THE DEVELOPMENT AND FUTURE POTENTIAL OF TREE CROP INDUSTRIES ON FARMLANDS IN WESTERN AUSTRALIA

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Abstract

For Western Australia the last decile of the twentieth century may well be seen by historians of wood-based industry as a time of revolutionary change. It has seen the beginnings of a quantum shift in both the ways in which government strategies are formulated and of the perceptions of land managers as to the nature and place of woody plant cropping in affordable land repair and conservation.

For most of the past century, plantation management had evolved around the purpose of self-sufficiency of supply of sawn or reconstituted wood products from two species of exotic pine. Large contiguous blocks of land mainly in the public estate were converted from native forests and woodlands. Due largely to environmental constraints on the availability of suitable land and opposition from sectors of the conservation movement, the level of plantings required for the targets of self-sufficiency fell further behind to the detriment of the nation's balance of payments. The significant scientific improvements in cultural techniques obtained by land managers over 50 years, served only marginally to ameliorate the growing deficit.

Completion of the State Government's Timber Strategy Review in 1987 marked a watershed in the character and content of land management strategies.

Recognition of (i) prospective use of a much wider range of species for saleable woody plant products, (ii) growing opportunity to exploit access to the vast area of Western Australia's farmlands in urgent need of tree planting for land repair, and (iii) seizure of commercial needs to service the escalating demand for secure future wood supplies in countries of the Western Pacific were all vital links in formulation of a strategy of integrated land management. This serves a variety of industries based on trees and woody shrubs both native and exotic and is funded by its profits.

Vigorous pursuit of this strategy by private sector investment and government encouragement will deliver great benefits in affordable land repair and conservation. It offers not only a prospect of achievement of our long term desire for self-sufficiency but a vision of a vibrant export trade to the growing economies to our north. It is by no means fanciful to envisage that the future landscapes of Western Australia might come to be known as the wood fibre bowl of the Pacific.

Introduction

For almost a century from its very modest beginnings in the late 1800s the basic strategy for the production of wood from Western Australian plantations of exotic tree species, as elsewhere on the continent, was developed at a measured pace and for a quite limited purpose – the attainment of timber self-sufficiency.

The characteristics which dominated this strategy were (i) sole management by a State agency, the Western Australian Forests Department, (ii) block plantings on public lands cleared of natural forests and woodlands for this purpose, and (iii) densely stocked monospecific stands of one or the other of two species of pines of temperate old world origin. Their product was destined primarily for conversion to sawn timber for sale on the domestic home building market. From the early 1970s generally unsuccessful plantation programs, based on the dark coloured and dense woods of Australian eucalypts, were initiated in expectation of producing sawn timber from areas of native forests which had been earlier severely damaged by the disease "jarrah dieback".

From the close of the Second World War until the early 1980s, cultural methods based on scientific advances in nutrition and tree selection were slowly improved. At the same time industrial methods for seasoning, slicing and reconstituting of wood by laminating, chipping and gluing of pines, increased the variety of their end uses.

Since the mid-1980s the Western Australian Government has supported a major and ongoing reappraisal of strategies for the use of plantings of a much wider range of woody plants for a greater variety of land use and land repair purposes on both public and private lands. New technical innovations have been developed to optimise their productive utility.

This effort has resulted in a far more diverse and extensive set of plantation programs now based on five major species of woody plants with diverse end uses. A significant investment of overseas funds of regional significance for land repair and rural employment has already been stimulated.

Western Australia now possesses the environmental, socio/political, and technical knowledge essential to develop the State's potential as a major source of supply of wood products to the burgeoning market in the Western Pacific region where severe over-exploitation of natural forests is already clearly evident.

In the 1980s a combination of political and environmental factors resulted in the initiation of a new approach by the Department of Conservation and Land Management (CALM) to plantation establishment – the establishment of tree crops on agricultural land. This paper summarises the history of plantation development in Western Australia, describes the factors that led to the initiation of the tree crops on farmland program, and the technical, economic and legal skills needed to ensure its success. The paper also outlines a vision for the future of the "tree crops on farms industry" in Western Australia.

The History of Plantation Development in Western Australia

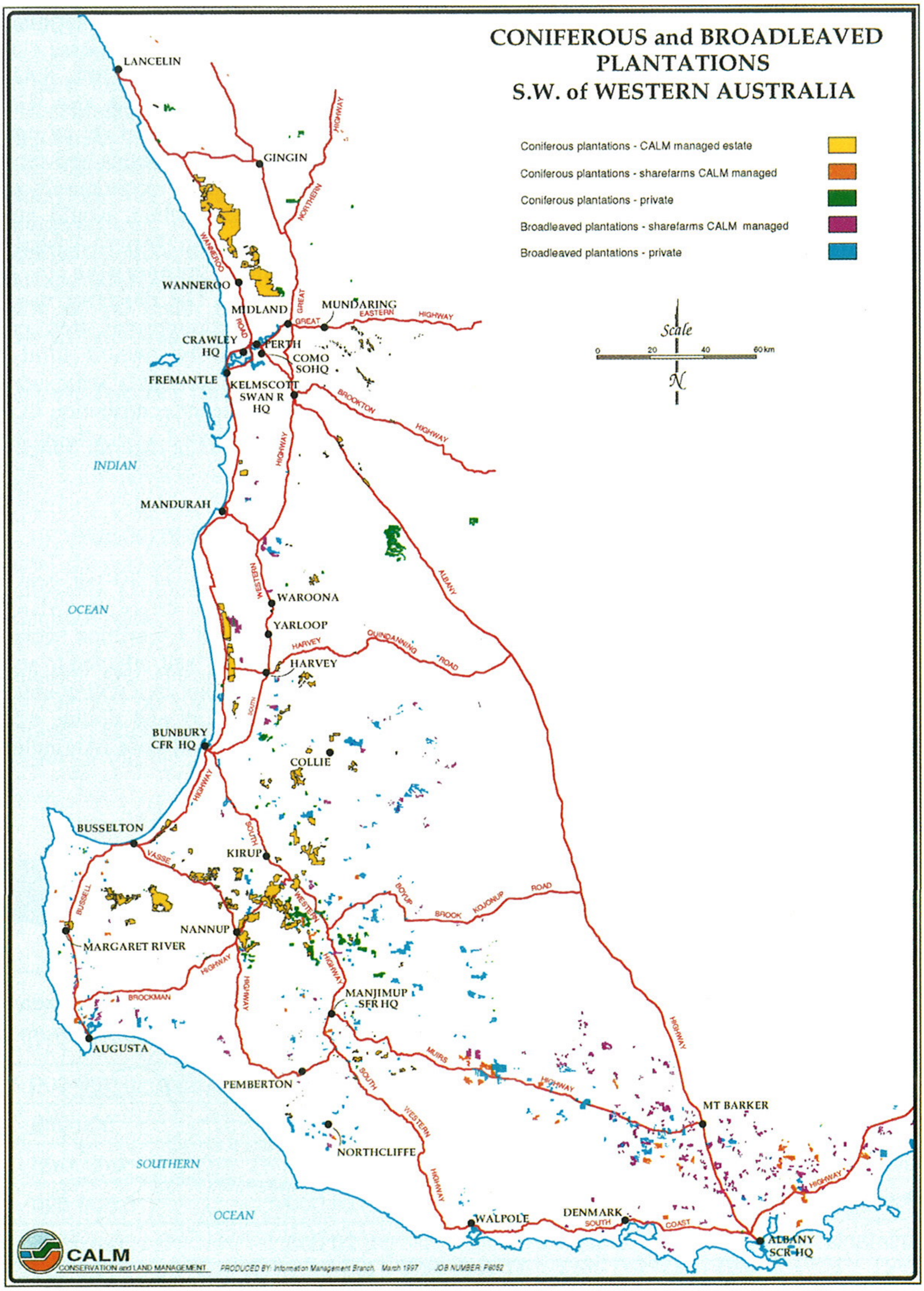
Western Australia's first hardwood plantations, initiated in 1926, were of *Eucalyptus astringens* (brown mallet), grown for tannin production. Six thousand two hundred hectares were established. Western Australia's first softwood plantations were established in the 1920s following trial plantings in 1896 to find a conifer suited to local conditions. From 1950, the area of softwood plantation increased steadily to 50 000 hectares by 1985 and 70 294 hectares by December 1995 (CALM 1996). There are two main softwood plantation areas; *Pinus pinaster* is grown at Gnangara north of Perth (24 659 hectares) and *Pinus radiata* in the Blackwood Valley in the south-west (38 220 hectares) (Figure 1).

Fifty two thousand hectares of softwood plantations were established on public land which had been cleared of native vegetation and 13 000 hectares of softwood plantations were established over the period 1933 to 1991 on agricultural land purchased for pine planting, principally in the Blackwood Valley. These plantations were funded by a combination of State and Federal Government funds under the Federal Softwood Forestry Agreement Acts of 1967 and 1972 (Bureau of Agricultural Economics, 1977). Over the period 1969 to 1975, approximately 17 000 hectares of *P. radiata* plantations were established by private companies on former agricultural land.

By the beginning of the 1980s, opposition to the clearing of native vegetation for the establishment of softwood plantations had become a major environmental issue. The Labor Party, then in opposition, adopted a policy which prohibited the clearing of native vegetation for plantation establishment. Consequently, when the Government changed in 1983, the Western Australian Forests Department's strategy to establish a 60 000 hectare area of softwood plantations over a period of 30 years in an area known as the Donnybrook Sunklands, south of the existing *P. radiata* plantation in the Blackwood Valley, was terminated (Forests Department 1982).

At the same time, the new Labor Government proceeded to reserve a major river catchment system (the Shannon River basin) which contained a significant hardwood timber resource. The Government promised to fund the establishment of an area of softwood plantations sufficient to compensate for the timber foregone because of the reservation of the Shannon River basin.

Figure 1



Plantations and tree crops
South-West of Western Australia

The purchase of agricultural land for pine planting by the State, which had been stopped in the 1970s in part because of objection from rural communities, recommenced in 1985. The decision to purchase agricultural land in the Manjimup Shire, where only 14 per cent of the land base was alienated and available for agriculture, provoked major opposition from both farmers and the local government. It was evident that land purchase by itself was not a viable way to achieve land for plantations.

In 1987, CALM undertook a major review of forest management and the forest industries in Western Australia which culminated in the production of a Timber Strategy (CALM 1987). With respect to the production of timber from plantations, the Strategy was influenced by two major developments.

Firstly, by the middle of the 1980s it had become apparent that a major wood fibre deficit was developing in the Pacific Rim countries (Groome 1987, Groome 1989). Secondly, it was recognised that the land and water degradation problems in Western Australia which had resulted primarily from clearing native vegetation and excessive fertilisation application could only be solved by the implementation of a major planting program of perennial crops on cleared agricultural land.

CALM recognised the potential of using the increasing demand for wood fibre to pay for the establishment of trees on farmlands which were required to reverse land degradation (Shea and Bartle 1988, CALM 1987). CALM abandoned the self-sufficiency strategy which had set an upper limit on commercial tree planting and set out to develop the technical, economic, social and legal mechanisms which would make wood fibre production on Western Australian agricultural lands competitive in the international market. The objective was to develop a major commercial tree crop industry, on privately owned land in partnership with farmers, at a scale which would make a significant contribution to the rehabilitation of degraded agricultural land and river systems.

The Land Degradation Problem

Western Australia has over 70 per cent of Australia's reported dryland salinity (Table 1). An estimated 1.8 million hectares of farmland are already salt-affected to some extent. If unchecked, this area will double in the next 15 to 25 years and double again before reaching an equilibrium (Agriculture WA *et al* 1996).

Table 1

Area of land reported to be affected by dryland salinity in Australia

State	Area salt-affected in 1982 (ha)	Area salt-affected in 1996 (ha)	Potential area at equilibrium
Western Australia	264 000	1 804 000	6 109 000
South Australia	55 000	402 000	600 000
Victoria	90 000	120 000	unknown
New South Wales	*unknown	120 000	5 000 000
Tasmania	*unknown	20 000	unknown
Queensland	*unknown	**10 000	74 000
Northern Territory	*unknown	minor	unknown
Total	**na**	**2 476 000**	**>11 783 000**

* salinity was likely to be present but its extent had not been assessed.

** only severe salinity

Source: Agriculture WA *et al* (1996)

Salinity is caused by replacing the deep-rooted, perennial native vegetation with annual crops and pastures used in agriculture which cannot transpire as much of the rainfall as the native vegetation. The result is an accumulation of excess groundwater, which causes water tables to rise, mobilising stored salts and causing waterlogging and salinity on low areas (Figure 2). Salt concentrations in river systems have increased in more than 50 per cent of the river and stream systems in the south-west region of the State. Enhanced runoff can cause erosion of stream lines.

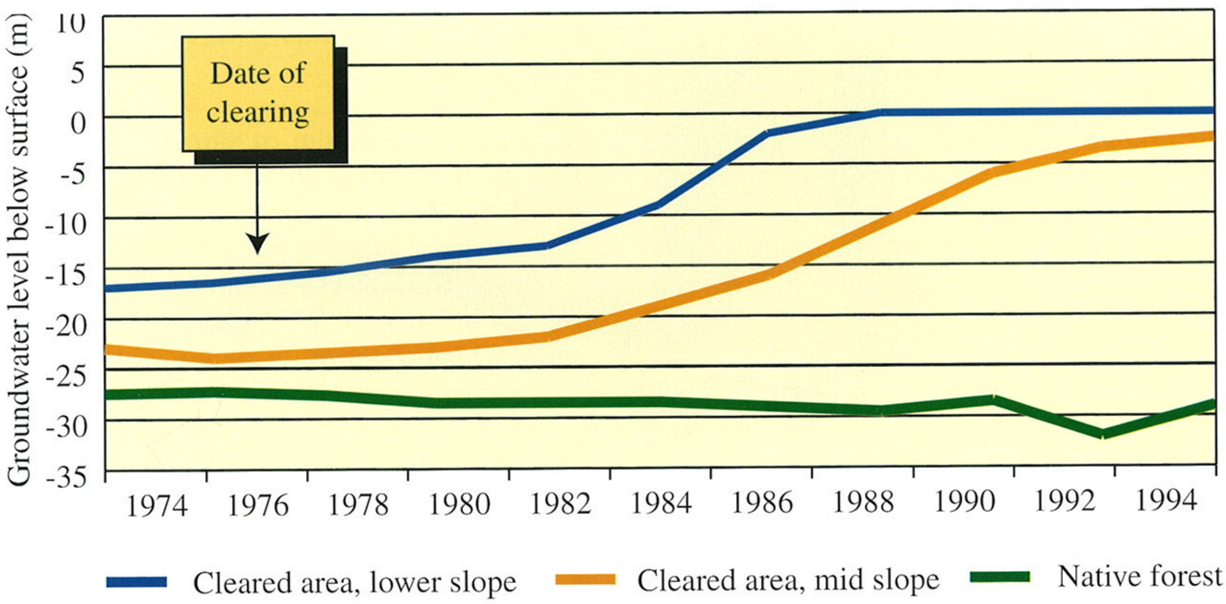
Excessive fertiliser runoff from agricultural land has also caused eutrophication of estuaries throughout the south-west of the State, with adverse effects on the biota, particularly fisheries, recreational utility and air quality in residential developments around the estuaries. Wind erosion is also a significant problem in the south coast agriculture zone.

Salination and eutrophication also have a major impact on conservation reserves and wetland systems. Most of the wetland systems in the agricultural zone have been destroyed by salination and if unchecked salination will destroy up to half of the remaining native vegetation in public reserves and on farmlands in the agriculture zone (Agriculture Western Australia *et al* 1996).

Revegetation with trees and shrubs is the only practical long-term option for controlling dryland salinity, although the magnitude of the replanting required will be reduced if the health and vigour of remnant vegetation can be improved and the water use of annual crops and pastures increased.

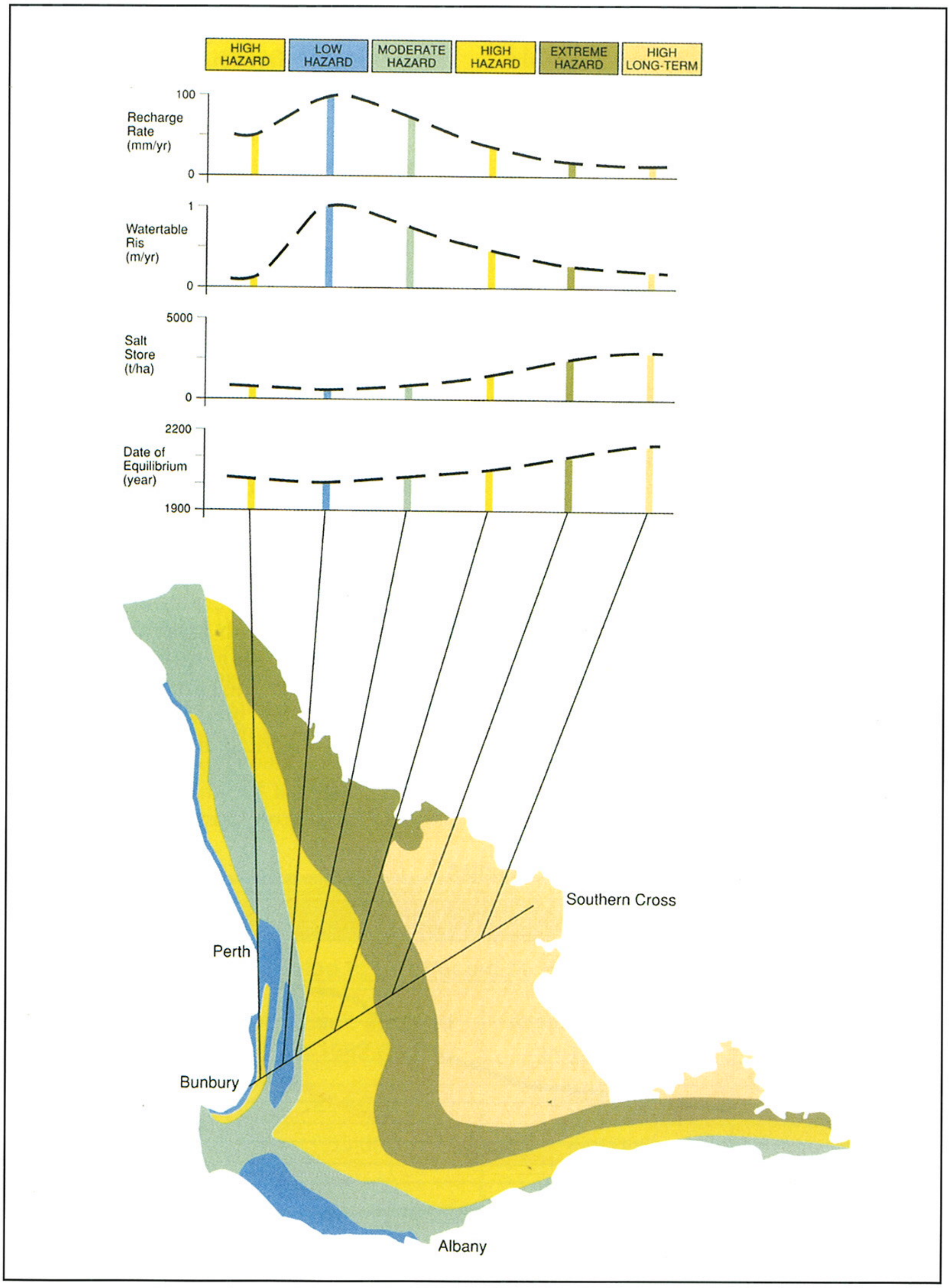
The capacity of tree crops to reduce water table levels significantly by exploiting water stored in the soil profile has been demonstrated in trials with several different species (Farrington and Salama 1996). The proportion of the landscape that needs to be revegetated with perennial crops will decrease in areas with lower annual rainfall because the winter rainfall "surplus" decreases and the amount of water transmitted to the groundwater table each year is less (Agriculture WA *et al* 1996) (Figure 3).

Figure 2



Groundwater level response at Lemon Catchment (annual rainfall 750mm)
(after Agriculture WA et al, 1996)

Figure 3



Salinity hazard zones in south-western Australia. Factors affecting salinity hazard are shown along a transect from the coast to the eastern edge of the wheatbelt. These factors change depending on land-use, geology and time since clearing, as measured by rate of water table rise, recharge rate and salt storage. It can be seen that salinity hazard ranges from high near the coast, to low in the high rainfall south-west, and from high to extreme throughout the lower rainfall regions.

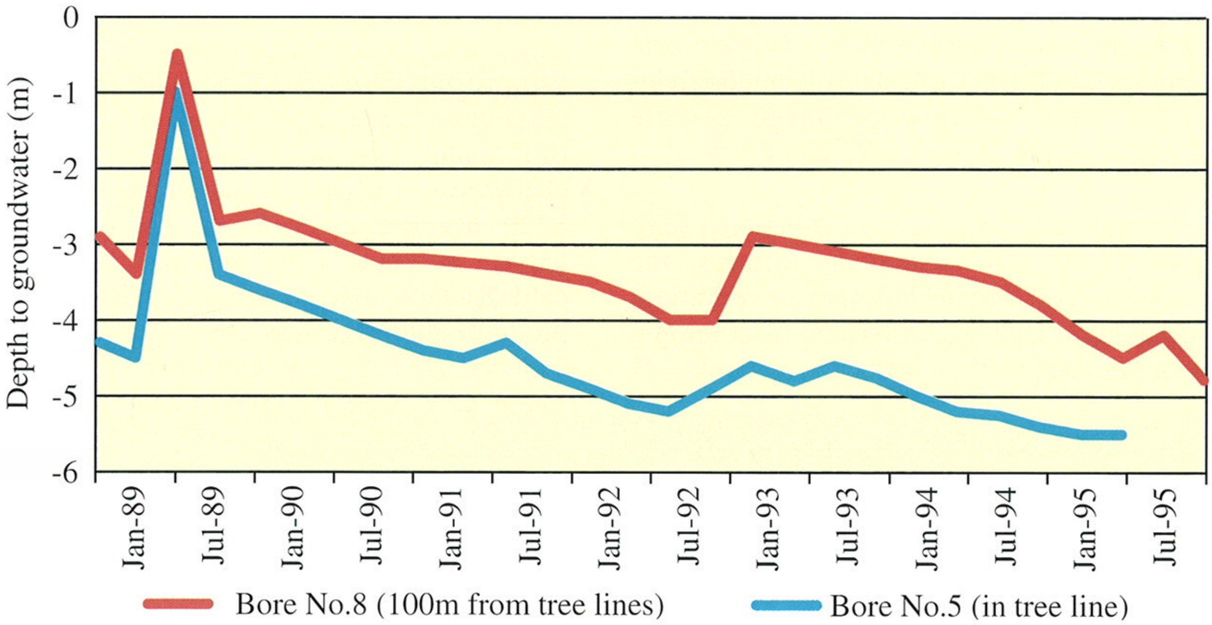
It has been estimated that provided trees are strategically located, groundwater control can be achieved by revegetating between 10 per cent and 30 per cent of the landscape with perennial crops (Schofield 1990, Farrington and Salama 1996). For example, in the south coast region *P. radiata* planted on a deep sand soil in three-row belts 200m apart for wind protection, is showing a steady lowering of the water table at a rate of approximately 50 cm per year across the whole land unit (Short and Skinner 1996) (Figure 4).

the soil and water systems of the agricultural zone, while at the same time providing another source of income to farmers.

Land Acquisition

Economic analyses of the relative profitability of grazing and forestry in the lower south-west demonstrated that the latter was more profitable but very few farmers had established, or intended to establish, commercial tree crops on their farms (Malajczuk *et al* 1984). Analyses of farmer

Figure 4



Hydrograph showing groundwater response to alley farming system (after Short and Skinner, 1996)

It is also possible to minimise or eliminate the opportunity cost of withdrawal of land from crop or pasture production by skilful location of tree crops. There is increasing evidence that grazing and crop productivity can be significantly increased by skilful integration of tree crops into farming systems (Shea *et al* 1994).

It is estimated that the three million hectares of trees and perennial shrubs will have to be established in the agricultural zone at a cost of $3 billion to control salination (Agriculture Western Australia *et al* 1996). The development of a major commercial tree crop industry on farmlands provides a method to fund partially the rehabilitation of

attitudes showed that there were a number of reasons for this, but one of the major factors was the relatively poor cashflow of tree crops. There was also strong community concern that whole farm tree planting would result in a reduction in basic services.

The strong opposition to whole farm purchase for plantation establishment and the large amount of capital required for land purchase made it essential that the alternative methods of land acquisition were developed. A review of the relevant costs of land purchase and leasing over the period of a 30-year pine rotation was undertaken. The study concluded that leasing would not cost more than land purchase and had the added advantage of requiring less up-front capital (Malajczuk *et al* 1984).

The first leases were developed in the mid-1980s to enable the establishment of *P. radiata* plantations on privately-owned farms. The agreement involved payment of an annuity throughout the rotation and ten per cent of the value of the final crop at harvest. These agreements were described as "pine sharefarming agreements" because the concept of "sharefarming" (that is, leasing of part of the farm to another farmer) was well understood by farmers. This simple model was adequate to procure land when the government was providing the finance and managing the scheme. But it was not robust enough to be used to establish hundreds of joint ventures between large private companies and individual farmers.

Consequently, extensive negotiations were undertaken with prominent farmers, the Western Australian Farmers' Federation, agricultural and legal advisers, to develop a new land acquisition package.

The central feature of the commercial land acquisition package that was developed is a Deed of Grant of Profit a Prendre in which the landowner grants to a third party a right to (in this case) establish, manage and harvest a plantation on the land. The contract is registered on the title to the land and is transferred with the sale of the property. The sharefarming contract between the landowner and CALM is based on the sharing of the harvest revenue in the same proportions as the discounted inputs of each party in the establishment and management of the crop.

The profit a prendre or timber sharefarming contract allows an investor the flexibility to cater for all sorts of landowner wishes.

The landowner can choose to be an active partner in the crop by taking a share of the returns through a lump sum return at harvest time only (full crop share). The landowners may elect to increase their share of the returns by investing directly in the establishment of the plantation – a $1000/ha investment increases the share to approximately 65-70 per cent and attracts a tax deduction for the investor in the year of establishment.

For landowners seeking some annual returns, the sharefarming contract allows for an advance payment of harvest returns of up to $90 per hectare per year which are subsequently deducted from the harvest lump sum.

In each of the above cases, the returns to the landowner are ultimately dependent upon the value and the volume of the timber at harvest time.

For those landowners who require maximum returns as early as possible, the full annuity option is most appropriate, characterised by annual payments of up to $220 per hectare with no share of the harvest revenue, with annuities based on haul distance to the processing plant and the productivity of the site.

There have been a number of variations of the basic sharefarm agreement developed in response to landowner requests. For example –

- Planting of non-commercial species on salt-affected sites unsuitable for main commercial species – offset against crop share or annuity payment, or paid for by the landowner at the marginal rate.

- Planting of alternative woodlot species for special purposes, eg specialty timbers, sawlogs, craftwood. Funded under similar conditions to above.

In each case, the landowners own the alternative planting outright, which provides them with opportunities to manage and market their own plantations.

Apart from the poor cashflows and concern about the impact of tree planting on the social structure of rural communities, there was a general lack of information about the benefits of tree crops. It is less than two decades since a condition was placed on purchase of land by farmers from the Government that required a proportion of the farm to be cleared within a specific period. Consequently, some farmers have found it difficult to adjust to the idea of re-establishing trees on farms. Consequently, CALM has implemented a major education and marketing program to inform farmers of the benefits of tree crops.

Trends in land acquisition for the establishment of *E. globulus* tree crops in the south coast region of Western Australia are shown in Table 2.

A total of 187 landowners have been involved in the establishment of *E. globulus* plantations on their properties in conjunction with CALM over the past nine years in the south coast region, resulting in a total plantation area of 10 676 hectares (up to 1996). The average area planted per individual landowner is 40 hectares.

Of the 187 landowners, 48 have planted trees on their properties more than once. Of the 48 repeat planters, 18 have planted twice, eight have planted three times and three have planted four times. The average area planted by landowners who have participated more than once is just over 39 hectares. Assuming an average farm area of 400 to 800 hectares in the target planting area, the average area planted by repeat participants represents between five and ten per cent of their farm area.

The average annual area planted per property which has increased from three hectares in 1988 to around 120 hectares in 1995 and 1996. This increase is in response to a number of factors but the most important is the general increase in acceptance amongst the farming community that commercial bluegum plantations are a viable alternative crop for the farm and contribute significantly to landcare.

The Tree Crop Species for Farmland

CALM is currently field trialling more than 44 species on farmland but *P. radiata, P. pinaster, E. globulus* and mallee

Table 2

E. globulus plantations established by CALM in the south coast region of Western Australia

Year	No. of land-owners	Cumul-ative	New parti-cipants	Repeat participants				Area planted	Property average	Planting range
				X1	X2	X3	X4			
1988	1	1	1					3	3	3
1989	32	33	32					324	10	1-80
1990	43	76	35	8				458	11	2-52
1991	32	108	22	7	3			440	14	3-35
1992	42	150	32	7	2	1		868	21	3-65
1993	39	190	22	12	2	3		1 174	19	9-91
1994	31	217	19	8	1	2	1	1 387	51	9-179
1995	23	240	11	3	7	1	1	2 756	120	9-385
1996	24	264	12	8	1	2	1	3 266	125	19-478
Total	264		187	48	18	8	3	10 676	40	1-478

Source: Ellis, G. R. (1994)

eucalyptus are the only species which are planted extensively for commercial purposes. More recently, salt resistant *E. camaldulensis* and *E. wandoo* and a range of *Acacia* species have been established in trials.

Tree Breeding

CALM has long-term tree breeding programs in place for its three main plantation species, *P. pinaster* (commenced in the 1950s), *P. radiata* (since the 1960s) and *E. globulus* (since the 1980s). More recently breeding programs for eucalyptus species being grown for the production of eucalyptus oil have been undertaken.

Tree breeding involves establishing a base population to capture as much of the genetic diversity of the natural range as possible. CALM has committed extensively to this concept with special scion collections being organised from Portugal for the *P. pinaster* program, the joining of the *P. radiata* program with others through the national Southern Tree Breeders Association (STBA) and the planting of over 100 000 trees to capture the *E. globulus* gene pool.

Pinus radiata

The breeding program for *P. radiata* in CALM was started in the early 1960s and it was soon found that CALM needed a special *Phytophthora* cinnamomi resistant line. A breeding strategy was formulated in 1985 to separate the breeding population into two lines, one for general afforestation and the other for *Phytophthora* resistance. In 1988 CALM joined the Southern Tree Breeders Association breeding program. The improvement gained in productivity with the general *P. radiata* breeding population has not been as significant as that which has been achieved with other species. With open pollination, improvement is between 16-18 per cent but a control pollinated cross can increase volumes by 25 per cent. Selecting for *Phytophthora* resistance has, however, been very successful enabling CALM to establish *P. radiata* on moisture gaining and infested sites.

The deployment of the genetic gains of *P. radiata* in CALM has been through seed. By 1997 all seed production of *P. radiata* will be from hedged artificially pollinated seed orchards (HAPSO). Although similar to the meadow orchards of New Zealand, these orchards use maleic hydrazide for the abortion of the male cones. It thus leaves the female cones available for the mass pollination of the best pollens, a controlled pollination system on mass scale. This high genetic value-type of seed is produced every fourth year in the seed orchard management cycle. The other two years' seed production is open pollinated with the fourth year being a recovery from the pollarding which is needed to keep the trees at an accessible height for the artificial pollination process. The application of a plant hormone, GA4/7 (gibberellic acid), in December greatly improves seed production efficiency.

E. globulus

CALM has a robust and diverse breeding population of *E. globulus* and trials have been established on a diverse range of sites in Western Australia. Many of the most superior trees have been cloned by grafting and are established in clonal orchards and archives. As well as breeding for volume, wood density, stem form, crown quality and drought tolerance; CALM also has trials for salinity tolerance and resistance to insect attack. Nine hundred and ninety one parent trees have been tested as 97 000 progeny in 32 trials occupying an area of 109 hectares. A further 27 hectares of King Island parents (endangered Bass Strait Islands populations) have been planted as a gene pool.

The Western Bluegum (WBG) trademark has been registered by CALM to be used for *E. globulus* seedlings or cuttings produced from CALM's Plant Propagation Centre that have been developed from CALM's tree breeding and improvement program. Western Bluegums are genetically superior for a number of specified traits. The use of the WBG trademark will always be qualified by the trait improved, and quantified by the degree of improvement. Based on measurements of two-year-old trials at

Mettler's Lake in south-west Western Australia, Western Bluegum have achieved gains of 32 per cent improvement in volume produced over routine seed, and stem and crown quality were also improved.

Genetic gains from breeding are to be deployed by seed and vegetative propagules. Paclobutrazol is used routinely to increase seed production but deployment via seed orchards has special problems for eucalypts, especially *E. globulus*. Flowering may vary from mid-March to December, with peak flowering in September to October. Some selections flower at an early age (three years), while others are still yet to flower at 16 years. If problems with flowering synchronization can be overcome, based on the performance of elite trees it will be possible to achieve productivity gains of 80 per cent (Butcher pers. comm.).

P. pinaster

Research on genetic improvement of *P. pinaster* commenced more than 40 years ago. Ninety seven genetic trials covering an area of 203 hectares and 216 000 trees have been established in Western Australia to provide the base population and database required to quantify genetical parameters of *P. pinaster*. Initial yield trials showed a ten per cent increase in diameter growth (36 per cent more volume). Recent orchard plantings have shown genetic gains in diameter of 15 per cent which is an increase of 50 per cent over the first seed orchards. For selections now being grafted, a breeding value of 22 per cent for diameter has been computed. This represents a 100 per cent improvement in productivity compared to the first seed orchards.

These genetic gains are being deployed by both improved seed (an additional 25 hectares of seed orchards were established in 1995/96) and vegetative cuttings.

Eucalyptus oil species

Seed orchards of selected high leaf oil content trees have been established. Deployment of gains will be achieved via seed produced, as mallee eucalypts flower prolifically within three years of age.

Site Selection for Tree Crops

The ability to predict site productivity is critical to the success of the establishment of tree crops on farmland. Site conditions can vary markedly on farms because of different fertiliser histories and salination. Accurate estimates of productivity are also required to ensure that annuity payments for the lease of land are correct.

The principal biological constraint on commercial tree crop growth in Western Australia with its Mediterranean climate is rainfall. Until recently, tree crops have been restricted to areas with rainfall in excess of 600 mm per annum. But *P. pinaster* grows on an annual rainfall of 400 mm and mallee eucalypt species occur naturally in areas where annual rainfall is >200 mm per annum.

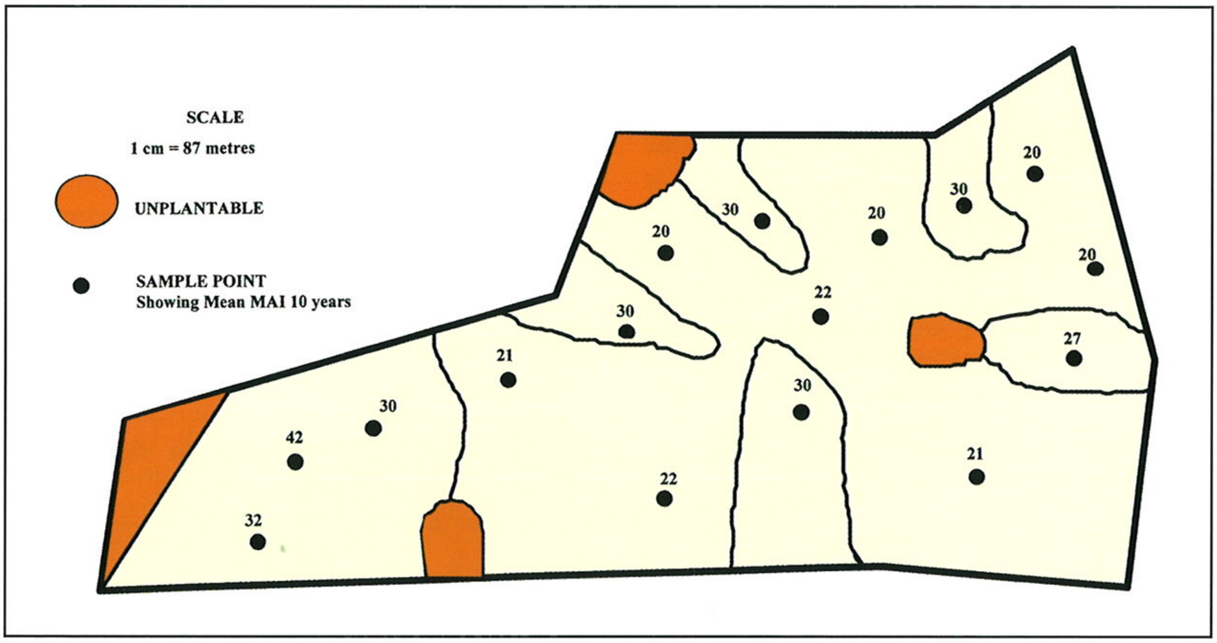
Eucalyptus globulus

Eucalyptus globulus is not established in areas where annual rainfall is <600 mm. The evaluation of land for *E. globulus* plantations in Western Australia is currently carried out using the *E. globulus* growth simulator (EGGS) (Beadle and Inions 1990, Inions 1991, Inions 1992). This model was developed by relating the growth of *E. globulus* in 56 different plots throughout the south-west of Western Australia to 74 environmental attributes (21 climatic variables, 29 soil physical and chemical properties and 24 other variables).

Soil samples are collected using a drill rig which extracts a core sample from 50 cm depth or from the clay horizon within one metre of the soil surface. The sample is analysed for both chemical properties and particle size and bulk density. Climatic data are generated by a Bioclimate Prediction System (BIOCLIM) developed by CSIRO scientists. Using inputs of longitude, latitude and elevation, the system outputs data pertaining to climatic variables for the particular sample point.

Using the combination of climatic, soil physical and soil chemical data from each site, the growth simulator predicts site potential in terms of a site index. Relatively small changes in site characteristics can have a profound effect on productivity (Figure 5).

Figure 5



E. globulus site productivity assessment for a typical farm

Productivity predictions coupled with expected growing costs and haul distance from the port are used to ensure that target costs of the project wood fibre (costs per bone dry unit free on board $/BDU FOB) are within specified limits.

Pinus pinaster

Soil factors which are most likely to affect *P. pinaster* survival and growth are related to soil water storage and salinity. For trees to establish successfully and grow in the 400mm – 600mm medium rainfall zone, soils must be non-saline, of adequate depth and have fresh water additions from seepage or groundwater (Harper, 1996).

Potential planting areas are assessed using aerial photography and land management units are identified by looking at landform and vegetation features. Soil sampling of different land management units (LMU) is then carried out using a hand-held auger in sandy soil, or a backhoe if necessary. Sampling intensity varies with changes in LMU, but a minimum of one observation hole every 25 hectares is required. For soil to be suitable for planting, depth of root-penetrable material must be 2-3m and white sandy soils (Munsell chromas < 3) are avoided. Sites with waterlogging, within 1m of the surface for more than two months of the year should not be planted.

Soil samples are taken (surface and at depth) to assess salinity, pH and nutrient content. Saline soils and soils with extreme alkalinity are avoided. A map comprising confident land management unit boundaries which show differences in drainage, depth of soil and texture is prepared. This, along with soil sample analysis is used to classify soils into a productivity rating for growing *P. pinaster.*

Pinus radiata

Land suitability criteria for *P. radiata* differ to those for *P. pinaster* in that *P. radiata* is less tolerant of waterlogged, infertile or drought prone sites. Planting is generally confined to areas with mean annual rainfall of >600 mm.

Tree Crop Establishment

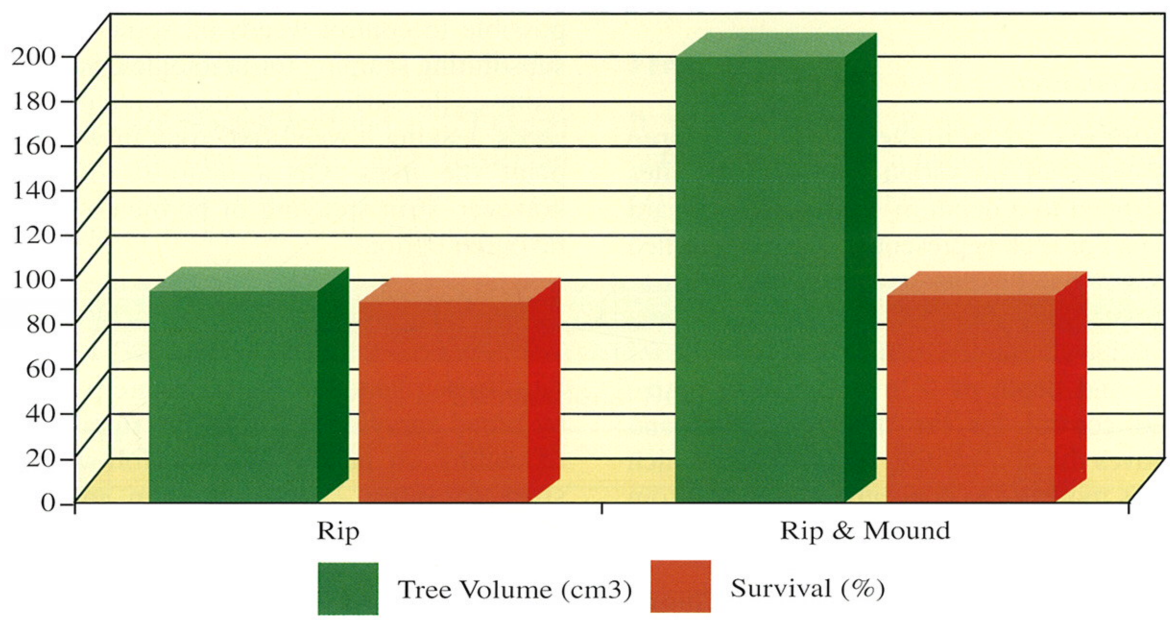
Eucalyptus globulus

The Western Australian climate is characterised by wet winters and long dry summers which result in an excess of moisture in winter and drought conditions in summer. The objective of site preparation is to improve tree survival and growth by improving soil characteristics by reducing the soil bulk density, releasing nutrients and improving absorption and soil moisture relations. Ripping is used widely on farmland soils because it improves tree growth through nitrification and moisture infiltration. Research has shown that advantages in ripping below 500mm exist only where there is a compacted clay or rock layer, and that mounding is beneficial over the rip lines on seasonally waterlogged sites. The rip and mound lines are aligned to drain excess water off the site. Nearly all sites are ripped and mounded, except when there is a risk of erosion. A combination of ripping and mounding improved tree volume over ripping alone (Ellis 1992, unpublished) (Figure 6).

One of the most vital components of successful *E. globulus* establishment on farmland, is control of weeds. Uncontrolled weeds or poor use of herbicide can markedly affect both survival and growth. Research has shown that the right combination of herbicides can improve survival from less than 50 per cent to over 90 per cent, and height can be increased by more than 50 per cent (Ellis, 1992). Target weed species are identified and an appropriate strategy is developed to provide for weed free conditions, adjacent to the trees, for the first year and preferably longer. Plantation areas are broadsprayed to control perennial weeds including sorrel, dock, kikuyu, couch and bracken. If the season permits, areas are broadsprayed prior to site preparation. Strip spraying no less than two weeks prior to planting is carried out using all-terrain motor bikes. This operation delivers knockdown herbicides to the planting lines as well as residual herbicides designed to achieve lasting weed control to the first summer. Second year weed control has been shown to increase tree volumes by up to 129 per cent on some sites and is standard practice (Figure 7).

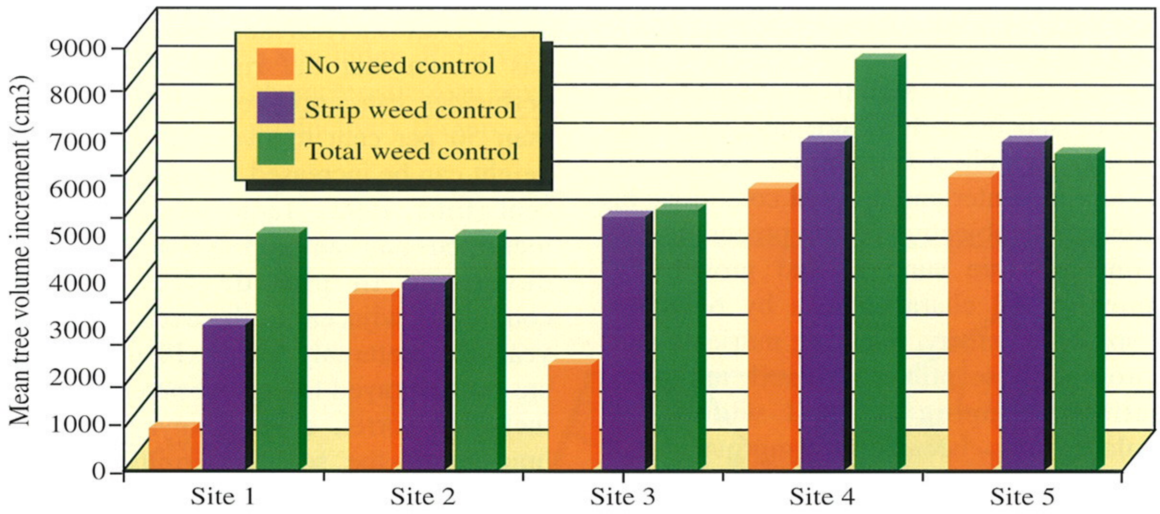
All seedlings are grown at CALM's Plant Propagation Centre are raised in 64 cell Kwikpots coated with a root inhibiting

Figure 6



Effect of site preparation on tree volume and survival of E. globulus after 9 months growth on a grey sand soil

Figure 7



Site 1 Quartz grit over sandy loam
Site 2 Deep leached sand
Site 3 Yellow sand over lateritic gravel
Site 4 Gravelly sandy loam over clay loam
Site 5 Sandy loam over clay loam

Response to second year weed control of E. globulus on different soils

paint designed to prevent root coiling within the container. Trials showed that seedlings grown in 64 cell Kwikpots can grow as well as, or better than, seedlings grown in twice the soil volume. Seedlings are top dressed in the nursery prior to field despatch to ensure rapid early growth of roots following planting.

Pinus pinaster

Strategies to achieve successful tree establishment are varied with site. All sites are ripped to a depth of 0.5m, unless a hard claypan or rock is present at depth (identified during the soil survey), when deep ripping to 0.9m may be required. On white sands of the Bassendean dunes, scalping to a width of 1.2m and depth of 0.3m provides effective weed control for the first two years and removes the non-wetting surface layer which allows moisture to concentrate at the bottom of the scalp line.

A combination of ripping and furrowlining on the yellow sands of the Spearwood dune system removes the non-wetting surface, but avoids any risk of erosion that may occur if scalping was used on these sites. Rich brown soils in the southern areas and any swampy sites are routinely ripped and mounded to remove the risk of waterlogging during winter.

In drier climates (<600mm rainfall), it is possible to control weeds on some sites by substituting scalping for herbicides. Scalping removes the surface layer that contains weed seeds, leaving a weed free zone in which to plant the trees. On a majority of sites, however, strip spraying of herbicides is the favoured option.

Pinus radiata

Sites to be planted to *P. radiata* are prepared by broad spraying of herbicide, ripping and mounding on nearly all sites, followed by strip spraying. Sites are then machine planted at 1 515stems per hectare (sph) (spacing of 3m x 2.2m) except on very rough areas where hand planting is done. Trees are not fertilised at planting because research has shown that fertiliser responses are minimal on ex-pasture sites. Foliar analysis is carried out every year to determine when extra nutrition is required, and fertilising is based on this. Weed control by strip spraying is carried out in the second year.

Silviculture

Pinus radiata

The silvicultural regime for *Pinus radiata* tree crops is shown in Table 3.

There are two thinnings at 12 and 24 years yielding mainly industrial wood and small sawlogs. Fertilising is planned for immediately after these thinnings so that the remaining crowns can quickly use the additional space created from the thinning. Clearfall occurs at approximately 30 years of age.

Pruning is only done on trees in the outside rows to allow access for fire control. The initial stocking of 1 500sph keeps branch sizes to a minimum. Grazing by rabbits can be a problem, but is controlled by baiting with 1080 oats. New plantations are surveyed for insect attack (particularly by wingless grasshopper and budworm) every week over summer, and if insects are detected, the plantation is sprayed with insecticide.

Eucalyptus. globulus

Seedlings are planted by hand at 1 200 sph (spacing of 4m x 2m), and fertilised according to the requirements of the site. Monitoring of insects is carried out on a weekly basis during summer, and insecticides are used where required. The main insects of concern in the first year are wingless grasshopper and spring beetle. After the first summer, CALM relies on the landowner to check for insect activity.

Second year weed control is undertaken on all *E. globulus* plantations. Maintenance fertilising is carried out as required. Foliar analysis is the preferred way of deciding how much and what type of fertiliser to use.

Plantations will be clearfelled at between six and 14 years of age depending on growth rates and wood flow requirements. The second rotation may be either a coppice rotation, or if genetic gains are large enough, it may be economic to replant with genetically improved stock.

Pinus pinaster

Two regimes have been determined for the maritime pine project. A conventional regime over a 30-year period (Table 4) and one which involves only one thinning and clearfall at 25 years (Table 5). The second regime is particularly aimed at farmers wanting multiple benefits from maritime pine, because it is suitable to narrow belts which produce timber while also providing shelter and controlling wind erosion.

Fertilisation

It was recognised at an early stage that nutrient supply was a major limitation to the productivity of plantations in southern Western Australia. The failure of early

Table 3

Conventional Regime

Year	Action	Product
0	plant 1500sph	
12	thin to 800sph fertilise	industrial wood
24	thin to 300sph fertilise	small sawlogs & industrial wood
30	clearfall	small & large sawlogs

Table 4		
Conventional Regime		
Year	Action	Product
0	plant 1500 – 1800 seedlings per hectare	
12-14	thin to 450 sph	industrial wood
20-22	thin to 150 sph	small sawlogs
30	clearfall	sawlogs & peeler logs

Table 5		
Single Thinning Regime		
Year	Action	Product
0	plant 1500 – 1800 seedlings per hectare	
12	thin to 150 sph	industrial wood
	prune to 6m	
25	clearfall	sawlogs, peelers & industrial wood

plantings were shown to be caused by deficiencies of phosphorus and zinc (Stoate 1950). These findings led to the recommended use of phosphate and zinc at establishment. During this period pine planting was confined to those sites which had greater than 300 ppm P_2O_5 "extractable in strong hydrochloric acid" and preferably 400 ppm (Stoate 1950). Even up until the 1970s only sites with HCl extractable P205 of 250 ppm (approximately 100 ppm P) were accepted for establishing *P. radiata* plantations.

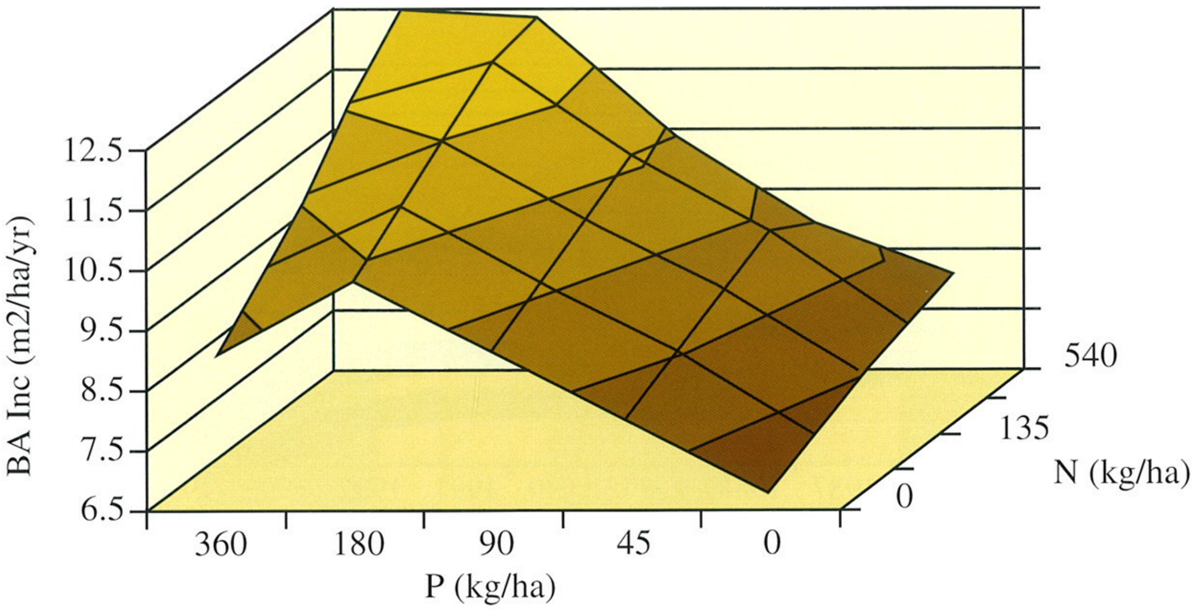
It was recognised in the early 1970s that the use of fertiliser could extend the range of soils suitable for pine plantations, and that further applications of fertiliser were required on certain sites to maintain the growth of pines. However, apart from the initial fertilisation at establishment little fertilisation of plantations was carried out.

The expansion of *P. radiata* plantations onto ex native forest sites in the Donnybrook Sunklands, the need to increase the productivity of existing plantations to meet contractual agreements and more recently the move to establish tree crops on farmlands which had been receiving decades of regular fertiliser led to a major expansion of fertiliser research in the late 1970s. Fertiliser regimes for the three key species are still being developed but use of fertiliser to improve productivity has been exploited whenever research trials have demonstrated an economic response.

Pinus radiata

Fertilisation following thinning has increased volume increments of P. radiata by between 50 to 75 per cent on a range of sites. Following the application of phosphorus and nitrogen in combination on a deep loam soil on cleared native forest with 1100 mm rainfall, growth was increased by 75 per cent in the first four years after fertilisation (Figure 8). Partitioning the response between

Figure 8



Basal area response to Nitrogen and Phosphorus over four years after fertilization

nitrogen and phosphorus in this trial over ten years showed a long lasting response to phosphorus and a substantial, but short lived response to nitrogen (Figure 9). In the first four years after fertilisation phosphorus accounted for about two-thirds of the response while nitrogen accounted for the remaining one-third. After the first four years only phosphorus had a significant influence on basal area and volume growth. Optimum applications of nitrogen and phosphorus produced an extra 119 m^3ha^{-1} over the decade following fertilisation. (McGrath pers. comm.).

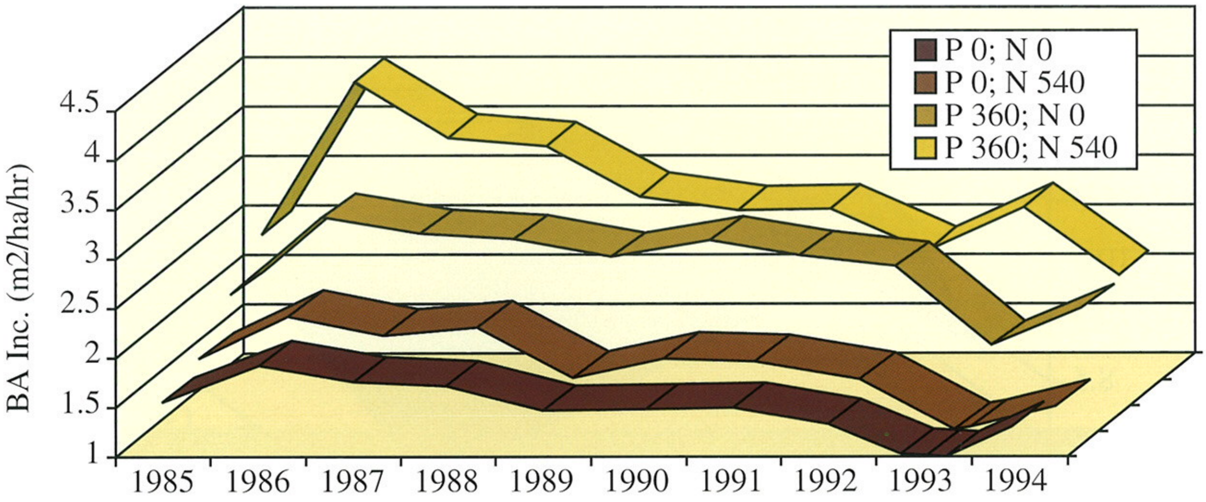
On deep sand dunes the response to fertiliser was less than on the loam soils relative to *P. pinaster.* The increase in volume increment in *P. radiata* was 45 per cent at 250 stems ha^{-1} declining to 12 per cent at 750 stems ha^{-1} (Figure 10).

The preliminary results from trials using optimum establishment, silvicultural and fertiliser regimes suggest that there is the potential to improve productivity of *P. radiata* and *P. pinaster* significantly. For example, trials in young radiata plantations using optimum establishment techniques and repeated fertiliser applications have shown volume production of nearly 300 m^3ha^{-1} in the first ten years of a rotation, and current annual increments of 50 m^3ha^{-1} between age nine and 11. This has occurred on sites that would fail to produce a crop of trees without fertilisation. (McGrath pers. comm.).

Pinus pinaster

The major limitation to the growth of the pinaster plantations north and east of Perth appears to be the availability of water during summer. Unthinned plantations use all the available soil moisture during spring and then cease growing, while thinned plantations deplete the available water more slowly and continue growing during summer. Butcher (1977) demonstrated that it took the whole summer for trees at a basal area of 7 m^3ha^{-1} to use all the available soil water, while in stands at a basal area of 25 m^3ha^{-1}, soil water was exhausted by early summer. Stands at the higher densities did not respond to fertilisation whereas thinned stands did respond to fertilisation. Trials have shown that basal area responses to phosphorus in thinned plantations are in the order of 30 to 50 per cent. On these sites further responses to nitrogen were either small and ephemeral or non existent (Hopkins and Butcher unpublished).

Figure 9



Basal area response to Nitrogen and Phosphorus application by thinned P. radiata

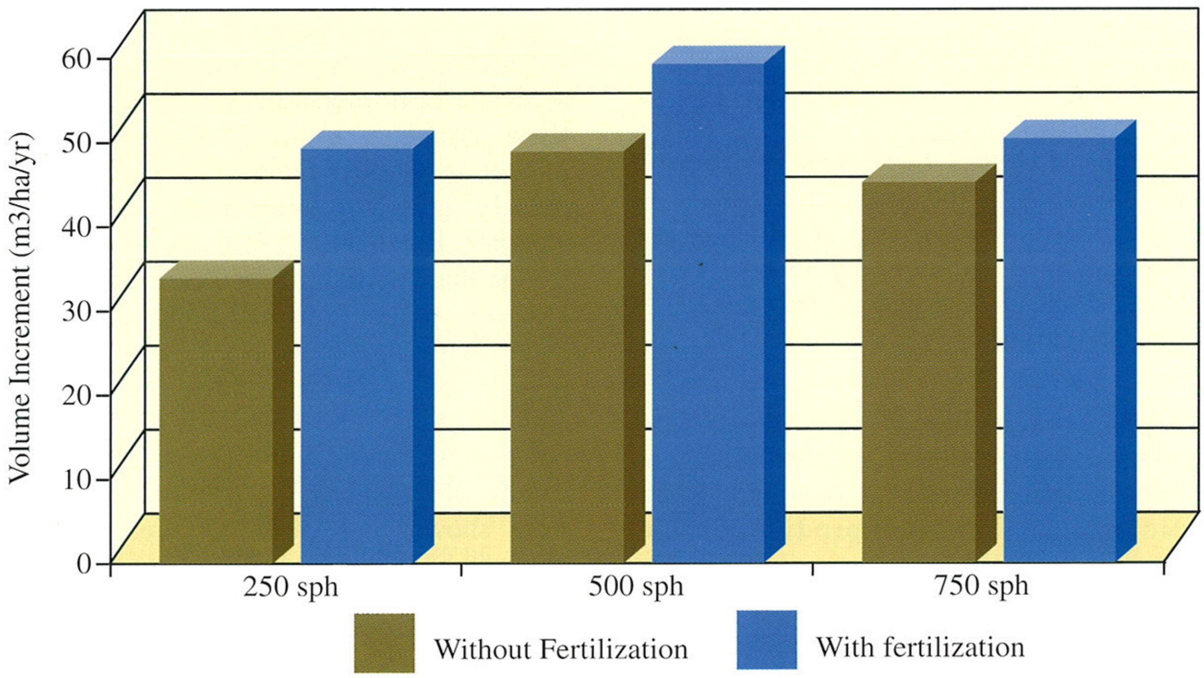
In higher (>800 mm) *P. pinaster* growing on deep sand dunes has exhibited a marked response to fertiliser application particularly at lower stockings (Figure 11) at 250 stems ha^{-1}, fertilisation almost doubled volume increment, at 500 stems ha^{-1} there was a 60 per cent increase and at 750 stems ha^{-1} there was a 44 per cent increase.

Given comparable silvicultural treatment (thinning and fertilisation) *P. pinaster* appears able to produce similar stem volumes as *P. radiata,* at least in an environment where growth is limited by summer water deficits. Thus the potential wood production from *P. pinaster* may be greater than has been envisaged in the past.

Eucalyptus globulus

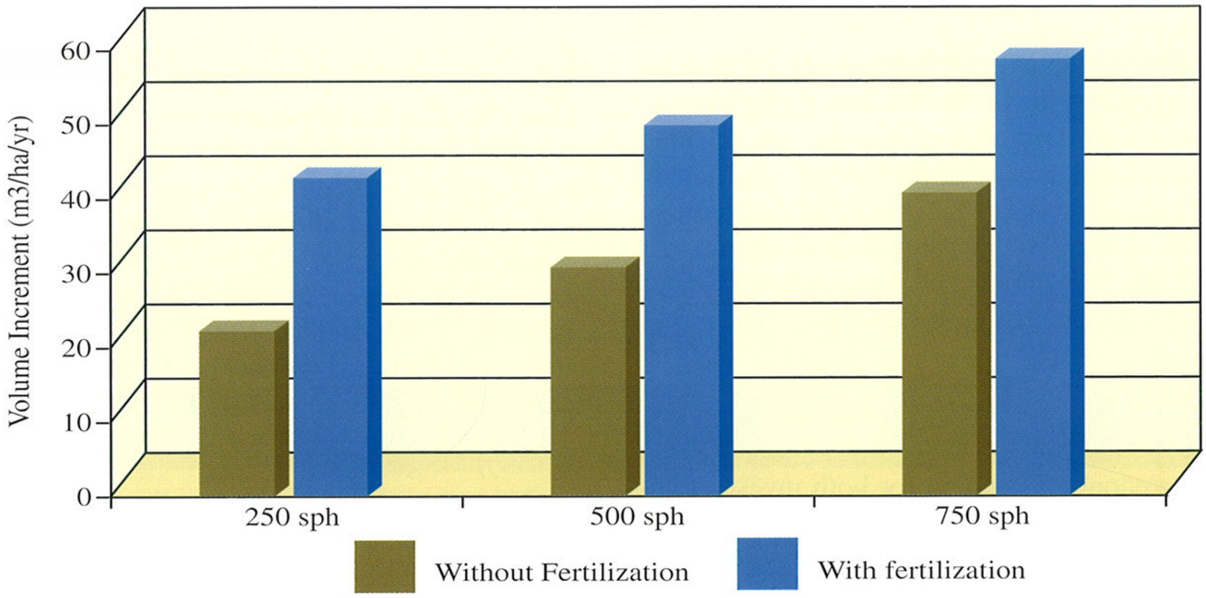
Unlike fertilisation on cleared native forest sites where responses to many nutrients

Figure 10



3 year P. radiata volume increment (m^3ha^{-1})

Figure 11

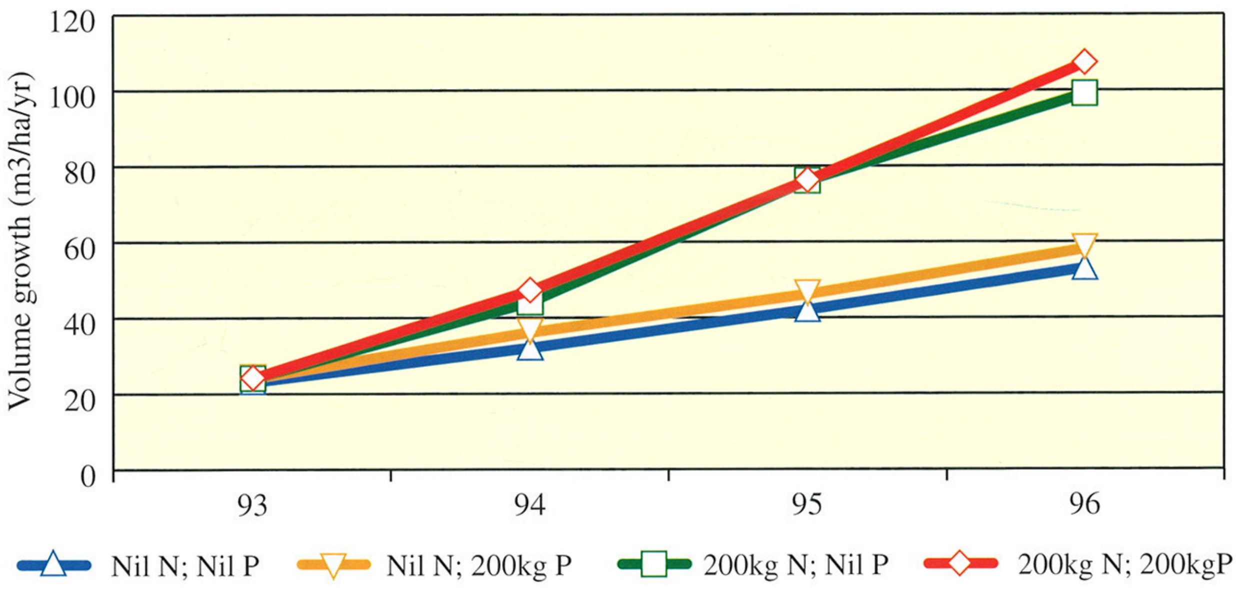


3 year P. pinaster volume increment (m^3ha^{-1})

occur, fertilisation of *E. globulus* tree crops growing on farmland has not generally produced large responses. Virtually no responses to phosphorus have been recorded. The exception is the response to the application of nitrogen on some light textured soils in the higher rainfall zones, which has produced some spectacular increases in growth. These responses appear to last for some years and have resulted in a doubling of growth on some sites (Figure 12).

The lack of response to phosphorus application on farmland sites is consistent with the long lasting responses to phosphorus fertilisation on a range of soils by *P. radiata*. The residual activity of phosphorus applied to annual crops and pastures appears to be sufficient to supply the

Figure 12



Volume growth by E. globulus following fertilization requirements of tree crops for at least a considerable part of the tree rotation.

Although nutrient supply is less likely to limit tree growth on farmland, responses to both nitrogen and potassium have been found on some sites in the early part of the rotation for both *P. radiata* and *E. globulus*. This suggests that substantial responses to fertilisation may occur later in the rotation or in subsequent rotations on these sites.

The Economic Return from Tree Crops

The economic returns for both investors and landowners varies with distance from port or factory, land productivity, costs of establishment and management and market price. Estimated average returns for investors and landowners are set out below for each of the major species.

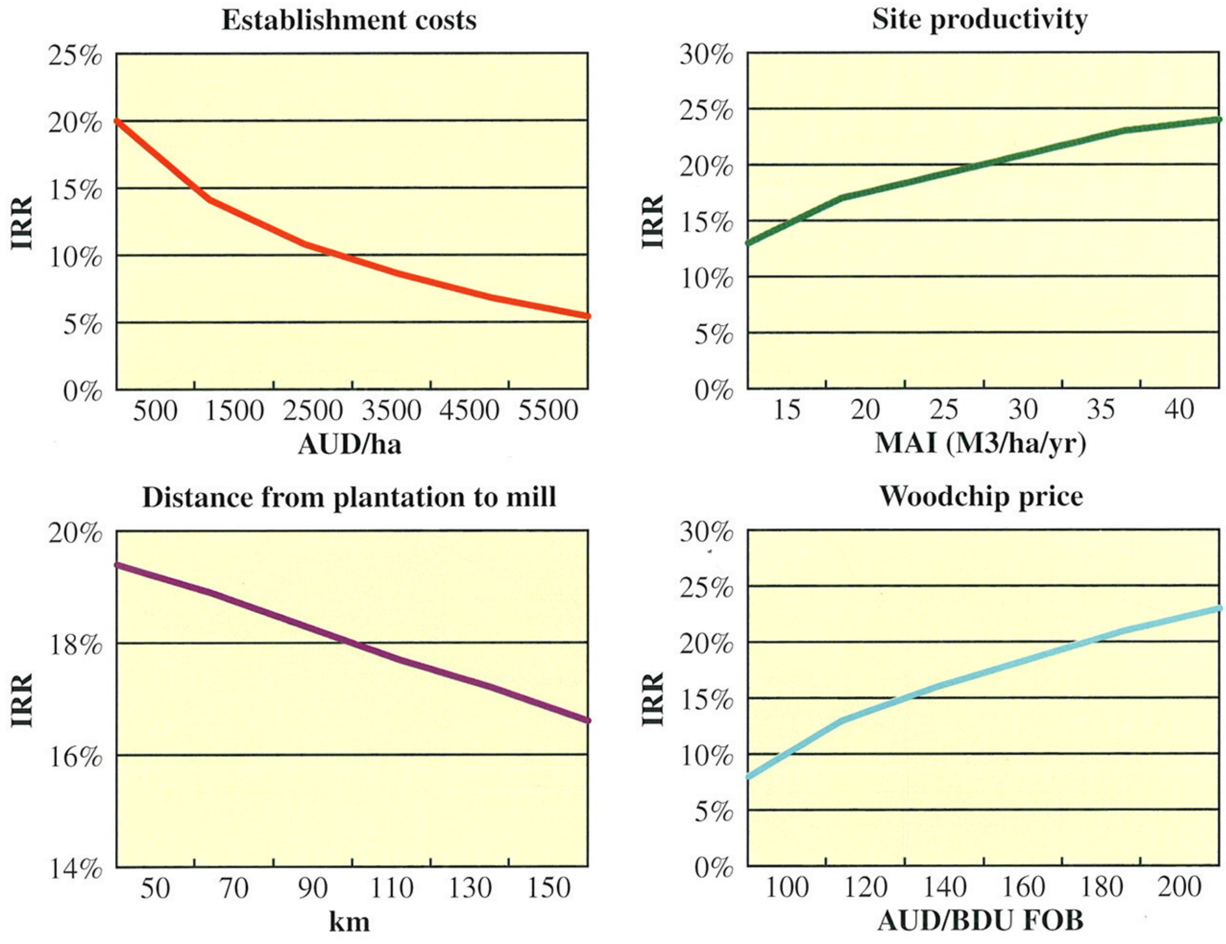
Pinus radiata

At the current land costs and prices for *P. radiata* sawlogs in Western Australia internal rates of return on this species are likely to be less than four per cent (Shea *et al* 1994). *P. radiata* as similar site requirements to *E. globulus* which has higher growth rates and shorter rotation length. It would be necessary for annual land rental costs to decrease to less than $100 per hectare if real rates of return for P. radiata tree crops were to rise above six per cent.

Eucalyptus globulus

Real rates of return for investors in *E. globulus* tree crops exceed 12 per cent at current market prices for wood fibre (Shea *et al* 1994) (Figure 13). Landowners are currently receiving between $120-$250 per hectare per annum.

Figure 13



Sensitivity of profitability for E. globulus
IRR (real)

Pinus Pinaster

Currently no schemes involving annuity payments are being offered for *P. pinaster* tree crops. The estimated return for investors and landowners at different log prices and probability levels are set out below. (Tables 6, 7 and 8).

Mallee eucalypts

A preliminary economic analysis was undertaken of the potential economic returns from mallee eucalypts by Bartle *et al* (1996). The analysis was based on a ten per cent planting of a typical wheatbelt farm in an alley-farming layout. All costs and benefits over a 20-year term were converted to net present value at a discount rate of 6.5 per cent. A halving of the rate of expansion in salinity was incorporated into the analysis. The analysis showed no reduction in net present value at an oil price of $2.65 per kilo, well below prevailing market prices, but

Table 6

Returns per hectare in 1997 dollars to an investor from maritime pine growing at 12 m3 per hectare per year under a 70:30 crop-share agreement

Year	Yield (m^3ha^{-1})	Investor $/ha (70% share)	Landowner $/ha (30% share)
12 (1st thin)	75	$715	$317
22 (2nd thin)	90	$1 394	$608
30 (Clearfall))	190	$4 832	$2 081

Table 7

IRR to an investor for various growth rates and increases in stumpage under a conventional regime of 30 years

	Internal rate of return to investor(%)	
Increase in stumpage (%)	**$12m^3ha^{-1}yr^{-1}$**	**$16m^3ha^{-1}yr^{-1}$**
0	4.9	6.5
25	6.0	7.7
50	7.0	8.7

Table 8

IRR to an investor for various growth rates and increases in stumpage under a single thinning regime of 25 years

	Internal rate of return to investor	
Increase in stumpage (%)	**$10m^3ha^{-1}yr^{-1}$**	**$14m^3ha^{-1}yr^{-1}$**
0	5.2	7.4
25	6.5	8.7
50	7.6	9.7

probably too great for rapid penetration of solvent markets. However, it also showed that net present value could be significantly improved by increased leaf oil content and reduced processing costs. Preliminary studies showed that both these factors can be significantly improved.

Pinus radiata Sharefarming

Approximately 7 000 hectares of *P. radiata* tree crops were established in the lower south-west and in the Albany region over the period 1987-1992. This program was funded by the State Government from capital borrowings. The program was phased out because of the shortage of capital funds and the difficulties of obtaining land because of competition from *E. globulus* tree crops.

The Bluegum Project

Eucalyptus globulus had been established in trial plots throughout the south-west of Western Australia since the 1960s. But it was not until 1980 that small operational plantings were commenced by the Western Australian Chip and Pulp Company (WACAP), (the major exporter of native woodchips from Western Australia) who foresaw the potential to supplement the native forest woodchip exports with high quality plantation grown *E. globulus* (Oldham pers. comm.). In the mid 1980s a proposal was made to establish a *E. globulus* estate on farmlands in the southern coastal region of Western Australia centred on Albany (McLean pers. comm.). But this was rejected by the Environmental Protection Authority principally because it was proposed to fund the plantations from the sale of woodchips derived from remnant vegetation on private farmland.

In 1989 the senior author approached the two major sawmilling companies in Western Australia (Bunnings and Western Australian Forest Industries) with a proposal to seek funds to establish a large commercial *E. globulus* (bluegum) tree crop estate on farmlands to assist land rehabilitation. The Western Australian Government subsequently approved the formation of a consortium consisting of CALM and the two private companies to investigate the potential of obtaining funds for tree planting on agricultural land. The proposal became known as "Tree Trust". Consultants were employed, and over a period of several months legal and financial vehicles were developed. But all attempts to induce the institutional funds and other potential investors to commit to the Tree Trust project failed and the consortium was dissolved in June 1990.

One of the participants in the consortium, Bunnings, decided to investigate the potential to raise funds for tree planting by forming a prospectus company. The first Tasmanian Bluegum prospectus was launched in 1990 and was only partially successful. The 1993 prospectus was withdrawn. By 1994, however, a number of companies were successful in raising funds for these bluegum plantings by public subscriptions.

Following the failure of "Tree Trust" CALM, on the advice of New Zealand forestry consultants (Groome Poyry), sought investment in the tree crops on farmland project from the major importers of fibre in the world – the Japanese pulp and paper companies. In 1989 the first of approximately 30 delegations of representatives of the Japanese pulp and paper industry visited Western Australia to examine the proposal in the field.

It soon became apparent that although the bluegum project was appealing to investors from either Australia or overseas, it required more than trial plots before they would commit funds. Consequently, CALM undertook an extensive planting program funded by loan funds. In the period 1988 to 1994, 8 000 hectares of *E. globulus* were established by CALM on farms throughout the south-west of the State using the sharefarming concept that had been developed for *P. radiata* tree crops in the mid1980s.

The fact that the Government was prepared to commit significant funding to establish tree crops on farms, the willingness of farmers to participate in the scheme and the overall success of the plantings resulted in major overseas companies agreeing to invest in the project.

Over the period from 1993-1995 CALM signed agreements to undertake the establishment and management of a total of 40 000 hectares of *E. globulus* on farmlands over a ten-year period with two groups of Japanese companies and a Korean company (Albany Plantation Forest Company of Australia Pty Ltd – a consortium of Oji Paper Company Ltd, Itochu Corporation and Senshukai Company Ltd; Bunbury Tree Farms – a consortium of Mitsui Plantation Development (Australia) Pty Ltd, Nippon Paper Company and MCA Afforestation Pty Ltd; Hansol Australia Pty Ltd. Subsequently the area has been increased to 60 000 hectares.

Each agreement is backed by an Agreement Act passed by the State Parliament and a legally binding contract with CALM.

The area of bluegum established by CALM with government funding and on behalf of the overseas companies is shown in Table 7.

The participation of large overseas companies who are end-users of high quality wood fibre for the production of pulp and paper has, in part, been responsible for a major increase in investment in bluegum by private companies in Western Australia. In 1997 it is estimated that 20 000 hectares of bluegums will be established on farmlands in south-west Western Australia.

Case Study: Potter's Farm

The way in which tree crops can be integrated into a farming system is best illustrated by the following case study. In November 1993 at a weekend local show the Potter family approached CALM to integrate a commercial tree crop into their existing farm (Figure 14).

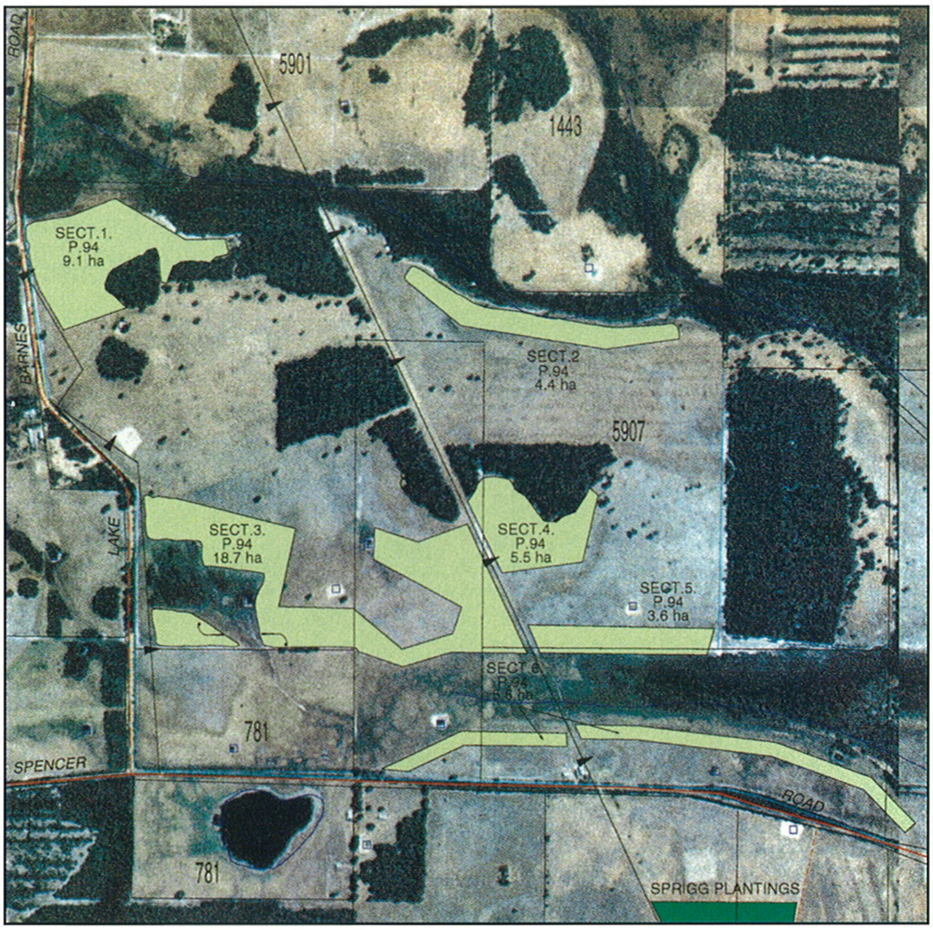
The process of tree crop layout and farm planning differs with every landowner depending on their objectives, what pre-planning has been done and the willingness of both parties to undertake farm redesign. Their objectives were -

Table 9

Annual area of *E. globulus* planted by CALM in sharefarm arrangements with landowners and investors.

	***E. globulus* area planted (ha)**				
Year	**CALM funded**	**APFL**	**Hansol**	**Bunbury Treefarm Project**	**Total**
< 1988	55				55
1988	1 555				1 555
1989	2 982				2 982
1990	743				743
1991	683				683
1992	1 009				1 009
1993	350	1 000	430		1 780
1994	79	984	780		1 843
1995	3	2 690	860		3 553
1996	–	3 021	2 250	1 050	6 321
Total	7 459	7 695	4 320	1 050	20 524

Figure 14



Case study – map of Potters farm

- Improved aesthetics – the farm appeared very run-down from the southern boundary road.

- Nutrient loss – land management units were separated to address differing abilities to bind or lose nutrients into surrounding drainage systems.

- Shelter – the southern half of the farm exposed to poor winter weather conditions had little remaining protection for both stock and crops.

- Salinity – areas of saline groundwater were appearing as both hillside seeps and watercourse baseflow.

- Management units – current design was on a north-south and east-west basis, with no heed paid to landform and soil productivity within those landforms.

- Remnant vegetation decline – none of the remnant native vegetation was protected from stock, and thus would inevitably decline.

- To carry out all the above at minimal cost to the landowner and preferably with a return from the tree crops equal to the agricultural crops they replaced.

The first part of the planning process involved identifying and mapping the different land types using aerial photography followed by on-farm proofing. Land types were identified as -

- Broad waterlogged flats – a large area dissecting the southern end of the farm in an east-west direction, also the north-west corner. Problems here included potential nutrient loss, increasing groundwater pressures and soil structure decline.

- Sandy gullies – areas leading onto the waterlogged flats. Here again was potential for nutrient loss, inconsistent crop and pasture growth and recharge areas for flats. There were two hillside seeps identified, one saline, the other at risk.

- Lateritic ridges and slopes – the most productive land for grazing, cropping and trees. Able to lock up nutrients on site and little risk of erosion or salinity. Waterlogging on the flats came from these ridges, due to the unhindered runoff.

- Deep sands – an area in the north-west corner above the waterlogged flat.

- Natural drainage lines – two drainage lines, one in the north-east corner, one in the south-east corner. Both are small catchments within the Sleeman Creek subcatchment of the Hay River, and both required protection.

The cleared land was surveyed to determine productivity, depth of soil profile and salinity profile to 1.2m. Productivity was determined using a eucalyptus growth simulator (see above) which predicted growth rates were approximately $25m^3an^{-1}$ per annum. Soil profiles were determined to a depth of 2m using a truck mounted drill rig with 100mm augers. The salinity profile was determined using EM38 conductivity metre.

In deciding where to place commercial trees in an integrated farm plan, a balance between growth rates and land care benefits is required. Section 1, an area of deep sand, produces poor pasture, is susceptible to erosion and due to its position in the landscape and the soil type leaks nutrients. Although it is a relatively poor site for commercial trees, the landcare benefits of planting there are substantial. Sections 3 and 4 are similar. Two areas of seepage on the hillside have been addressed and the nutrient runoff and recharge onto the waterlogged flats will be reduced. Care was taken here to maintain as much of the lateritic soil type for pasture as it provided sheltered grazing and cropping.

Sections 2, 5 and 6 meet landcare objectives, as well as being better areas for wood production. Remnant vegetation on the watercourse in the north-east corner was protected in section 2, by strategic planting which also serves as a nutrient filter for fertilisers spread upslope on the adjacent paddock. Sections 5 and 6 are planted on productive soils at the base of lateritic ridges and slopes. These trees clearly define the border between two landforms, an area of broad waterlogged flats, and serve as nutrient filters as well as reducing the amount of recharge onto the waterlogged areas and providing stock and crop protection.

The Potter family chose a full crop share option, that is, a lump sum payment at harvest.

The parameters used to calculate the return to the landowners were:

MAI ($m^3ha^{-1}an^{-1}$)	25
Stems per hectare	1 250
Net area (ha)	41.6
Haulage distance (km)	37
On farm stumpage ($\$/m^3$)	30.99
Farmer share (as per landowner/investor inputs)	35.25%

The predicted harvest return for the Potters at years ten and 20 based on 1994 dollars was $113 623 at each harvest.

Part of the investor input was an allowance for fencing of $70/ha available as a direct payment to the landowner on receipt of evidence of materials purchased.

Maritime *(Pinus pinaster)* Pine Project

In 1986 the Western Australian Government endorsed a CALM proposal for a major expansion of the tree crop industry into the intermediate rainfall areas of the State and selected catchments on the coastal plain.

The maritime pine project is a significant component of the government's salinity strategy (Agriculture WA *et al* 1996). The intermediate rainfall zone in the State makes its disproportionate contribution to the salinity problem because of its relatively high winter rainfall surpluses, high salt loads and broad valley systems (Figure 3). It is also important to establish tree crops on sandy soils on the coastal plain in key catchments to ameliorate the impact of excess fertiliser discharge into the river and estuary systems from agriculture.

The maritime pine project also aims to capitalise on the increasing demand for softwood wood fibre in Pacific Rim countries. Competition for land from intensive agriculture and the rapidly expanding bluegum industry makes it unlikely that it will be possible to establish significant additional areas of *P. radiata* in the south-west of the State in the future.

Maritime pine has a much greater capacity to tolerate soil water deficits than either *E. globulus* or *P. radiata* and in trial plots it has achieved respectable growth rates in areas with 400 mm of annual rainfall. *P. pinaster* can potentially grow as fast as *P. radiata,* provided there is adequate nutrient levels, on sites where water availability appears to be limiting. (McGrath pers. comm.).

Land in the 400-600 mm rainfall zone and on the Swan Coastal Plain north and south of Perth have been analysed for their suitability for *P. pinaster.* This area contains 5.8 million hectares of cleared farmland within 150 kilometres of potential processing sites. The soil factors most likely to affect *P. pinaster* survival and growth in this environment are related to soil water storage and salinity. Thus regional soil and landscape mapping (Northcote *et al* 1967) was used to determine the area extent and location of deep, non-waterlogged and non-saline soils. An area of three million hectares was identified. Trees will be integrated with farming in belts or blocks and occupy no more than 20 per cent of farms, resulting in a potential area of 0.6 million hectares which potentially can be used to establish *P. pinaster* tree crops (Figure 15).

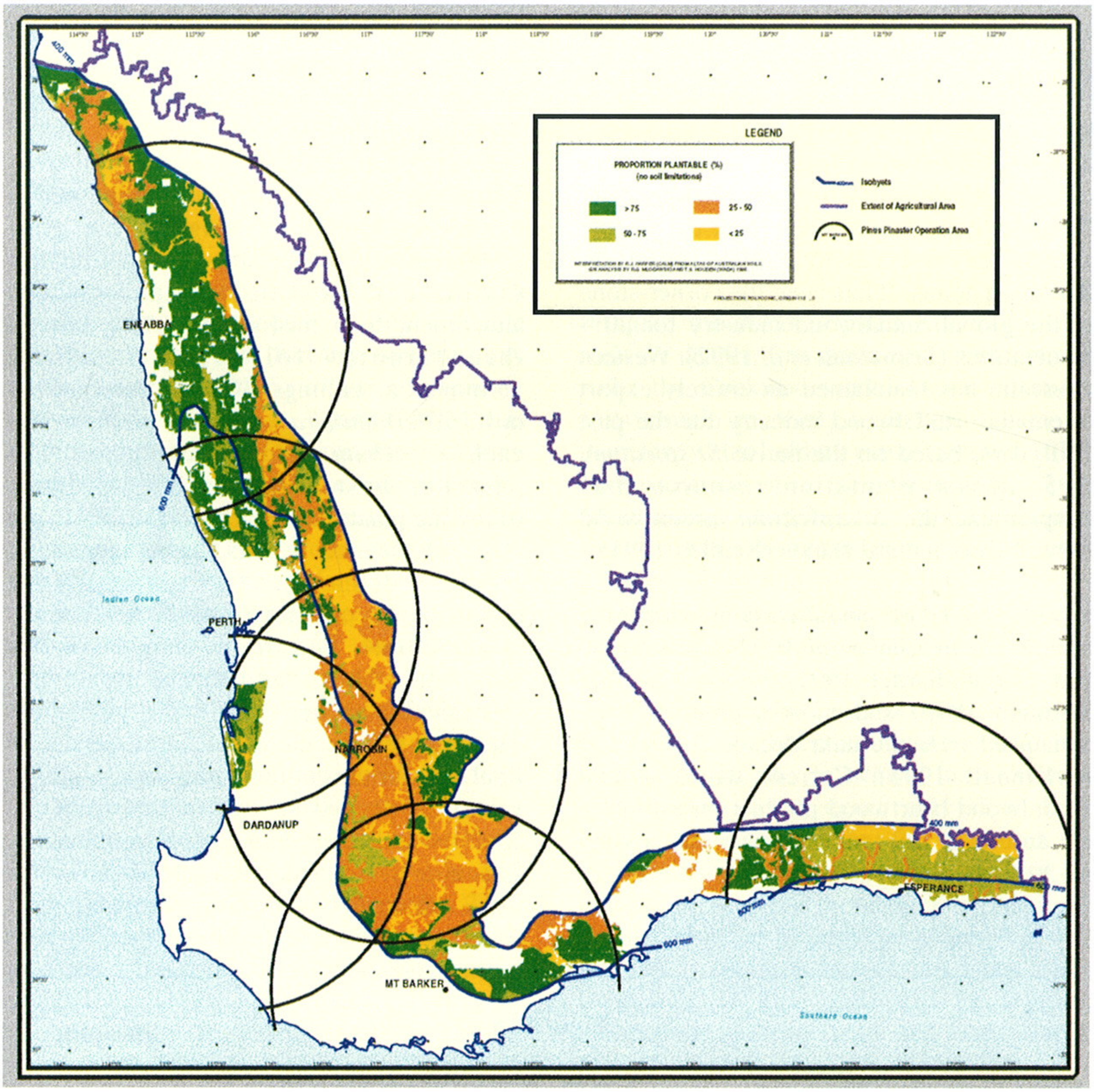
Maritime pine has already been planted extensively in Western Australia and 30 000 cubic metres of maritime pine sawlogs are harvested for packaging and structural products and 90 000 cubic metres of wood is used annually to produce medium density fibreboard and particleboard in Western Australian factories.

While productivity of *P. pinaster* is significantly less than that achieved by *P. radiata* and *E. globulus,* land costs and establishment costs for maritime pine are significantly lower than these species. Thus rates of return for maritime pine tree crops, although less than those achieved for *E. globulus,* are comparable to *P. radiata.*

The maritime pine tree crop industry is at a similar stage of development to *E. globulus* was in the mid-1980s. Currently there is very little private establishment of tree crops in the target areas described above by either farmers or investors. Accordingly, the Government has endorsed a proposal for CALM to establish 150 000 hectares of *P. pinaster* in partnership with private landowners over the next ten years on coastal plain sands and in the intermediate rainfall zone to demonstrate to the private sector the capacity for the commercial viability of this species. As part of the decision to establish maritime pine as a tree crop, the Government has decided to cease planting on Government-owned land north of Perth where the majority of existing *P. pinaster* plantations are established and progressively convert that 50 000 hectare area into a conservation reserve over a period of 20 years. The decision is in part as a consequence of the fact that there is increasing conflict between intensive plantation development and exploitation of a groundwater mound located under the plantations. Catchment managers require that existing plantations be thinned to sub-optimum levels to ensure recharge of the groundwater aquifer and there are increasing constraints on the use of herbicides and fertiliser.

The maritime pine project will be funded by CALM from profits derived from commercial plantation activities and by the sale of assets, including land purchased to establish *P. radiata, P. pinaster* and *E. globulus* plantations in the 1970s and 1980s. Maritime pine plantings will be supplemented with commercial and non-commercial plantings of native species,

Figure 15



Land availability in the itnermediate rainfall zone for maritime pine

including *Santalum spicatum* (Western Australian native sandalwood).

The first 700 hectares of P. pinaster tree crops were established on farms in 1996 and in 1997 this has been increased to 2 000 hectares, with the objective of achieving an annual rate of 15 000 hectares by the year 2000.

Tree Crops on Irrigation Land

The investigation into the potential for irrigated tropical forestry in northern Western Australia is possible by an immense (980 – 1050 km^2) man-made body of water, Lake Argyle, 50 kilometres south of Kununurra. Water, entirely gravity fed, irrigates 13 000 hectares of agricultural land, known as the Ord River Irrigation Area (ORIA). It is proposed to expand the irrigated area to 70 000 hectares (Government of Western Australia 1996).

A new and innovative CALM silvicultural research program in northern Western Australia has resulted in the development of an intensive tree crop silvicultural system for *Santalum album* (Indian sandalwood) (Radomiljac in press). There is also the potential to develop tropical tree crops on irrigated land.

Sandalwood as a tree crop

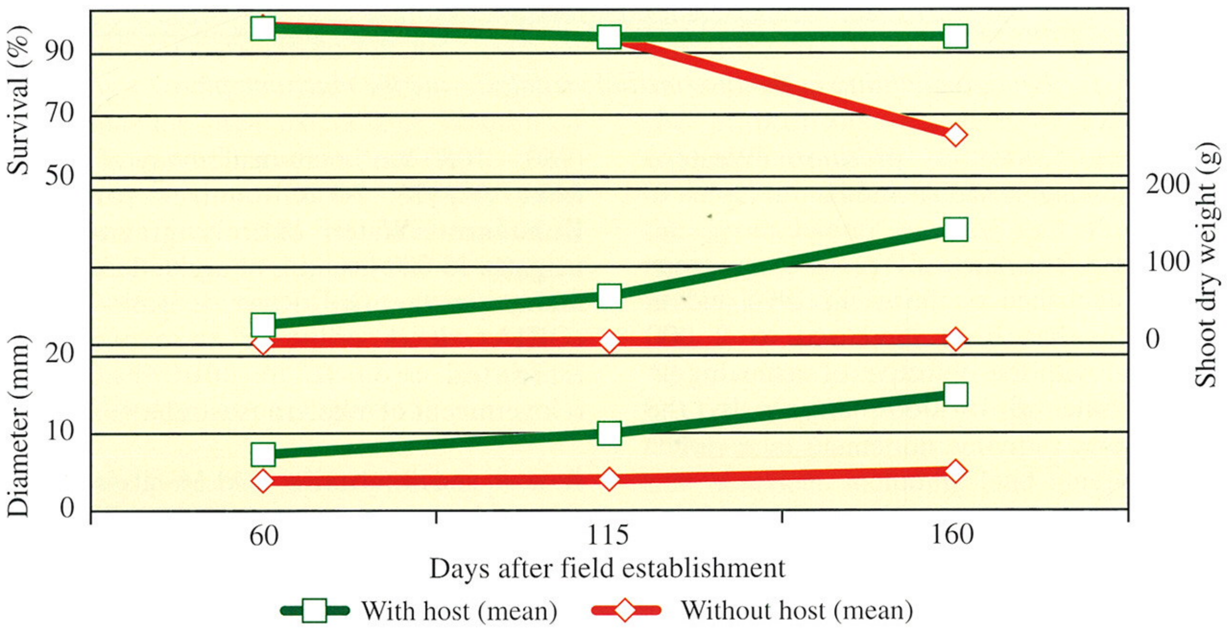
Due to the high heartwood santolol oil content, diverse utilisation and inherent religious significance, Indian sandalwood is the most important species from the widely distributed and economically important *Santalum* genus. It has been the corner-stone of the global sandalwood industry for 20 – 30 centuries (Srinivasan *et al* 1992). Western Australia has maintained an entirely export orientated sandalwood industry for the past 150 years, based on the native *S. spicatum*. A *S. album* plantation resource may supplement the *S. spicatum* green-wood harvest from natural stands (Kealley 1991).

World sources of sandalwood are declining rapidly (Srinivasan *et al* 1992, Harisetijono and Suriamihardja 1991, Radomiljac and Borough 1995) and most sources will be exhausted over the next decade (Havel and McKinnell 1993). Current world annual sandalwood heartwood production estimates are around 5 100 tonnes. Assuming, a yield of 20 tonnes ha^{-1} with a rotation length of 25 years, a plantation resource of around 6 400 hectares is required to meet current global sandalwood consumption.

A biodiverse farm forestry system appears possible due to *S. album's* parasitic silvicultural requirement for a series of host species. A range of species is required to perform as hosts throughout the plantation rotation.

Initially, *S. album* is propagated from seed in nursery containers. Although it can grow photo-autotrophically for several months, vigour and growth decline without attachment to a host (Figure 16). Two to three months following *S. album* germination, cuttings of a herbaceous pot host, *Alternanthera* spp, are planted into each *S. album* seedling container. The parasite: host combination continues following plantation establishment. Early pot host senescence results from increasing parasite demands. The simultaneous establishment of other host species, termed intermediate and long term-hosts, is essential. These additional hosts are strategically planted within the plantation. The long-term host, which must persist as final host for the entire rotation length (25-30 years), is planted several metres from the *S. album* and *Alternanthera* spp combination. This is to avoid obstruction of the growth of the *S. album* as both *S. album* and long-term host have large crowns. An intermediate host is therefore required to bridge the pot host

Figure 16



Sandalwood growth and vigour with and without attachment to host and the long-term hosts, a period of two to five years. CALM research has found that ideal intermediate hosts are fast growing, short lived leguminous trees. Once parasitism is initiated *S. album* remains highly heterotrophic and this sequence of hosts is required to maintain high plantation productivity.

Rather than considering *S. album's* parasitic requirements an impediment to plantation development, a potentially highly valuable and biodiverse farm forestry system may arise as a result of *S. album's* enigmatic heterotrophic existence. Thus, CALM has conducted research on the suitability of long term host species based on several principles (i) host: parasite compatibility, (ii) bio-climatic matching, (iii) flood irrigation and site suitability, (iv) market familiarity and (v) declining global supply, inherent utilisation and strong market demand. Most tropical forests are exposed to considerable over-exploitation and other adverse land uses which have resulted in the declining supply of high-valued tropical timbers (Evans 1986) whilst market demand remains strong.

Long-term host species that produce a valuable timber may offer the potential for two or more timber products from one plantation system. Thus, CALM is increasing plantation viability and product diversity by complimenting S. album plantation mixed species dynamics. Successful species introductions to date include the CITES listed *Swietenia macrophylla* (Brazilian mahogany), *S. mahogani* (Cuban mahogany) and *Dalbergia melanoxylon* (East African Ebony).

Coupled with the obvious commercial benefits, CALM's *S. album* farm forestry system also offers a seemingly cost effective method to control the early onset of rising water tables within the ORIA. Most irrigated agricultural systems inevitably lead to rising groundwater table levels. Even though, at present the ORIA sub-soil and groundwater salt levels are comparatively low, waterlogging poses significant long term risk to agricultural productivity. An alkaline, heavy clay soil (the Kununurra clay) constitutes a large proportion of the intensively cropped land, and when saturated it becomes highly anaerobic and logistically inaccessible. The use of commercial tree crops integrated with agricultural activities have the potential to play a critical role in the development of a sustainable land management system for the region.

Tropical tree crops

Fringing the flood irrigated Kununurra clay soils are deeper, free draining, lighter textured soils: the Cockatoo sands. These expansive soils remain relatively under-utilised due to their low water-holding capacity, low fertility and presence of a voracious insect pest *Mastotermes darwiniensis* (giant termite). Early arboretum plantings coupled with more recent introductions, grown in trickle-irrigated plantations, have shown that species which can grow successfully on these soils include *Tectona grandis* (teak), *Pterocarpus indicus* (narra) and *P. macrocarpus* (Burmese padauk). This silvicultural system is far less complex than the *S. album* farm forestry system. However, a significant risk to these plantations is posed by the potential for infestation by *M. darwiniensis*. Screening for species with low susceptibility to *M. darwiniensis* is underway. Teak appears resistant to *M. darwiniensis* attack due to the presence of the phenolic heartwood compounds anthroquinone and tectoquinone (Tewari 1992).

Oil Mallee Project

Eucalyptus oil occurs in high concentrations in the leaves of many eucalypt species. The oil has value for both the pharmaceutical industry and as a natural solvent (Barton 1989). Mallee eucalypt species grow naturally in the drier <400 mm rainfall zone and several species have high oil content.

The world industrial solvent market is large and diverse and consists of predominantly petrochemical based materials. Some solvents contain chlorine and their loss to the atmosphere contributes to ozone depletion. The potential for eucalyptus oil to meet demands for environmentally safe solvents, cleaning and degreasing materials is large (Barton *et al* 1997), but to be competitive the cost of production of eucalyptus oil needs to be reduced from $4-$8/kg to less than $2/kg.

The area of oil mallee plantations required to meet demand on the world pharmaceutical market is around 30 000 hectares, but to meet the needs of the world industrial solvent market is around 7.5 million hectares. It is estimated that 1.5 million hectares of the drier region of the agricultural zone needs to be revegetated with a perennial crop to stabilise water tables (Agriculture WA *et al* 1996). The development of a commercial eucalyptus oil industry could provide the mechanism to fund this revegetation.

In the early 1980s mallee species were identified as having oil-producing potential by scientists at Murdoch University and later that decade Agriculture Western Australia conducted experiments to measure production and water use of eucalypt oil species, and constructed a mobile steam extraction still. In 1992 CALM recognised that for a commercial oil mallee resource to develop, some financial incentive was required. A sharefarming concept was developed where CALM contributed the seedling finance and commenced a species selection and genetic improvement program.

Small-scale planting commenced at Woodanilling and Lake Toolibin in 1992/93, and a three-year planting program commenced in six regional centres, with funding support from the Commonwealth Farm Forestry program and National Landcare program. These six centres were chosen to cover a range of wheatbelt environments, to minimise haulage distances and to minimise extraction costs. Each centre aims to establish 5 000 hectares within a 30 kilometre radius. The Oil Mallee Association of Western Australia was formed in 1995 to represent farmers in the development of an oil mallee industry. It aims to do this by providing a forum for discussion, a structure for involvement and an avenue for communication to as wide a farm audience as possible.

Table 10

Oil Mallee Planting Areas and Farms

	1994		1995		1996	
Location	**Km hedge**	**No. farms**	**Km hedge**	**No. farms**	**Km hedge**	**No. farms**
Canna	230	23	407	42	549	49
Kalannie	285	23	450	38	550	37
Narembeen	75	10	213	27	451	38
Wickepin	60	7	265	23	312	43
Woodi	66	9	114	27	120	28
Esperance	139	11	115	16	165	25
Total	**855**	**83**	**1 564**	**177**	**2 147**	**258**

Conclusion

Large areas of the plantations of exotic species established principally by the Western Australian Forests Department on Crown land and funded by the taxpayers are now reaching maturity. Logs derived from these plantations support a significant manufacturing industry which includes major sawmills and panel board plants. If early foresters had not had the foresight to establish these plantations, there would not have been an infrastructure and funding platform on which a tree crops on farmland based industry has developed. With an Australian net import bill of $2 billion in timber products it is apparent, however, that Western Australia, along with other States in the Federation, has failed by a long margin to achieve self-sufficiency. Included in the nation's imports are – eucalyptus pulp, Tasmanian bluegum veneer, tannin derived from Acacia species, and eucalyptus oil.

We have also failed to capitalise on opportunities provided by the increasing demand for wood fibre in nations in the western Pacific which is occurring concurrently with a diminishing capacity among our neighbours to supply wood fibre from native forests, particularly in the tropics.

This deficit is likely to increase as wood becomes recognised as the natural material which contributes most positively to the environment (Shea 1993), and as relatively new timber products, such as medium density fibreboard, oriented strand board and laminated veneer lumber material move into markets currently occupied by other materials.

The institutional compartmentalisation of agriculture and forestry (in both private and public sectors) has also contributed substantially to our failure to use the increasing demand for wood fibre to drive the rehabilitation of degraded soils, rivers and wetlands in the agricultural region by effectively integrating tree crops into farming systems. However, we are convinced it is not too late to take advantage of new tree crop and wood utilisation technologies, market opportunities and the demand for trees to repair the environment.

In 15 years the tree crop on farmlands industry in Western Australia has grown from a few hundred hectares to more than 50 000 hectares. Since 1987, CALM alone has established 34 000 hectares of tree crops in partnership with 918 farmers. It is estimated that $80 million per annum is currently being expended on establishing and maintaining new tree crops on farmlands in Western Australia. Even if the current rate of private plantings of bluegums (20 000 hectares per annum) is halved and private investment in maritime pine is not taken up, we estimate conservatively that by the year 2010 there will be 350 000 hectares of softwood and hardwood tree crops growing wood worth $500 million at the mill door each year.

If this is achieved, it will go a long way towards realising CALM's vision to participate in making Western Australia one of the major wood fibre bowls of the world based on a tree crop industry on farmlands which concurrently is driving the rehabilitation of the land and waters in the south-west of the State.

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