle (pers comms) identified A. bartleana is a potential short rotation specialty sawn timber species.

2.2.5 Acacia microbotrya

Suitability

A. microbotrya has an extensive natural distribution throughout southern WA, is likely to be salt tolerant and has a preference for loam soils (Maslin, 2001), although it does grow on soils ranging from sands to clay loams (Maslin and McDonald 2004). It occurs in the 420-625 mm/annum rainfall zone.

Growth

This species has been identified as fast growing, usually with a single trunk to approximately one metre before branching (11cm diameter at base), or divides at ground level into two to four main trunks (6-9cm DBH2) (Maslin, 2001). Its longevity is between 20 and 30 years and it will achieve a height of 4-8m. Coppicing potential is unknown but is considered to be likely.

Silvicultural options

Maslin and McDonald (2004) identified phase cycle and coppice cropping (subject to acceptable coppicing ability) as suitable for this species.

2.2.6 Acacia saligna

Suitability

A. saligna has a large natural distribution in the south west of WA, growing across a variety of habitats and exhibiting morphological variation in growth form (Byrne, 2003). A. saligna prefers sandy soils, and should grow well on the Gnangara sands (J.Bartle pers comms). It was assigned the highest categorical ranking (1) of all

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2 DBH refers to diameter at breast height. DBH is an indicator of tree growth and is used to calculate total tree volume.
species assessed in the AcaciaSearch project indicating that it has fast growth and is considered to be a good prospect for development of a wood crop plant (Maslin and McDonald, 2007). However, *A. saligna* grows with multiple stems and this could pose limitations to commercial crop development due to the difficulty and cost of harvesting.

**Growth**

Maslin and MacDonald (2004) ranked *A. saligna* as having a fast to very fast growth rate. Fox (1995) stated that there is likely to be a relationship between rainfall and height growth, and in the absence of added fertiliser, growth may be poor.

A trial undertaken by Brand et al (2003) using *A. saligna* as a host species for *S. spicatum* measured growth in height to be 1.7 m at 1 year old and 3.3 m at age 4 years.

Maslin and MacDonald (2004) state that the longevity of *A. saligna* is between 10 and 20 years and it will achieve a height of 2-10 m. It has a high coppicing ability.

**Silvicultural options**

Maslin and McDonald (2004) identified phase cycle and coppice cropping as suitable silvicultural regimes for this species.
2.3 Hardwood plantation species

This section outlines a number of potential hardwood species that may provide suitable plantation alternatives on the Gnangara Groundwater System:

- *Corymbia maculata* (spotted gum);
- *Eucalyptus cladocalyx* (sugar gum);
- *Eucalyptus saligna* (Sydney blue gum); and
- *Eucalyptus gomphocephala* (tuart).

Mallee species are discussed separately in Section 2.4.

2.3.1 Potential products

Table 2-1 outlines a range of potential products from hardwood species. The production of sawlogs, posts and poles and firewood may be the most feasible options for the Gnangara Groundwater System as they can be grown under less intensive regimes with lower stockings and multiple thinnings. More intensive plantation regimes that aim to produce products such as bioenergy or pulpwood are likely to have much higher water usage, but shorter rotations and more frequent fallow periods.

<table>
<thead>
<tr>
<th>Products</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawlogs for timber production</td>
<td><em>C. maculata</em> (^1,^3)</td>
</tr>
<tr>
<td></td>
<td><em>E. cladocalyx</em> (^1)</td>
</tr>
<tr>
<td></td>
<td><em>E. saligna</em> (^4)</td>
</tr>
<tr>
<td></td>
<td><em>E. gomphocephala</em> (^5)</td>
</tr>
<tr>
<td>Posts and poles</td>
<td><em>C. citriodora</em> (^2)</td>
</tr>
<tr>
<td>Firewood</td>
<td><em>C. maculata</em> (^1)</td>
</tr>
<tr>
<td></td>
<td><em>E. cladocalyx</em> (^1)</td>
</tr>
<tr>
<td></td>
<td><em>E. saligna</em> (^1)</td>
</tr>
<tr>
<td>Bioenergy</td>
<td><em>C. maculata</em> (^1)</td>
</tr>
<tr>
<td></td>
<td><em>E. cladocalyx</em> (^1)</td>
</tr>
<tr>
<td></td>
<td><em>E. saligna</em> (^1)</td>
</tr>
<tr>
<td>Pulpwood</td>
<td><em>C. maculata</em> (^1,^3)</td>
</tr>
<tr>
<td></td>
<td><em>E. cladocalyx</em> (^1)</td>
</tr>
<tr>
<td></td>
<td><em>E. saligna</em> (^1)</td>
</tr>
</tbody>
</table>

Source: \(^1\) R. Hingston, pers comms; \(^2\) ICRAF, 2008; \(^3\) Lee et al 2006; \(^4\) Jovanovic and Booth, 2002, \(^5\) Timber Advisory Note

The hardwood species examined generally have hard and durable timber. End uses for sawlog timber products include construction applications such as unseasoned framing (except *Corymbia* species which are susceptible to Lyctus borer), round timber and engineered wood products; and high value products such as flooring, furniture and joinery. A 2001 feasibility study that looked at eucalypts for high-grade timber in the medium rainfall zone of WA on a variety of soil types found that *E. saligna*, *E. cladocalyx* and *C. maculata* were some of
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the most prospective species for a hardwood sawlog project (FPC, 2001). The study also highlighted the need for ongoing research and development to improve tree breeding, silviculture, pest management and processing.

### 2.3.2 Hardwood silviculture principles

General hardwood plantation silvicultural principles are outlined in Table 2-2. The management regime outlined in the table would be suitable for producing sawlogs, posts and poles and firewood, and can be considered applicable to the Gnangara Groundwater System site. FPC has silvicultural specifications and standards for eucalypt sawlogs which provide more detailed guidance on silviculture prescriptions.

<table>
<thead>
<tr>
<th>Management requirement</th>
<th>Silvicultural specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishment</td>
<td>Tree spacing 5m between rows and 2m between trees and stocking to 1,000 trees/ha.</td>
</tr>
<tr>
<td>Site cultivation</td>
<td>For Bassendean sands, furrowline to width at soil surface of 1m and depth of 200-300mm. Alignment of furrows on eroded deep white sands should be at right angles to the direction of the prevailing wind.</td>
</tr>
<tr>
<td>Fertiliser application</td>
<td>Only applied if site has demonstrated history of poor fertilisation. Test soil to determine nutrient deficiencies. Fertiliser should be buried as a spot application between 10 and 15 cm downhill side of the seedlings before the end of August.</td>
</tr>
<tr>
<td>Weed control</td>
<td>Pre-planting weed control to a width of 1-1.5m (can be wider for sandy soles that are not easily eroded by wind). Post plant weed control where necessary. Consider second year weed control where the survival of trees is at stake or growth is likely to be seriously retarded.</td>
</tr>
<tr>
<td>Thinning</td>
<td>Thinning at two stages:</td>
</tr>
<tr>
<td></td>
<td>• First thinning when trees are approximately 4–5 years. Stocking reduced to 300 trees/ha;</td>
</tr>
<tr>
<td></td>
<td>• Second thinning when trees are approximately 6-7 years. Stocking reduced to 150 trees/ha.</td>
</tr>
<tr>
<td>Pruning</td>
<td>Progressive pruning</td>
</tr>
<tr>
<td></td>
<td>• First pruning when stem diameter reaches 10cm at 2-3m above ground (usually age 2-3 years). Prune no higher than the point on stem where diameter is 10cm and no higher than 50% of tree height; and</td>
</tr>
<tr>
<td></td>
<td>• Prune progressively over 3 or 4 years until the desired height is reached, usually 6m.</td>
</tr>
<tr>
<td>Harvest</td>
<td>Clearfell at 23-28 years.</td>
</tr>
</tbody>
</table>

The optimal timing of pruning will depend on plantation productivity.

Source: FPC, 2008a
2.3.3 Water use

Little data on the LAI of similar eucalypts was noted in the literature. A study in mountain ash forest in Victoria determined a relationship between individual tree diameter and leaf area, although it should be noted that this data has limited relevance to the species considered for the Gnangara Groundwater System. The study was based on three age classes of native mountain ash forest. The relationship was found to be:

\[
\text{Leaf Area (m}^2\text{)} = 60.551 \times e^{0.0153 \times \text{diameter}}
\]

The formula can be used to estimate LAI of a uniform area of mountain ash trees. Further work on water use and LAI of hardwood species is being undertaken and results are expected to be published in the future. This study demonstrates that it is possible to develop LAI relationship for hardwood species, which would assist in the development of water use and recharge modelling for the Gnangara Groundwater System.

2.3.4 Corymbia maculata

Suitability

The climatic range of \textit{C. maculata} encompasses that of the Gnangara Groundwater System and the species has the potential to be suitable for the site (R.Hingston pers comms). FPC (2001) reports that \textit{C. maculata} grows on a wide range of soils. It grows best on soils that are slightly moist, but well drained with moderately heavy texture, such as those derived from shales. However, it should be noted that there has been no consensus on the best provenances of the species to use for commercial production (Paul et al 2007). \textit{C. maculata} has a natural occurrence across coastal northern NSW and southern Queensland and grows within zones of a mean annual rainfall (MAR) of 580-1500 mm (Jovanovic et al 2002). Average annual evaporation in these regions varies from about 1,400-1,800 mm, which is slightly lower than the Gnangara Groundwater System area.

Growth

Paul et al (2007) (also see Paul et al, 2008) undertook studies, including destructive sampling, to calibrate parameters of 3PG\textsuperscript{3} for \textit{C. maculata} stands, and then used it to predict growth. Data used in the study was collected from 37 \textit{C. maculata} stands in temperate regions of Australia. Plantations varied in age from 1 to 50 years, and were located across a broad range of climatic regions where annual rainfall varied between 365 and 995 mm, with an average of about 650 mm. The 3PG model simulates thinning events but not pruning (the stimulated thinning schedule was not specified). Key findings from these studies included:

- There was considerable variation in observed stem diameter for any particular age (see Figure 2-1);
- In the trees that were destructively sampled, stem wood density averaged 654kgm\textsuperscript{-3} regardless of stand age or tree size; and
- The predicted rotation lengths to reach a DBH of 50cm ranged from 21 to 30 years.

\textsuperscript{3} The Physiological Principles in Predicting Growth model (3PG) (Landsberg and Waring, 1997; Landsberg et al, 2003) is a process-based model that has been adapted and calibrated for hardwood species in different environments.
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Figure 2-1  Variation in observed DBH with age for *C. maculata*

![Graph showing variation in observed DBH with age for *C. maculata*.](image)

Source: Paul et al, 2007

Table 2-3 describes recent growth records from agroforestry plantations of *C. maculata* grown in WA under the Australian Master TreeGrower Program. Average annual evaporation at the Yallingup site is 1,200-1,400 mm, which is lower than the Gnangara Groundwater System area. Gillingarra would have a similar evaporation rate to the Gnangara Groundwater System area.

**Table 2-3: Growth records for *C. maculata* in Western Australia**

<table>
<thead>
<tr>
<th>Site</th>
<th>MAR (mm)</th>
<th>Age (years)</th>
<th>Mean DBHOB (cm)</th>
<th>Mean height (m)</th>
<th>Basal area (cm²)</th>
<th>Volume (m³)</th>
<th>MAI (m³ ha⁻¹ yr⁻¹)</th>
<th>Density (trees ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yallingup^</td>
<td>950</td>
<td>15.4</td>
<td>30.0</td>
<td>19.5</td>
<td>9.8</td>
<td>63.7</td>
<td>4.1</td>
<td>137</td>
</tr>
<tr>
<td>Gillingarra*</td>
<td>450</td>
<td>6.0</td>
<td>12.8</td>
<td>8.5</td>
<td>2.1</td>
<td>6.2</td>
<td>1.0</td>
<td>163</td>
</tr>
</tbody>
</table>

Source: Hingston and Jenkins, 2002

^ Growth at this site is estimated to be above what would be expected on the Gnangara Groundwater System due to the high rainfall at this site.

*Growth at this site is estimated to be below what would be expected on the Gnangara Groundwater System (R.Hingston, pers commns). The trees were planted in a 10-row wide belt.

**Water use**

In the study undertaken by Paul et al (2007), specific leaf area (SLA) (leaf area as a proportion of leaf mass) was estimated to be approximately 6 m² kg⁻¹. In a separate study Paul et al (2008) observed LAI and basal area of *C. maculata* at three sites in Victoria and NSW (Table 2-4).

**Table 2-4  *C. maculata* stand observations**

<table>
<thead>
<tr>
<th>Property</th>
<th>MAR (mm)</th>
<th>Age (years)</th>
<th>Current stocking (stems/ha)</th>
<th>Basal area (m²/ha)</th>
<th>LAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koonda</td>
<td>563</td>
<td>5</td>
<td>609</td>
<td>4.44</td>
<td>0.44</td>
</tr>
<tr>
<td>Larundel</td>
<td>555</td>
<td>48</td>
<td>287</td>
<td>24</td>
<td>0.82</td>
</tr>
<tr>
<td>Woodlands</td>
<td>600</td>
<td>75</td>
<td>646</td>
<td>42</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Source: Paul et al, 2008
2.3.5 *Eucalyptus cladocalyx*

**Suitability**

This species is drought tolerant and can grow on alkaline and saline soils (Marcar et al 1995 cited in Jovanovic 2002). FPC (2001) suggests that *E. cladocalyx* is suitable for the 450-600 mm/annum rainfall zone of WA and can grow on shallow (skeletal) or podsolic soils. It is also found on sodic brown soil, deep sands and ironstone gravels.

**Growth**

Paul et al (2007) (also see Paul et al, 2008) undertook studies, including destructive sampling, to calibrate parameters of the model 3PG for *E. cladocalyx* stands and used it to predict growth. Data used in the study was collected from 55 *E. cladocalyx* stands in temperate regions of Australia. Plantations varied in age from 1 to 79 years, and were located across a broad range of climatic regions where annual rainfall varied between 345 and 850 mm, with an average of about 600 mm. Key findings from these studies included:

- There was considerable variation in observed stem diameter for any particular age (see Figure 2-2);
- Sites with a MAR of greater than 700 mm could expect to reach a DBH of ~22 cm after 20 years, while sites of less than 500 mm MAR may only reach 13 cm DBH within the same period; and
- The required rotation lengths to reach a predicted stand average DBH of 50 cm ranged from 32 to 45 years.

![Figure 2-2 Variation in observed DBH with age for *E. cladocalyx*](source: Paul et al, 2008)

There are recent growth records from agroforestry plantations of *E. cladocalyx* in WA under the Australian Master TreeGrower Program (Table 2-5). The sites are potentially comparable to that of Gnangara Groundwater System (R.Hingston, pers comms). Average annual evaporation at the Scaddan site is 1,600-1,800 mm, which is slightly lower than the Gnangara Groundwater System area. Gillingarra would have a similar evaporation rate to the Gnangara Groundwater System area. The trees at Gillingarra were planted in a 10-row wide belt.
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Table 2-5 Growth records for *E. cladocalyx* in Western Australia

<table>
<thead>
<tr>
<th>Site</th>
<th>MAR (mm)</th>
<th>Age (years)</th>
<th>Mean DBH (cm)</th>
<th>Mean height (m)</th>
<th>Basal area (cm²)</th>
<th>Volume (m³)</th>
<th>MAI (m³ ha⁻¹ yr⁻¹)</th>
<th>Density (trees ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaddan</td>
<td>425</td>
<td>10.8</td>
<td>18.1</td>
<td>12.3</td>
<td>4.1</td>
<td>17.2</td>
<td>1.2</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.8</td>
<td>12.2</td>
<td>7.6</td>
<td>11.0</td>
<td>32.1</td>
<td>0.9</td>
<td>837</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.8</td>
<td>9.7</td>
<td>6.2</td>
<td>7.7</td>
<td>17.4</td>
<td>0.5</td>
<td>947</td>
</tr>
<tr>
<td>Gillingarra</td>
<td>450</td>
<td>6.0</td>
<td>10.8</td>
<td>7.8</td>
<td>1.5</td>
<td>4.2</td>
<td>0.7</td>
<td>156</td>
</tr>
</tbody>
</table>

Source: Hingston and Jenkins, 2002

Note: The trees on these sites are relatively young and early age growth rate data should be treated as indicative only.

**Water use**

In the study undertaken by Paul et al (2007) specific leaf area was estimated to be approximately 5 m² kg⁻¹. In a separate study Paul et al (2008) observed LAI and basal area at four sites in Victoria and NSW (Table 2-6).

Table 2-6 *E. cladocalyx* stand observations

<table>
<thead>
<tr>
<th>Property</th>
<th>MAR (mm)</th>
<th>Age (years)</th>
<th>Current stocking (stems/ha)</th>
<th>Basal area (m²/ha)</th>
<th>LAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koonda</td>
<td>563</td>
<td>5</td>
<td>1125</td>
<td>5.8</td>
<td>NA</td>
</tr>
<tr>
<td>Rotherlea</td>
<td>764</td>
<td>10</td>
<td>250</td>
<td>6.8</td>
<td>0.79</td>
</tr>
<tr>
<td>Yallock</td>
<td>678</td>
<td>13</td>
<td>143</td>
<td>5.2</td>
<td>0.71</td>
</tr>
<tr>
<td>Apex Park</td>
<td>687</td>
<td>55</td>
<td>300</td>
<td>41</td>
<td>1.43</td>
</tr>
</tbody>
</table>

Source: Paul et al, 2008

2.3.6 *Eucalyptus saligna*

**Suitability**

*E. saligna* occurs naturally from Maryborough in Queensland to the south coast region of New South Wales and is mainly found within 120km of the coastline. If occurs on sites with a MAR of 615-2,300 mm. Average annual evaporation in these regions varies from about 1,200-1,800 mm, which is lower than the Gnangara Groundwater System area. Noble (2000) indicates that best growth has been on good quality alluvial flats. Other preferred soil types are sandy loams, podzols and volcanic loams. The species has been observed to grow well in plantations established on deep dry sands on the edge of the Darling Scarp, north of Gingin WA (R.Hingston, pers comms). The site consists of deep dry sand soils and it is likely that the trees have access to shallow groundwater. The minimum MAR for commercial plantation growing is approximately 700 mm (Jovanovic et al 2002). FPC (2001) states that *E. saligna* grows on moderately fertile soils, which are moist but not waterlogged (parent rocks could be shale, sandstone, conglomerate or basalt).

**Growth**

On the Gingin site trees have reached a height of 20 metres at age 13. Total standing volume at the same age was 245 m³/ha (MAI 18.8 m³/ha/annum) with a stocking of 456 stems/ha in a normal plantation configuration (Hingston and Jenkins, 2007).
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**Water use**

A study by Ares and Fownes (2000) of *E. saligna* plantations in Hawaii found that LAI decreased with increasing elevation (and decreased rainfall). Although the study was undertaken in a high rainfall region (1,200-2,600 mm/annum) and on sites of rich volcanic ash soils which are much more productive than the Gnangara Groundwater System area, it indicates that *E. saligna* can make physiological adjustments to reduced water availability (see Error! Reference source not found. ). Stocking rates for the sites varied from 111 to 573 trees/ha, with an average of 327 trees/ha.

**Figure 2-3** Relationship between LAI and elevation for *E. saligna*

**Plate 2-1** 18-year old Sydney blue gum established at Dinninup, WA

Source: Ares and Fownes, 2000

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**2.3.7 Eucalyptus gomphocephala**

**Suitability**

*E. gomphocephala* (tuart) is a native tree to Western Australia. It occurs naturally in a 400km long band from Jurien Bay to Sabina River on the Swan Coastal Plain, WA, and prefers alkaline or limestone soils close to the coast (DEC, 2008). Natural *E. gomphocephala* are currently undergoing a severe and extensive dieback. Extensive research is being undertaken to determine the cause of the dieback and it is thought that several physical and biological factors are likely to be contributing to the problem. The Tuart Atlas (DEC 2003) shows existing remnant pockets of tuart on the Gnangara Groundwater System. Tuart plantations could provide connectivity between these remnants.

**Growth**

Growth data for two plantation plots of *E. gomphocephala* at a site in Scaddan WA is described in Table 2-7. The site has shallow grey sandy duplex soils over clay, and is comparable to conditions on the Gnangara
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Groundwater System (R. Hingston, pers comms). Average annual evaporation at the Scaddan site is 1,600-1,800 mm, which is slightly lower than the Gnangara Groundwater System region.

There is limited information about the use of this species in plantations. There are some *E. gomphocephala* plantings in the Esperance region which are reported to have grown well, however growth data has not been collected.

Table 2-7  
**Growth records for *E. gomphocephala* at Scaddan, Western Australia**

<table>
<thead>
<tr>
<th>MAR (mm)</th>
<th>Age (years)</th>
<th>Mean DBHOB (cm)</th>
<th>Mean height (m)</th>
<th>Basal area (cm²)</th>
<th>Volume (m³)</th>
<th>MAI (m³ha⁻¹yr⁻¹)</th>
<th>Density (trees ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>425</td>
<td>11.8</td>
<td>23.0</td>
<td>12.6</td>
<td>13.3</td>
<td>56.4</td>
<td>2.3</td>
<td>314</td>
</tr>
<tr>
<td>425</td>
<td>11.8</td>
<td>23.8</td>
<td>12.7</td>
<td>9.0</td>
<td>38.6</td>
<td>3.3</td>
<td>201</td>
</tr>
</tbody>
</table>

Source: Hingston, 2007

*Water use*

Initial studies into the role of water relations in the health of tuart indicate that water stress alone is not the cause of the *E. gomphocephala* dieback. Further studies are being conducted by Murdoch University to increase knowledge of water use efficiency and relationship to canopy decline in tuart.
2.4 Oil mallee species

Oil mallee species have been widely planted throughout south west WA, primarily as a salinity control and mitigation measure in agricultural landscapes. Since the early 1990’s almost 13,000 ha of mallees have been established in WA. They have been observed to exhibit adaptations to low nutrient soils, long periods of drought and seasonal high temperatures (Wildy et al 2003). Oil mallee plantings are readily combined with large scale annual cropping systems (Bartle et al 2007) and have a large and extensive root system that makes them ideal for erosion control and preventing topsoil loss.

2.4.1 Potential products

A range of potential processing options and products exist for oil mallees. There has been a significant focus on processing oil mallees to produce multiple products. Integrated wood processing (IWP) has been considered as a production option, in which the wood fraction of the trees is used to produce activated carbon, *Eucalyptus* oil is produced from the leaves, and all residues are used to produce bioenergy. Western Power (now Verve Energy) completed construction of a trial IWP plant in 2006 and undertook operational scale testing. A range of other products can also be produced from oil mallees, either through stand alone processes or as part of an integrated production process, including bioenergy, wood pellets, composite wood products, charcoal, biofuels and carbon (URS 2008).

2.4.2 Site suitability and growth

Oil mallee species have a natural distribution across southern Australia in the 300-450 mm/annum rainfall zone (Wildy et al 2004) and have been planted throughout the WA wheatbelt in mid-low rainfall zones (300-600 mm MAR). Mallee species include; *Eucalyptus loxophleba* subsp. *lissophloia*, *E. kochii* subsp. *plenissima*, *E. kochi* subsp. *borealis*, *E. loxophleba* subsp. *gratiae*, *E. polybractea*, *E. kochii* subsp. *kochii*, *E. myriadena* and *E. angustissima* subsp. *angustissima*. Studies have found *Eucalyptus kochii* subsp. *plenissima* and *E. kochi* subsp. *borealis* to perform well on yellow sands (Wildy et al, 2003).

Growth

The rate of growth of mallee plantings is affected by a number of variables including climate (rainfall, temperature and evaporation); soil (depth, type and structure); and the quality of site preparation and management, particularly weed and pest control.

Huxtable and Bartle (2007) reported yields of above ground biomass range from 5-10 dry tonnes ha\(^{-1}\) year\(^{-1}\) based on measurements at ages 7 to 11 years. Using these growth increments to adjust a previously developed process-based model developed by Cooper et al (2005), Huxtable and Bartle (2007) predicted productivity to range from 5-15 dry tonnes/ha/annum over the rainfall range 350-550 mm MAR. These yields are based on two row shelterbelts (see Silvicultural options below). If four row belts are established the overall productivity is expected to be around 25% lower and block plantings may only achieve 30-50% of the productivity of the two row belts (J. Bartle, pers comms).

Water use

Mallee belt plantings have a significant capacity for both utilising water stored in the soil that surrounds the root zone and for capturing lateral flows. Robinson et al (2002) established that mallee belts created soil water deficits and hydraulic gradients up to a depth of 10m deep within 7 years of planting and Robinson et al (2006) showed that this deficit extends outside the planted area. Wildy et al (2003, 2004) also demonstrated that water uptake in mallee plantings was significantly greater than that from rainfall alone, therefore suggesting
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substantial capture of lateral flows. Water availability can be influenced by mallee planting design, and research in this area is being conducted (Eastham et al 1993, Milthorpe et al 1998, Okimori et al 2003, Smith 2006, Cooper et al 2005).

Wildy et al (2004) details a study comparing mature *E. kochii* subsp. *plenissima* trees in natural bushland to young trees planted in belts through cleared agricultural land as uncut saplings or regenerating coppice at Kalannie in WA (320 mm MAR). The study compared water use efficiency and other physiological characteristics and identified LAI on a Projected Canopy Area basis (PCA-LAI). Table 2-8 shows the results observed in the belt-plantings.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Age (years)</th>
<th>Tree height (m)</th>
<th>Leaf weight (kg dry matter)</th>
<th>LAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncut saplings</td>
<td>7.2</td>
<td>7.2</td>
<td>7.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Coppice</td>
<td>2.7</td>
<td>2.8</td>
<td>3.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Coppice</td>
<td>2.0</td>
<td>1.5</td>
<td>3.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Source: Wildy et al, 2004

*Silvicultural options*

Oil mallee plantation systems have been developed that are complimentary to agricultural systems with trees planted in belts and cropping maintained between the belts (Plate 2-2). Agriculture is unlikely to be incorporated into systems on the Gnangara Groundwater System, and block plantings are an option on this land. While the block planting will produce lower yields than the belts (which have access to water from both sides) it may be an equally viable option because the opportunity cost of using the land for other purposes is low.
2.5 Santalum spicatum (Sandalwood)

There are several different species of sandalwood found throughout Australia. The WA sandalwood species (Santalum spicatum) has been exported internationally for over a century. Tree crops totalling approximately 10,000 ha have been developed in southern WA and are expected to add to existing supply in coming years.

2.5.1 Potential products

A range of products can be produced from sandalwood. The sapwood is commonly used to produce incense, but is also used as a material for woodcrafts and carvings. The heartwood contains oil which is extracted and used in the fragrance industry. There is a growing domestic market for sandalwood nuts, which are produced by the trees annually from age five.

2.5.2 Site suitability and growth

Suitability

S. spicatum occurs naturally in southern WA, and stands of sandalwood were common in the wheat belt before agriculture (FPC 2008b). S. spicatum is a root hemiparasite and requires establishment near a suitable host species (Brand et al 2003) that must also be suited to the growing conditions. Trials have shown that Acacia species can be an excellent host for sandalwood (FPC 2006). Soil type has a significant influence on the survival and growth of both S. spicatum and the host species. S. spicatum prefers sites with sandy-loam over clay duplex soils, however it will also grow on some loamy-gravels, yellow sands and red sands on well drained sites. Deep white sands are generally not suitable (Brand 2006).

Growth

S. spicatum grows slowly, with diameter growth approximately 1-2 mm per year in natural stands (Brand et al 2003). The predicted time for stems to reach commercial size is approximately 20 years in 400-600 mm MAR zones of the WA wheat belt (Brand and Jones 1999). Stem diameter growth rates that have been observed for S. spicatum planted with Acacia hosts are outlined in Table 2-9.

<table>
<thead>
<tr>
<th>Location</th>
<th>Host species</th>
<th>Age (years)</th>
<th>Diameter growth (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northampton¹</td>
<td>A. acuminata</td>
<td>4-9</td>
<td>4.5–7</td>
</tr>
<tr>
<td>Katanning²</td>
<td>A. acuminata</td>
<td>1-5</td>
<td>7-10</td>
</tr>
<tr>
<td>Narrogin³</td>
<td>A. saligna</td>
<td>1-3</td>
<td>9-18</td>
</tr>
<tr>
<td>Dandaragan³</td>
<td>A. saligna</td>
<td>1-3</td>
<td>15-26</td>
</tr>
</tbody>
</table>

Source: ¹Brand et al 1999; ²Brand, 2002; ³Brand et al, 2003
Brand et al (2003) undertook a study of *Acacia* host trials established at Narrogin (loamy sand over clay) and Dandaragan (well-drained loamy sand over gravel) on farmland sites in WA. The study tested four *Acacia* host species (*A. acuminata*, *A. saligna*, *A. microbotrya* and *A. hemiteles*) and measured the highest diameter growth of *S. spicatum* at Dandaragan site with *A. saligna* as a host species (see Table 2-9). In addition, the survival rate and seedling growth of *S. spicatum* was observed to be greatest when *A. saligna* was the host species.

### Water use

No specific information was observed in the literature with regard to *S. spicatum* and its water use physiology. As discussed in Section 2.2, little is known also about water use of *Acacia* host species.

### Silvicultural options

Direct seeding of sandalwood near 1-5 year-old *A. acuminata* has been successful on farmland in the Midwest of WA, with MAR of 350-600 mm (Brand et al 2003). In trials undertaken by Brand et al (2003), the *A. saligna* provenance selected was fast growing (1.7m height at age 1, 3.3m at age 4 years) and *S. spicatum* could be established at age 1. However it was noted that *A. saligna* may not live long enough to host *S. spicatum* to a harvestable size (age 15-20 years) with 27 percent of *A. saligna* trees observed to be dead at age 4. *A. saligna* is also a high maintenance host crop and requires regular pruning to ensure sandalwood growth and site access (Brand 2006). Trials of *A. acuminata* have shown that it is a suitable long term host species (15-30 years) for *S. spicatum* on a range of soil types (Brand, 2006).

Brand (2006) describes general silvicultural principles for the establishment of *S. spicatum* plantations:

- Rip site in rows 4-5m apart to 0.4m depth;
- Undertake weed control in early winter;
- Establish 6 month old host seedlings two weeks after spraying, spaced at 1.6-2m intervals (1000-1250 stems / ha);
- Apply approximately 50g of NPK fertiliser (optional);
- Establish *S. spicatum* in April using direct seed when host trees are 1-2 years age (1m tall) with 2-3 seeds approximately 0.4m from every second host tree;
- Undertake weed control prior to *S. spicatum* emergence (usually 4-6 weeks after planting); and
- Thin *S. spicatum* to ensure that the tree to host ratio is 1:2-3 when *S. spicatum* is 2 years of age.

Further research is required to determine optimal planting arrangements and silvicultural management of plantation stands (Brand et al 2003, FPC 2008b).

### 2.6 Summary of alternative plantation species suitability

#### Acacia species

- Some *Acacia* species are expected to grow well on the Gnangara Groundwater System due to preference for sandy soils and acceptable rainfall.
- Little is known about water use of the species and no LAI data was observed in the literature. Soil moisture will be required to maintain rapid growth and some species appear to have the ability to grow deep roots.
Assessment of Alternative Plantation Species

- Bioenergy and MDF both appear to be viable potential products (see section 3 for further discussion), but are likely to require high density planting, which will result in higher water uptake.
- *A. saligna* appears to be the best species for bioenergy or MDF as it has fast growth and will coppice, however its poor form will make it difficult to harvest.
- Plantations grown in long cycle cropping for specialty sawn timber could be grown at lower stockings and hence have lower water uptake, but these markets are not well developed.

**Hardwood plantation species**

- Sawlog plantations could feasibly be managed to keep water use within require levels through planting at lower stockings and thinning.
- While research and development of hardwood sawlog plantation has been occurring, there is still a need to further refine species, tree breeding, silviculture and processing technologies to achieve commercially viable plantations.
- *C. maculata*, and *E. cladocalyx* have been grown successfully in trial plantations in WA and in commercial plantations on the east coast, although observed growth rates are low.
- *E. saligna* has been established successfully as a commercial crop in wetter regions of WA.
- Some LAI and SLA information is available. Data is limited but could be used as an indicator for hardwood plantations on the Gnangara Groundwater System.

**Oil mallee species**

- Oil mallee species appear suited to the conditions of the Gnangara Groundwater System. Plantings would need to be in belts or dispersed blocks in order to keep water use within acceptable limits.
- Some information on LAI is available and could be used to estimate oil mallee regimes that will meet the LAI constraints on the Gnangara Groundwater System.

**Sandalwood**

- It appears that some of the soils on the Gnangara Groundwater System may be suitable for sandalwood, but areas of deep white sands should be avoided. These areas are substantial on the Gnangara Groundwater System. As sandalwood is a high value crop, it is feasible to establish small plantations were suitable soils are found.
- Water use is unknown and needs to be considered as a system – sandalwood and the host.
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Market opportunities

The ability to market or sell products grown in plantations of alternative species on the Gnangara Groundwater System is critical to the economic feasibility of the project. Where markets currently exist, the price that can be achieved for the sale of products is influenced by the supply-demand balance and capacity-to-pay of the processor. Where established markets do not exist, a critical scale of resource is generally required to support the development of new industries and markets. This section provides a brief analysis of the market opportunities for the potential products that could be produced on the Gnangara Groundwater System. The potential products are summarised in Table 3-1.

<table>
<thead>
<tr>
<th>Plantation species</th>
<th>Potential products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia species</td>
<td>Composite wood products (eg, MDF)</td>
</tr>
<tr>
<td></td>
<td>Biomass for bioenergy</td>
</tr>
<tr>
<td></td>
<td>Specialty sawn timber</td>
</tr>
<tr>
<td></td>
<td>Activated carbon</td>
</tr>
<tr>
<td></td>
<td>Chemical extracts (secondary products)</td>
</tr>
<tr>
<td>Hardwood species</td>
<td>Sawn timber</td>
</tr>
<tr>
<td></td>
<td>Posts and poles</td>
</tr>
<tr>
<td></td>
<td>Firewood</td>
</tr>
<tr>
<td></td>
<td>Biomass for bioenergy</td>
</tr>
<tr>
<td></td>
<td>Pulpwood</td>
</tr>
<tr>
<td></td>
<td>Charcoal</td>
</tr>
<tr>
<td>Oil mallees</td>
<td>Biomass for bioenergy</td>
</tr>
<tr>
<td></td>
<td>Eucalyptus oil</td>
</tr>
<tr>
<td></td>
<td>Activated carbon</td>
</tr>
<tr>
<td></td>
<td>Composite wood products</td>
</tr>
<tr>
<td></td>
<td>Wood pellets</td>
</tr>
<tr>
<td></td>
<td>Charcoal</td>
</tr>
<tr>
<td></td>
<td>Biofuels</td>
</tr>
<tr>
<td>Sandalwood</td>
<td>Timber</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
</tr>
<tr>
<td></td>
<td>Nuts</td>
</tr>
</tbody>
</table>

Note that carbon sequestration is not considered as a market opportunity as the Gnangara Groundwater System lands do not meet the Kyoto Protocol criteria for lands be cleared prior to 1990. Harvesting of the pine trees on the Gnangara Groundwater System will result in an increase in greenhouse gas levels in Australia national greenhouse inventory as forest harvesting is regarded as an emission activity. Any replacement of harvested pines with forestry plantations will act to counteract this emission and will provide a positive contribution to meeting Australia’s Kyoto protocol targets.

### 3.1 Overview of market opportunities in WA

WA has established forest industries including hardwood and softwood sawmilling, MDF and particleboard manufacture, woodchip export operations and a Laminated Veneer Lumber (LVL) mill (utilising *P. pinaster*). WA also has some smaller scale forest product markets, such as sandalwood, and a number of emerging markets opportunities such as the production of biomass to produce bioenergy.
Market opportunities

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URS recently undertook a study (URS Forestry, 2007) to identify and rank market opportunities for existing and new forest products around Australia. Table 3-2 and Table 3-3 have been adapted from this study to provide a summary of market opportunities for the potential products identified for the Gnangara Groundwater System.

More detailed analysis of the key market opportunities with prospects for the Gnangara Groundwater System is provided in Sections 3.2 to 3.7.

Table 3-2 Existing market opportunities in south west WA

<table>
<thead>
<tr>
<th>Products</th>
<th>Processors</th>
<th>Total current input estimate</th>
<th>WA market opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood sawn timber</td>
<td>11 sawmills</td>
<td>~200,000 m³</td>
<td>Declining harvest volumes from public native forests provide good opportunities for hardwood plantations in the region. The opportunity will depend on the ability to achieve suitable scale. Acacia provides opportunities for sawn timber via specialist mills, but markets are smaller and less developed.</td>
</tr>
<tr>
<td>Posts &amp; poles</td>
<td>Several post and poles treatment plants</td>
<td>N/A</td>
<td>There are a number of small processors across the region that process posts as a by-product of hardwood and softwood sawlog plantations. There are opportunities to add to this supply in the future.</td>
</tr>
<tr>
<td>Composite wood products</td>
<td>1 particleboard mill, 1 MDF mill</td>
<td>~310,000 m³</td>
<td>There is potential demand from existing processors for supply of by-products from sawlog plantations.</td>
</tr>
<tr>
<td>Woodchip exports</td>
<td>Port of Albany</td>
<td>1,400,000 m³</td>
<td>Large increases in exports of hardwood woodchips from maturing plantations have already commenced and will expand over next few years.</td>
</tr>
<tr>
<td></td>
<td>Port of Bunbury</td>
<td>1,100,000 m³</td>
<td></td>
</tr>
</tbody>
</table>

1 Around 10,000 ha of hardwood plantations will be required to supply a competitive hardwood plantation sawmill.

Source: URS Forestry, 2007
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Market opportunities

Table 3-3 Small scale and new market opportunities

<table>
<thead>
<tr>
<th>Market</th>
<th>Current situation and outlook</th>
</tr>
</thead>
</table>
| Sandalwood¹ (timber, oil and nuts)   | - Supply of natural sandalwood is decreasing globally due to restrictions on native harvesting.  
  - International demand for sandalwood is expected to remain strong. However, prices will be sensitive to the supply/demand balance and could be volatile, particularly if there are large increases in resource availability. |
| Firewood                             | - Markets for firewood are largely informal and localised, with the majority collected from private native forests.  
  - Demand has shown signs of decreasing, as natural gas has become more accessible in some rural areas.                                                                                                               |
| Biomass for bioenergy                | - Strong market opportunities exist in Australia for bioenergy production. Small scale co-firing is being implemented around Australia and there are currently several proposals to develop dedicated bioenergy plants in south west WA.  
  - Opportunities for renewable electricity in Australia are growing as a result of government policies, particularly the Commonwealth Governments Mandatory Renewable Energy Target (MRET) scheme and several similar state schemes.  
  - The placement and size of bioenergy plants can be linked closely to the electricity grid in an area with excess network transmission capacity, and must have sufficient long term feedstock supplies within viable transport distances.  
  - Pacific Energy is undertaking feasibility assessment to develop a bioenergy plant in the Perth region. The Gnangara Groundwater System would be well located to supply resources to such a facility. |
| Eucalyptus oil                       | - Most of Australia’s Eucalyptus oil consumption is based on imports from China and there appears to be an attractive opportunity for domestically produced oil to replace imports.  
  - Eucalyptus oil is a niche product and large scale production has the potential to significantly lower prices and reduce viability of the industry.  
  - Only likely to be feasible as a co-product of other industrial processes e.g. IWP².                                                                                                                                   |
| Activated carbon                     | - The majority of Australian activated carbon supply is imported and opportunities exist to replace imports of activated carbon into Australia, particularly for use in the gold industry and water filtration systems.  
  - There are no significant wood based processors, and scale requirements for production are uncertain.                                                                                                                   |
| Wood pellets                          | - Principal markets for wood pellets are in Europe, Canada, Japan and the United States. There is increasing interest from Australian investors to export wood pellets. Tests have shown that pellets manufactured from mallee will meet the standards required for the export market.  
  - Export represents the clearest opportunity for Australian wood pellets in the short term, notwithstanding the significant transport distances and increasing domestic production in Europe. |
Market opportunities

### Market Current situation and outlook

<table>
<thead>
<tr>
<th>Market</th>
<th>Current situation and outlook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charcoal</td>
<td>Two types of charcoal could be considered: industrial carbon which is used in the steel industry as a substitute for coking coal, and biochar which is used as a soil additive.</td>
</tr>
<tr>
<td></td>
<td>It will be very difficult for industrial carbon produced from biomass to compete with the current coking coal industry, where supply is well established and low prices for coal are highly competitive.</td>
</tr>
<tr>
<td></td>
<td>Further development of the biochar product and markets is required.</td>
</tr>
<tr>
<td>Biofuels</td>
<td>Biofuel production is an emerging market for forest products arising from concerns about the negative impacts of fossil fuels on the world’s climate as well as limitations in global oil supplies.</td>
</tr>
<tr>
<td></td>
<td>Technologies to produce biofuels, such as lignocellulosic ethanol and bio-oil, are still being developed.</td>
</tr>
</tbody>
</table>

1. The FPC is currently finalising a sandalwood Industry Development Plan in conjunction with the Australian Sandalwood Network.
2. A full scale IWP plant would have an annual intake of around 100,000 tonnes of biomass per annum, which would require around 10,000 ha of oil mallee plantations.

### 3.2 Hardwood sawn timber

#### 3.2.1 Sector trends

Demand for hardwood sawn timber is primarily driven by the housing market where it is used for appearance applications (e.g. flooring, joinery) and higher strength purposes (e.g. large beams, lintels, stair treads). The hardwood sawn timber industry has faced declining supplies of native hardwood resources and this has created an opportunity to complement native forest resources with sawlog plantation development.

In line with the reduction of hardwood sawn timber availability, consumption of hardwood sawn timber has steadily declined over the last 20 years, at an average rate of 2.3% per annum nationally. Softwood sawn timber has replaced hardwood timber in house framing as well as some higher strength applications through the manufacture of softwood engineered wood products.

#### 3.2.2 Future outlook

The steady reduction in supply of native hardwood logs from Australian forests over the last twenty years has resulted from government decisions to withdraw areas of native forest available for commercial production. This policy trend is expected to continue in the future. It is also expected that constraints imposed on access to resources in countries producing tropical timbers (e.g. Indonesia and Malaysia) will limit the ability of tropical hardwood imports to capture an increasing share of the Australian market. It is expected that hardwood sawn timber prices will, at least, be maintained in real terms.

The greatest market opportunities for hardwood sawn timber lie in higher value-added appearance applications, particularly furniture, joinery and flooring. Markets for hardwood sawn timber in more commodity-oriented structural uses are expected to be subject to ongoing pressure from softwood sawn timber and engineered products (both softwood and hardwood).

#### 3.2.3 Market risks

As new hardwood plantation estates mature, sawmills with new processing equipment will need to be developed and the plantations will need to be at sufficient scale (approximately 10,000 ha) to supply a competitive operation. The FPC has some existing hardwood plantations in south west WA and new plantations on the

Prepared for Forest Products Commission, 12 January 2009
Gnangara Groundwater System could be combined with these resources to assist with the development of sufficient scale.

While it appears that there will always be a strong domestic market for higher value solid timber hardwood furniture and mouldings, these markets are subject to competition from imports, which are currently acting to restrict prices. Achieving suitable timber quality and recoveries from plantation grown hardwood timber also presents challenges.

### 3.3 Composite wood products

Composite wood products produced in Australia include MDF, particleboard and hardboard. Composite wood products are made by combining wood particles with resin, to produce a strong, uniformly finished wood product. Product applications include furniture, mouldings, weatherboards, kitchen and bathroom units and flooring.

#### 3.3.1 Sector trends

Consumption of composite wood products is driven by a range of sectors including the construction, manufacturing and furniture sectors. Per capita consumption of composite wood products in Australia has been increasing and greatest growth is in the production of MDF, which substitutes for solid wood in a range of markets. Since 1991/92, production of MDF has increased by an average of 6.2% per annum and around 40% of all MDF produced in Australia is currently exported. Current production of composite wood products in Australia is based primarily on plantation softwood resources. There are only two hardboard producers utilising hardwood pulpwood. The MDF mill near Perth is based on softwood resources.

#### 3.3.2 Future outlook and market risks

Consumption of composite wood products is likely to continue to increase in Australia and the local processing sector is generally cost competitive. However, the profitability of MDF exports is strongly influenced by the strength of the Australian dollar. Existing mills are able to utilise non-softwood resources such as *Acacia* species or oil mallee, but the capacity-to-pay for wood fibre is very low compared to sawlogs and many other forest products.

### 3.4 Sandalwood

#### 3.4.1 Sector trends

Australia’s sandalwood supply currently comes from the harvest of native sandalwood forests (*S. spicatum*) in WA (Clarke 2006) and small quantities of different species in Queensland. Plantations of *S. spicatum* totalling approximately 10,000 ha have been developed in WA and are expected to add to existing supply in coming years (Geoff Woodall pers comms.). There are also some trial plantations (of both *S. spicatum* and *S. album*) established in other states (Queensland, NSW, SA, Victoria and the NT) accounting for around 400 ha in total (Clarke 2006) and there are plans for commercial establishment of *S. album* in Queensland and in the Ord River Irrigation Area in northern WA. Australia produces approximately 2,000 tonnes per annum of sandalwood comprising a mixture of logs, chips and powder (Henschke, 2000), which has been estimated to account for around one third of world supply.

Approximately half of the Australian sandalwood harvest is exported as logs for overseas processing (Henscke 2000). Most of these logs are destined for South East Asia. The remainder is sent as processed woodchips (mostly to India) for oil production or as other sandalwood products. Australia also produces approximately 12,000 tonnes per annum of sandalwood oil, of which 11,000 tonnes per annum is produced by Mt Romance.
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Australia, which has a contract for 550 tonnes per annum of native sandalwood chip supply until 2014 (Clarke 2006).

International demand for sandalwood appears strong. The largest markets for sandalwood logs and woodchips internationally are Hong Kong and Taiwan which are reported to account for 60% of exports. China also represents a growing market, and India is also expected to demand an increasing volume of imports due to local supply constraints. The largest importers of sandalwood oil are the USA, France and the Middle East where consumers pay high prices for the niche product.

India and Indonesia have traditionally been major suppliers of sandalwood, owing to their extensive native sandalwood (S. album) forests. S. album differs to the Australian species with the former producing a higher quantity and quality of oil. It is therefore often regarded as a higher quality product in international markets. Both Australian sandalwood oil and wood products have historically been sold at price discounts to Indian sandalwood. The price for S. spicatum on the world market has been reported to be in the vicinity of one third of the price of S. album (Clarke 2006). However over-harvesting has reportedly reduced the supply of sandalwood significantly (TED 1998). In both countries unsustainable harvesting has prompted governments to initiate harvesting and trade restrictions to protect the resource.

3.4.2 Future outlook

Strong international demand for sandalwood and constraints on international supplies present a good rationale for expanding the production of sandalwood. Australia is an established supplier of sandalwood and sandalwood oil internationally. The low rainfall requirement of WA sandalwood makes it suitable for farm forestry in lower rainfall regions, where it could also contribute environmental services. In addition, sandalwood products demand a high price by weight on the market making it an attractive prospect for smaller scale plantation investors.

Although plantings of sandalwood have been increasing rapidly since 2000, plantation production remains in the early stages and silvicultural and management techniques are still being developed. Sandalwood is a complex species to farm and will require significant investment in the future to optimise plantation techniques and improve the genetics of plant stock. Identifying the optimal rotation length (to maximise investment returns) may prove pivotal to the feasibility of sandalwood plantations.

3.4.3 Market risks

There are several challenges and market risks associated with sandalwood production. Rapid plantation development could lead to over-supply and associated price volatility/decline. There is also a market risk that prices for lower quality WA sandalwood, S. spicatum currently being planted extensively in WA, will decline due to product substitution in the lower value sandalwood oil market, or through successful plantation developments in other countries.

The market for sandalwood is a niche market. Niche markets are typically price sensitive to fluctuations in the supply/demand balance, meaning that returns may be unreliable for investors. Any substantial increase in the supply of Australian sandalwood may therefore have a downward effect on price in the market. There are also technical risks associated with the still-developing knowledge of plantation silviculture and management (URS Forestry, 2007).
3.5 Eucalyptus oil

3.5.1 Sector trends

Global consumption of Eucalyptus oil is currently estimated to be around 7,000 tonnes per annum, of which Australia produces around 3%. China produces around 70% of global supplies, mostly produced as a by-product of large scale Eucalyptus plantations. Accurate production statistics are difficult to source due to re-processing of imported oil and ingredients being obscured by customs coding. Australia is reported to produce around 200 tonnes per annum of Eucalyptus oil, of which approximately 60-70% is exported (Pain in press, http://www.oilmallee.com.au). The US is the largest importer of Australian Eucalyptus oil, accounting for around 20% of Australian exports by quantity. Thailand, New Zealand and Canada are also important export destinations (Pain in press).

Prices for Eucalyptus oil in recent years have been relatively stable, in the region of $US 4,500 to $US 5,000 per tonne. Australian oil has a price premium in the US market being valued significantly higher than the Chinese product (Pain in press).

3.5.2 Future outlook

Australia can potentially increase its competitiveness by harvesting Eucalyptus oil as a product of multi-purpose plantations. Opportunities for plantation production for Eucalyptus oil is most likely to depend on development of an integrated wood processing facility that produces a range of products from mallee eucalypts, such as bioenergy and activated carbon.

3.5.3 Market risks

Markets are small on a global scale and it is difficult for Australia to compete with the cost structures of other countries. While prices have remained relatively stable, they may respond negatively to any large increase in supply unless new products are developed and commercialised. A commercial scale IWP plant may present a financially viable option for the production of Eucalyptus oil, although the small scale of the world oil market presents limitations, particularly as any expansion in oil supply may cause prices to decrease. Returns from an IWP plant will depend on several products.

3.6 Bioenergy

Bioenergy refers to the production of renewable energy based on solid biomass. A range of technologies exist for generating electricity from wood including direct combustion of wood, co-firing with other energy sources, and gasification.

3.6.1 Sector trends

Bioenergy production from wood is creating significant enthusiasm internationally and government renewable energy frameworks are developing. Growing interest in wood bioenergy has been driven by government policy promoting the development of renewable energy. In 2001, the Commonwealth government introduced the MRET scheme. This mandated that 2% of Australian electricity output will be from renewable sources by 2010. In 2007 the Commonwealth government extended the scheme and committed to ensuring that 20% of Australia’s electricity supply comes from renewable energy sources by 2020.

The Australian electricity industry has sought to meet its obligations for renewable energy under the MRET scheme via the lowest cost sources available. Significant examples of this are wind farms and land-fill gas projects which have been implemented since the scheme was introduced. Analysis of the relative costs of the
alternative forms of energy indicates that bioenergy from biomass is competitive with most other sources of renewable energy, as shown in Figure 3-1.

**Figure 3-1  Estimated electricity generation costs, 2006**

The two main opportunities for additional renewable electricity generation in WA come from wind and biomass. Wind is well understood and technology is readily available. Bioenergy offers more predictable supply that can potentially replace other base load generation, however secure access to long term feed supplies is required. Current proposals for bioenergy plants in WA are based primarily on plantation residues, however growing dedicated bioenergy crops of species such as oil mallees or *Acacia* species may also be an option.

### 3.6.2 Future outlook

The success of wood bioenergy will ultimately be determined by price competition in the energy market, which is directly determined by production costs relative to other energy sources. A significant factor affecting these costs will be government policy supporting renewable energy. A system of Renewable Energy Certificates (RECs) has been established to allow convenient trading in renewable energy to meet MRET obligations. The price of RECs is not fixed and so availability and other market forces dictate their traded value. However, the penalty for not meeting an MRET target is $40/MWh before tax.

Notes: pf = pulverson fuel; IGCC = integrated gasification combined cycle; PCC = post-combustion capture; CCS = carbon capture and storage.

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Market opportunities

There are currently several proposals for bioenergy plants in WA, which potentially creates opportunities to develop dedicated bioenergy plantations on the Gnangara Groundwater System or to sell residues from other alternative plantations. The feasibility of dedicated plantations will depend on the development of cost effective silviculture and harvesting systems and the proximity of the resource to the power plant. Pacific Energy is currently investigating the feasibility of building a bioenergy plant on the Gnangara Groundwater System.

3.6.3 Market risks

Wood based bioenergy appears to have cost advantages over some other renewable energy sources. However, other technologies are developing rapidly and there is uncertainty over the competitiveness of wood based bioenergy and the potential to utilise existing residues.

3.7 Wood pellets

Wood pellets are a standardised form of wood bioenergy produced by grinding wood material into small particles, then compressing the material through a perforated matrix which acts to heat and bind the wood together.

3.7.1 Sector trends

The market for wood pellets is driven by international markets, particularly the European Union (EU), and there is developing interest from Australian investors to export wood biomass for bioenergy production in these markets. The EU has created strong incentives for renewable energy production especially wood based bioenergy. It has established a carbon emissions trading scheme aimed at reducing commercial carbon emissions and has also set a renewable energy target for member countries of 20% by 2020. At present bioenergy accounts for around 4% of the EU’s energy supply and wood pellets form a significant and increasing proportion of this supply. The strong incentive created in the EU for wood based bioenergy has increased demand for wood pellets, and international trade and prices for wood pellets in the EU have increased as a result.

Canada is currently a major exporter of wood pellets to the EU market, shipping pelletised wood waste from the west coast of the country to markets in Northern Europe. Anecdotal information suggests that Canadian companies earn good returns, as increasing demand in Europe has recently pushed prices to record levels (Daugbjerg-Jensen 2007).

3.7.2 Future outlook

Internationally, wood bioenergy production is developing rapidly as a result of the increasingly supportive policy environment for renewable energy. At present there are reported to be investors in WA and NSW pursuing wood pellet production for export to the EU. Production is reported to be based on forestry and agricultural residues but there is interest in other feedstock such as mallee eucalypts (John Bartle pers comms.). One company, Plantation Energy, is planning to manufacture and export pellets from Albany, WA. Residue is sourced from the harvest residues of Tasmanian blue gum (E. globulus) plantations. The initial goal is to manufacture 145,000 tonnes per annum (www.plantationenergy.com.au).

3.7.3 Market risks

Production of wood pellets for export also raises potential environmental issues which may need to be addressed by Australian exporters in the longer term. The use of wood pellets is driven by the demand for a carbon neutral and sustainable/renewable fuel source. When the full costs of Australian exports to the EU are considered, carbon emissions created to transport the pellets may compromise their environmental benefit.
Market opportunities

Section 3

Other limitations such as policy uncertainty and the high cost of technology make potential returns on investment uncertain, particularly in Australia.
The analysis in the previous section identified that there are likely to be several plantation types that could grow on the Gnangara Groundwater System and which have market prospects. Data on the LAI of different species was limited and cannot be directly translated to the conditions on the Gnangara Groundwater System. Table 4-1 provides a summary of the alternative species opportunities for the Gnangara Groundwater System.

**Table 4-1 Summary of opportunities for alternative species on the Gnangara Groundwater System**

<table>
<thead>
<tr>
<th>Species</th>
<th>Best product / market prospects</th>
<th>Water use</th>
<th>Opportunities, risks, limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia species</td>
<td>Bioenergy, MDF</td>
<td>Little is known about water use of the species and no LAI data was observed in the literature. Soil moisture will be required to maintain rapid growth and some species appear to have the ability to grow deep roots.</td>
<td>Some Acacia species are expected to grow well on the Gnangara Groundwater System due to preference for sandy soils and acceptable rainfall. Proposed bioenergy projects present new market opportunities. A. saligna appears to be the best species for bioenergy or MDF as it has fast growth and will coppice, however its poor form will make it difficult to harvest. Plantations grown to produce biomass for bioenergy will normally be planted at high stocking and managed to maximise growth. Alternative plantation regimes with lower stocking or planting only a proportion of the area in block plantings would be necessary on the Gnangara Groundwater System to keep water use within acceptable limits. Suitability for MDF production needs to be proven. Plantations can be grown over long rotation for specialty sawn timber products, however these markets are not well developed.</td>
</tr>
<tr>
<td>Hardwood species</td>
<td>Sawn timber, Bi-products from sawlog rotation such as posts/poles and biomass</td>
<td>Some LAI data is available. Data is limited but could be used as an indicator for hardwood plantations on the Gnangara Groundwater System.</td>
<td>It is expected to be feasible to manage hardwood sawlog plantations to meet LAI constraints as they can be planted at lower stocking and thinned. Several species have been grown successfully in trials on sites similar to the Gnangara Groundwater System, although growth rates are low. Tree breeding, silviculture and processing technologies are still being developed. There may be opportunities to aggregate with existing FPC hardwood plantations in south west WA.</td>
</tr>
<tr>
<td>Oil mallee species</td>
<td>IWP, Dedicated bioenergy plant, Pellets</td>
<td>Some LAI data is available. Data is limited but could be used as an indicator for oil mallee plantings on the Gnangara Groundwater System.</td>
<td>Oil mallee species appear suited to the conditions of the Gnangara Groundwater System. Proposed bioenergy projects present new market opportunity. Belt or dispersed block plantings would be required to keep within LAI constraints.</td>
</tr>
</tbody>
</table>
Summary and next steps

<table>
<thead>
<tr>
<th>Species</th>
<th>Best product / market prospects</th>
<th>Water use</th>
<th>Opportunities, risks, limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandalwood</td>
<td>Timber, oil, nuts</td>
<td>No data identified during the literature review. Water use needs to be considered for a system including sandalwood and host species.</td>
<td>Sandalwood may be suited to some soils on the Gnangara Groundwater System. Growing interest and investment in sandalwood plantations in south west WA and good market prospects. High value crop appropriate for small plantings on suitable soils.</td>
</tr>
</tbody>
</table>

### 4.1 Next steps

Several potential species have been identified and further work is now required to assess the relative economic benefits of different plantation types and consider the silvicultural management that will be required to meet LAI constraints. The opportunities for plantation development of alternative species on the Gnangara Groundwater System can then be assessed and ranked.

In the URS proposal for this project, it was proposed that Stage 2 of the project would involve growth and yield modelling using STANDPAK to model the growth of an individual hectare of plantation and to estimate LAI based on known relationships between basal area and LAI. Unfortunately, LAI data available in the literature is insufficient to undertake this level of modelling for all of the potential species.

For Stage 2 of this project URS proposes to undertake the following:

- Meet with FPC to discuss the information and findings presented in this report, and to discuss the feasibility of different options with specific consideration to:
  - The feasibility and suitability of belt or block configurations for growing biomass, where a proportion of Gnangara Groundwater System would not be utilised for tree crops; and
  - FPC strategic plans hardwood and sandalwood plantations and opportunities to expand these estates through plantations on the Gnangara Groundwater System.

- Based on the LAI information available, estimate the silvicultural regimes that would need to be employed for each species to meet LAI constraints, including the proportion of the Gnangara Groundwater System that could be planted and the area that would need to remain in fallow or some other land use.

- Review and model the economics of the following plantation regimes on a per hectare basis. This will draw on economic information available in literature and will be supplemented by additional economic modelling undertaken by URS:
  - Hardwood sawlog plantation;
  - Oil mallee plantations for biomass;
  - Acacia plantations for biomass; and
  - Sandalwood plantations for timber and nuts.

- Using the assessment of LAI and results of the economic analysis, compare and rank the opportunities.
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Summary and next steps

- Based on the best identified plantation option or options, identify further work to be undertaken to confirm LAI and water use of the preferred option/s, and refine silvicultural regimes as necessary to meet LAI constraints.

Depending on the outcomes of the analysis described above, FPC may wish to proceed to detailed growth and yield modelling, economic analysis and feasibility study for a preferred plantation option.
URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of the Forest Products Commission and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 27 May 2008.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 1 June 2008 and 17 December 2008 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.
Section 6

References


References


Section 6

References


