IMPLEMENTATION OF THE CODD REPORT

THE REASONS LEADING TO THE EXPANDED USE OF THE SHELTERWOOD SILVICULTURAL PRESCRIPTION, THE RESEARCH BEING UNDERTAKEN AND THE IMPLICATIONS FOR FOREST YIELD

Department of Conservation and Land Management

January 2000

Summary and Conclusions

Reasons for the Increase in Use of Shelterwood

In setting out the reasons for the expanded use of the shelterwood treatment, there are five principal points that CALM makes. Firstly, the increase in the use of the shelterwood treatment is not because the silvicultural prescription or guideline has changed. The guideline has remained essentially the same over the period of the Forest Management Plan. Secondly, there has been a change in the mix of forest types and forest structures that have been harvested over the course of the Forest Management Plan. This is always likely to occur over the course of a management plan or from one management plan to another. Thirdly, and as a consequence of this change in mix of forest types and forest structures, there has been a change in the mix of silvicultural treatments. As a result of a greater area of forest in medium rainfall zones being harvested, and these areas having an inadequate stocking of regeneration prior to harvest, there has been an increase in the use of the shelterwood treatment. Fourthly, the shelterwood treatment is the appropriate treatment for the areas that were cut-over. The use of the shelterwood treatment in areas where adequate regeneration is not present prior to timber harvest, demonstrates an appropriate precautionary approach. Fifthly, the application of the shelterwood treatment is entirely consistent with the Forest Management Plan. The Forest Management Plan makes no predictions about the level of harvest or the proportion of shelterwood cutting. Rather, silvicultural prescriptions and guidelines are discussed as the means of ensuring regeneration and perpetuation of jarrah. The guidelines that the plan refers to have been appropriately applied to the area planned for harvest. In 1992 CALM advised that predicting detailed silvicultural proportions in advance of surveys was not possible.

In CALM's view, the increase in use of the shelterwood treatment does not represent a change to the Forest Management Plan.

Reasons for the Increase in Area Harvested

In relation to the increase in area of forest that has been harvested, there are three main points that CALM makes. Firstly, the increase in area harvested is a consequence of the increase in proportion of the forest cut to shelterwood. As less volume of timber per hectare is harvested in areas cut to shelterwood than in areas cut to gap, more area will be harvested to supply the contracted volume of timber. Secondly, the increase in area harvested is also a reflection of the lower standing volumes in areas harvested in later years compared to those harvested in the earlier years of the plan. Again, as less volume of timber per hectare is harvested, more area will be harvested to supply the contracted volume of timber. Lastly, CALM makes the point that the area of forest cut-over as a result of the use of the shelterwood treatment is similar to what would be cut under other forms of selective cutting.

The increase in area of forest cut-over does not represent in CALM's view a change to the Forest Management Plan.

Research Undertaken Into Regeneration of Jarrah

The development and application of silvicultural treatments to regenerate jarrah forest is underpinned by a long history of research and development. The report sets out the research undertaken into regeneration of jarrah in terms of seedling emergence, mortality of seedlings, growth of seedlings, other research and operational experience into regeneration of jarrah, regeneration surveys, accounting for variation in site, and future research.

Implications for Forest Yield Predictions

Within the jarrah forest, different yield regimes reflecting different site quality, stand structure, timing and intensity of log removal, and hence the sequence of wood flows, have been developed for each silvicultural objective.

The shelterwood regimes specifically provide for a prolonged period of establishment between the initial removal of the overwood and the subsequent gap treatment. This period is nominally projected to be between 15 to 25 years depending on the geographic location and site quality.

Because the exact timing of the shelterwood removal operation (gap treatment) cannot be consistently predicted in advance, a precautionary approach is adopted in the yield scheduling by assuming no future merchantable growth accrues on the retained shelterwood trees.

It is CALM's view that implications of the use of the shelterwood treatment are adequately catered for in the systems used to predict forest yields.

Background

Under the agreed outcome of discussion between Dr Shea and Mr Bowen contained in the January 1999 Codd Report the following commitment was agreed:

"Condition 2.2 Changes to the proposal which are not substantial may be carried out with the approval of the Minister for the Environment following advice from the EPA

The EPA drew attention, in relation to jarrah harvesting, to the increase in the use of shelterwood silvicultural prescription and the increase in the area harvested.

CALM maintains that no baseline was set for such practices in the Forest Management Plans 1994-2003 and that the change in balance in favour of shelterwood rather than the more intensive "gap" harvesting was made in accordance with the precautionary approach required by Ministerial Condition 3.

Whilst CALM has advised that expanding the use of the shelterwood silvicultural prescription with associated increases in the area harvested was the proper course of action under the precautionary approach, the matter has been identified by the EPA as being of such importance that CALM has agreed to provide a report to the EPA within 12 months – after consulting with the DEP on the scope of the report and progressively on its development – setting out the reasons leading to the change in the balance of use of prescriptions (ie, regeneration techniques), the research being undertaken in regeneration success, and the implications for forest yield predictions.

The EPA will then report to the Minister within 4 months."

Consultation with DEP on Scope and Development of the Response

In accordance with the above CALM consulted with the DEP on a number of occasions. Condition 2.2 was first discussed with other items arising from the Codd Report at a meeting on 16 March 1999 which involved Mr Bowen, Ms Robinson and Dr Mattiske from the EPA and Dr Jenkins and Mr Sippe from the DEP, together with various officers of CALM.

Constructive consultation occurred subsequently in July and early December 1999 following which draft reports were prepared and forwarded to the DEP for their comment. These comments have been considered in finalising the report.

Reasons Leading to the Change in the Balance of Use of Prescriptions (Regeneration Techniques)

The characteristics and significance of the jarrah forest together with the silvicultural practices that have been applied to it, particularly in a historical context, have been described in a number of papers, including Dell et al. (1989), Stoneman et al. (1989) and most recently Bradshaw (1999). Readers of this report are referred to these papers.

This report will focus on the more recent application of silviculture in the jarrah forest which was initiated in 1985 by CALM. Appendix 1 provides a brief review of the silvicultural practices that have been applied in the jarrah forest.

This section of the report describes the reasons leading to the increase in use of the shelterwood treatment and the reasons leading to the increase in the area harvested.

Reasons for the Increase in Use of Shelterwood

As highlighted by the EPA, the use of the shelterwood treatment has increased significantly during the period 1992/93 to 1997/98 (EPA 1998). However, in the more recent years the area where the shelterwood treatment was used appears to have leveled out.

There are five principal points that CALM makes in the following discussion relevant to the use of the shelterwood treatment:

1. The increase in the use of the shelterwood treatment is **not** because the silvicultural prescription or guideline has changed.
2. There has been a change in the mix of forest types and forest structures that have been harvested, as will always happen over the course of a management plan or from one management plan to another.
3. As a consequence of this change in mix of forest types and forest structures there has been a change in the mix of silvicultural treatments.
4. The shelterwood treatment is the appropriate treatment for the areas that were cut-over.
5. The application of the shelterwood treatment is entirely consistent with the Forest Management Plan 1994-2003 (the Proposal).

1. The increase in the use of the shelterwood treatment is *not* because the silvicultural prescription or guideline has changed.

By applying the knowledge of the process of regeneration and the lessons available from approximately 100 years of practical application of harvesting and silviculture in the jarrah forest, a revised silvicultural prescription was developed and published in 1985 (Bradshaw 1985).

In simple terms, Bradshaw (1985) identified three primary silvicultural objectives to be applied to the jarrah forest subject to timber harvesting. These were :

- Where the overstorey was mature and regeneration on the forest floor was present and adequate both in numbers and stage of development for release, remove the overstorey and allow the regeneration to develop (**Gap**).

- Where the overstorey was mature but regeneration on the forest floor was inadequate (in numbers or stage of development or both) for release, remove part of the overstorey and encourage regeneration to establish and develop (**Shelterwood**).

  Once regeneration was developed to a stage suitable for release a second harvesting operation would remove remaining commercial trees to create a gap.

- Where past disturbance had provided for a vigorous stand of young developing trees, remove some to favour the growth of identified crop trees (**Thinning**).

This prescription was implemented in stages across the jarrah forest from 1985. In 1989, the prescription was revised with the release of Silvicultural Specification 7/89 "Treemarking and Silvicultural Treatment in Multiple Use Jarrah Forest". This specification supplemented the CALM Leaflet "Treemarking and Silviculture in the Jarrah Forest 1987" and provided staff with more detail on application.

In 1991, the prescription was reviewed and Silvicultural Specification 2/91 "Treemarking and Silvicultural Treatment in the Jarrah Forest" was released in October of that year. In essence, Silvicultural Specification 2/91 was little different to Silvicultural Specification 7/89 with respect to application of the three silvicultural objectives. However, the revised specification included more allowance for maintenance of non-timber values and in particular amalgamated Silvicultural Specification 7/89 with Silvicultural Specification 5/89 "Maintenance of Habitat for Hole Nesters in Timber Production Areas of the Jarrah Forest'.

In 1995, the jarrah prescription was again reviewed with the release of Silvicultural Guideline 1/95 "Silvicultural Practice in the Jarrah Forest". This Guideline was little different to Silvicultural Specification 2/91 with respect to the three primary silvicultural objectives. However, the revised Guideline included clearer instructions on the maintenance of habitat values.

As can be seen from the above, the silvicultural prescription applied to the jarrah forest has been reviewed a number of times since 1985. This has allowed for adaptive silvicultural management, based on best available information, developed from either research findings or from observations of the outcomes of silvicultural practices. It is CALM's view that this is clearly within the requirements of Ministerial Condition 3 dealing with precautionary and adaptive management.

Notwithstanding the changes in the silvicultural prescriptions over time, the silvicultural objective of cutting areas to shelterwood where the overstorey is mature but regeneration on the forest floor is inadequate, has not varied over this period.

The implementation and review of silvicultural prescriptions applying to jarrah forest is more fully described in Appendix 1.

2. **There has been a change in the mix of forest types and forest structures that have been harvested, as will always happen over the course of a management plan or from one management plan to another.**
3. **As a consequence of this change in mix of forest types and forest structures there has been a change in the mix of silvicultural treatments.**
4. **The shelterwood treatment is the appropriate treatment for the areas that were cut-over.**

The following discussion deals with the above three points as they are closely interrelated.

The increased use of shelterwood reflects the application of the appropriate silvicultural objective to the jarrah forest subject to harvesting each year. This can be explained by a trend of harvesting activity moving out of the jarrah forests of the Southern Forest Region into the more northern forests, for example east of Harvey and Dwellingup (See Map 1). An increased area of lower quality, lower rainfall sites tend to have been planned for harvest. In general, these forests contain a lower total volume per hectare and also predominantly require shelterwood application.

Forest Consultant Mr F J (Jack) Bradshaw was invited to inspect and analyse harvesting and silvicultural data and maps for the period of concern. Bradshaw (1999) states:

"*There are several reasons for the change in proportion of silvicultural objectives from the mid 1980's. During the period 1986 to 1998 there has been a shift in the source of the total volume harvested, with a decreasing proportion from the southern region and an increasing proportion from the other regions, in particular the Swan region (Figure 4* – Figure 1 of this report*) i.e. a shift to areas of generally lower volume per hectare.*

Examination of the harvest objectives by regions for the period 1990-1998, when more detailed information is available, show a changing pattern of silvicultural objectives over time (Figures 5a, 5b, 5c – Figures 2a, 2b, 2c of this report*).*

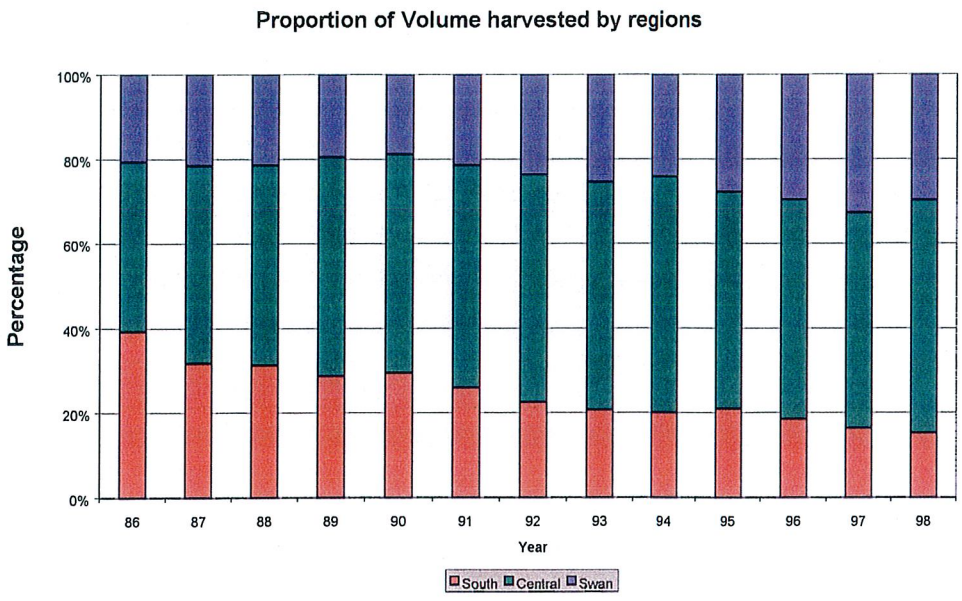

Figure 1: Proportion of total volume of wood harvested by region from 1986 to 1998 (from Bradshaw 1999).

Figure 5a (Figure 2a of this report) *for the Southern region shows a predominance of gap creation throughout the period with a reduction in total area harvested in recent years as volume removals from this area decreased. This is consistent with the type of forest being harvested.*

Figure 5b and 5c (Figure 2b and 2c of this report), *for the Central and Swan regions, show an increase in the total area harvested with the increased proportion of volume harvested from these regions. There is also a trend of a reducing proportion of thinning and an increasing proportion of shelterwood. The most dramatic increase, and that responsible for the greatest increase in harvested area is in the Swan region. The reason for this change is the general shift in logging operations to the drier, eastern jarrah forest during this period. The more easterly site types are much more likely to require shelterwood treatment than the higher quality western forest. This is supported by the higher Gap: Shelterwood ratio in the period 1990- 1993 for both regions. Map 1 shows the location of harvested areas for the periods 1990-1993 and 1994-1998 and illustrates the eastward trend."*

Changes in the proportions of various silvicultural objectives have not been a consequence of changing prescription, which has remained essentially the same for the last decade, but the outcome of the application of the prescription to different sites and forest structure.

It is CALM's view that the use of the shelterwood treatment in areas where adequate regeneration is not present prior to timber harvesting, demonstrates an appropriate precautionary approach whilst implementing the most appropriate silvicultural treatment.

Figure 2a

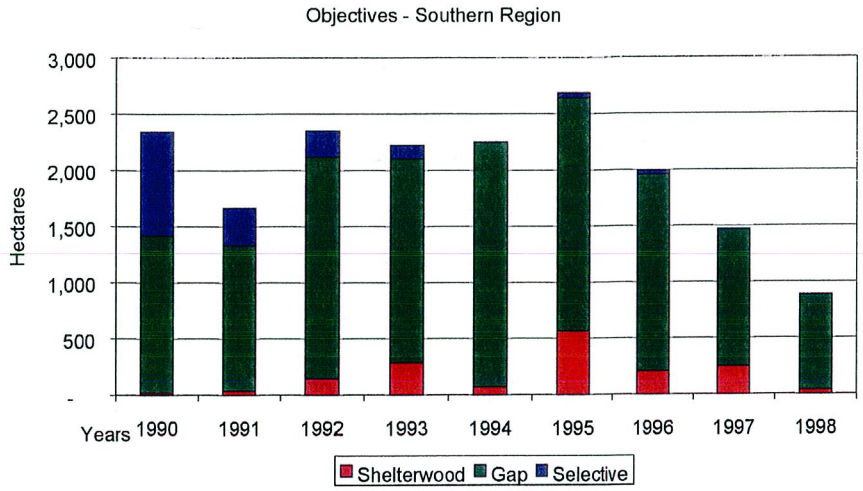

Figure 2b

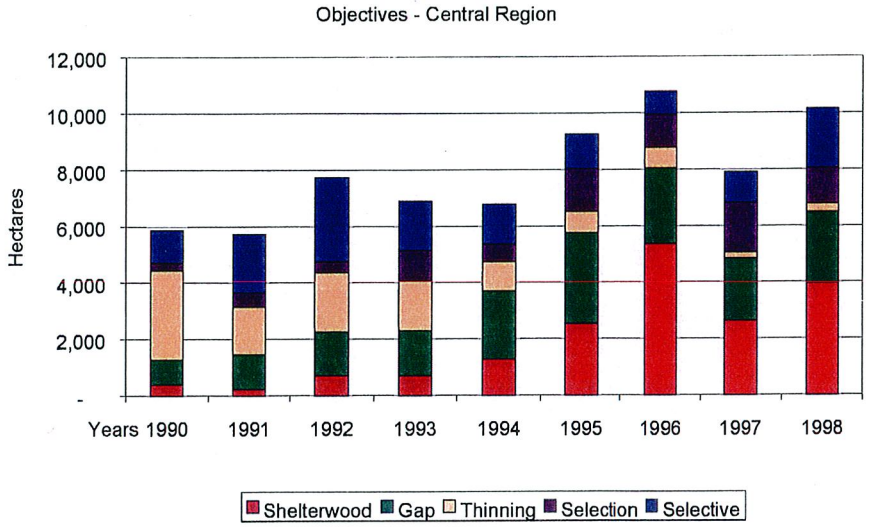

Figure 2c

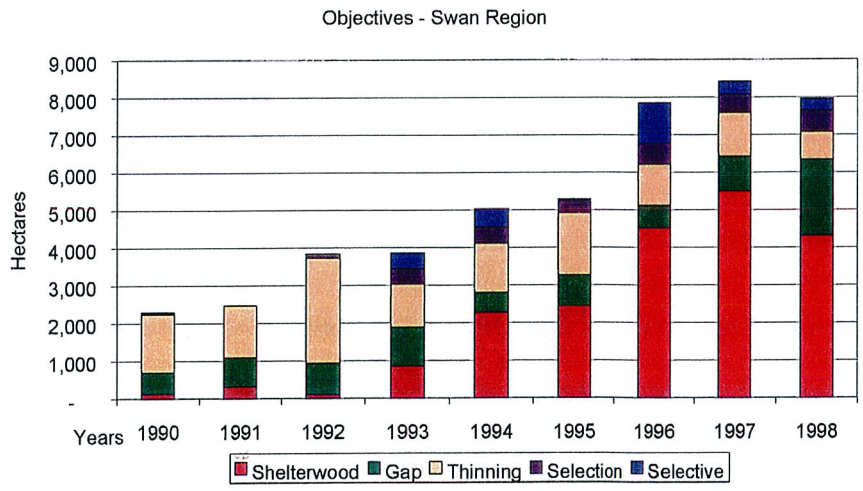

Figure 2a,b and c: The area of forest in each region to which different silvicultural objectives were applied over the period 1990 to 1998 (from Bradshaw 1999).

5. The application of the shelterwood treatment is entirely consistent with the Forest Management Plan 1994-2003 (the Proposal).

The Forest Management Plan makes no predictions about the level of harvest or the proportion of shelterwood cutting. Rather, silvicultural prescriptions and guidelines are discussed as the means of ensuring regeneration and perpetuation of jarrah. The guidelines that the plan refers to have been appropriately applied to the area planned for harvest.

6. The EPA interpretation of CALM's 1993 advice.

In 1992, the EPA sought advice as to the projected area of jarrah forest that would be subject to the three components of the 1991 jarrah prescription. In its reply to the EPA, CALM stated:

"It is not possible to answer this question because detailed mapping of jarrah forest structure and lignotuber stocking density, the factors which determine the treatment to be applied, is not available.

The forest officer in charge of the logging must determine which treatment is applied virtually on a hectare by hectare basis.

Areas cut over (hectares) in the past 3 years have been;

	Northern	*Central*	*Southern*	*Total*
1989/90	*2950*	*7470*	*4100*	*14520*
1990/91	*2570*	*6710*	*3190*	*12470*
1991/92	*1970*	*7140*	*1800*	*10910*

Areas cut over in the future are expected to be of a similar order and mapping done during 1991 has shown (1991/92 Annual Report) the following approximate percentages.

Thinning	*25%*
Gap creation	*55%*
Shelterwood	*5%*
Single tree selection	*13% (marginal forest where it is not possible to create a gap commercially)*
Other (clearing etc)	*2%*

At this stage we can only assume the proportions will be similar for the next decade."

The EPA report on compliance with ministerial conditions, (EPA 1998) emphasized the advice relating to the proportions of the silvicultural objectives applied in the period 1989 to 1992 and not the statement that it was "...not possible to answer this question...". In good faith, CALM provided an indication of historic proportions based on best available information at that time. Unfortunately, this did not adequately provide for a changing focus of location of harvesting within the forest over time.

The EPA in their report to the Minister for the Environment in 1992 with respect to implementation of the Forest Management Plan (EPA 1992), were concerned about the intensification of harvesting activity as a result of the silvicultural prescription proposed to be applied, particularly in the central and northern parts of the jarrah forest. It is noted that the current issue (shelterwood and total area harvested) is actually reflecting a less intensive practice than the 1991 level analysed by the EPA (EPA 1992).

Reasons for the Increase in Area Harvested

From 1991 to 1998 the total annual area of jarrah forest subject to harvesting has increased from 10 910 hectares to 19 670 hectares.

There are three principal points that CALM makes in the following discussion as to the reasons for the increase in the area harvested:

1. The increase in the area harvested is a consequence of the increase in proportion of the forest cut to shelterwood.
2. It is also a reflection of the lower standing volumes in areas harvested in later years compared to those harvested in the earlier years of the Plan
3. The area of forest cut-over as a result of the use of the shelterwood treatment is similar to what would be cut under other forms of selective cutting.

1. The increase in the area harvested is a consequence of the increase in proportion of the forest cut to shelterwood.

2. It is also a reflection of the lower standing volumes in areas harvested in later years compared to those harvested in the earlier years of the Plan.

The following discussion deals with the above two points as they are closely interrelated.

The increase in the area cut to shelterwood has resulted in an increase in the area of forest harvested. There is nothing surprising in this relationship as shelterwood application by definition does not provide for all potentially available timber to be available in the one harvest. If less timber is available per hectare of forest harvested, more area will need to be harvested to supply the same volume.

The area of forest harvested each year is simply a function of the volume of timber required to be delivered to customers under contracts of sale and the volume of timber available for removal in those forest areas planned for harvest. The volume of timber available within those areas planned for harvest is a function of the total volume standing in the forest, the portion that meets product criteria and the amount provided for removal after allowance for silvicultural requirements including that required for wildlife values. The total volume of timber standing in the forest is largely a function of site quality and past disturbance history, in particular past timber harvesting.

The volume of timber to be removed in any one year is determined firstly by the total allowable cut which has been determined by government based on available yield calculations. The annual sustainable timber resource available for allocation was determined in accordance with Ministerial Condition 8.2. Although this total annual volume may be committed to customers under contracts of sale for a set period this does not mean that the total allowable volume will be supplied in any particular year, or all years.

The economic cycle and other factors result in changes in demand for wood from sawmillers and others. These market fluctuations result in variations in the actual quantity supplied from year to year.

Except for timber removals required to meet contractual commitments in accordance with Ministerial Condition 8.2, all of the other factors above are interdependent.

Site quality and past disturbance history strongly influence the applied silvicultural objective. Shelterwood is far more likely to be required in low rainfall, lightly disturbed forest than in high rainfall heavily disturbed forest. The silvicultural treatment in turn has a large impact on the volumes of timber that is removed. For example, given the same total standing volume of timber per hectare, more is available for immediate removal under gap treatment than under shelterwood treatment. This is because a proportion of the timber is retained in the shelterwood treatment to meet the silvicultural objective. If several of these factors are superimposed on each other eg low rainfall, low total standing volume and application of shelterwood, a greatly reduced timber removal per unit area of forest harvested will result.

There is not necessarily a connection between total area cut over, the applied silvicultural objective and the capacity to sustain timber yield. The connection is more one of the timing of the availability of the yield. The timber remaining standing in a shelterwood is still available and growing and will be harvested in a gap treatment at a future time when the regeneration has established. As long as this is factored into total yield calculations there is no implication for forest yield projection. This is discussed in more detail in a later part of this report.

3. The area of forest cut-over as a result of the use of the shelterwood treatment is similar to what would be cut under other forms of selective cutting

CALM is of the view that the EPA (1998) took an inappropriate reference point against which to compare trends in the area cut-over. The area cut-over in 1991 was abnormally low. Indeed, 1991 saw the least area cut-over in recent history and is a quite inappropriate reference point against which to compare trends in the area of forest cut-over. The current area harvested is quite comparable with earlier years where selection cutting was the predominant silvicultural treatment.

Bradshaw (1999) states;

"*Figure 1* (Figure 3 in this report) *indicates that there has indeed been an increase in area harvested during the period in question and that there has been an increase in the proportion of shelterwood operations. Figure 2* (Figure 4 in this report) *shows that there has been an increase in the ratio of shelterwood to gaps from 1994.*

However in relation to the total area cutover, longer term data shows that the base date of the early 1990's was a period of particularly low harvest levels relative to periods before and after. This is due in part to variations in the annual volume harvested (Figure 3 – Figure 5 in this report*) and partly to the location of harvesting and the prescription in use at the time. Selective cutting was practiced in most areas until the late 1980's from which time versions of the current prescription were in operation, with the various combination of objectives indicated in Figure 1* (Figure 3 in this report)."

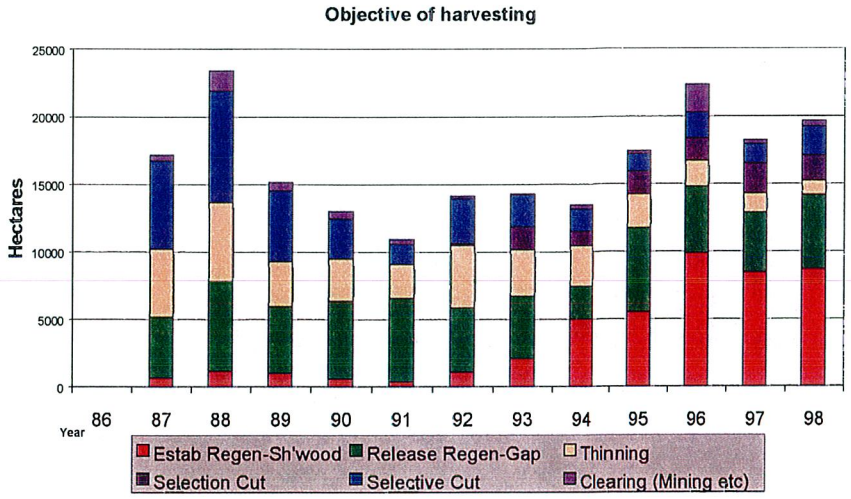

Figure 3: Area of forest cut to various silvicultural objectives from 1987 to 1998 (from Bradshaw 1999).

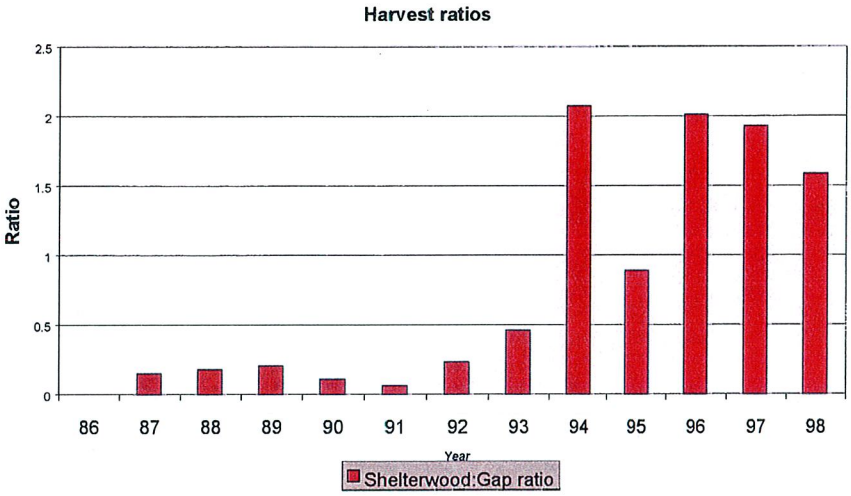

Figure 4: Ratio of the area cut to shelterwood treatment in comparison to the area cut to gap treatment from 1987 to 1998 (from Bradshaw 1999).

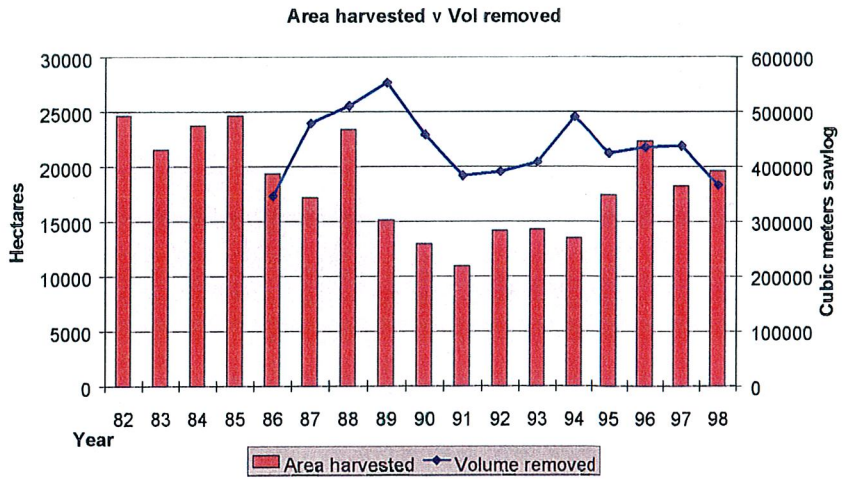

Figure 5: Area of forest harvested from 1982 to 1998 and the volume of sawlog harvested from 1986 to 1998 (from Bradshaw 1999).

Research Undertaken Into Regeneration of Jarrah

The aim of shelterwood treatments is to provide for establishment of jarrah seedlings on areas of jarrah forest where regeneration is deficient, thus enabling the forest to be effectively regenerated and all of the available timber volume to eventually be accessed.

To achieve this the forest is treemarked prior to harvesting to retain a portion of the standing mature jarrah trees. These will provide seed for seedling establishment as well as a continuation of forest values while seedlings slowly develop to the ground coppice stage. After harvesting, post-harvest treatments are completed to facilitate seedling establishment. These post-harvested treatments entail soil disturbance and prescribed burning under appropriate conditions.

The application of the above process is underpinned by a long history of research and development. Abbott and Loneragan (1986) summarise relevant early work. More recently Stoneman et al. (1989) have contributed a clearer understanding.

This section sets out the research undertaken into regeneration of jarrah in terms of seedling emergence, mortality of seedlings, growth of seedlings, other research and operational experience into regeneration of jarrah, regeneration surveys, accounting for variation in site, and future research.

Seedling Emergence

Stoneman and Dell (1994) found the major factor affecting emergence of jarrah seedlings was predation of seed. Although in the experiment vertebrates were responsible it was considered that this reflected the time of sowing and under natural seed fall conditions invertebrates (ants) would be more important predators. Abbott and Van Heurck (1985) found this to be the case.

Predation can be removed by covering the seed with soil. There was greater predation on low quality sites than on high quality. Removal of understorey and litter, which made seed more visible, increased predation. However in the absence of predation removal of understorey and litter increased seedling emergence. In practice this could be achieved by the application of fire. Emergence of seedlings is reduced in the absence of an overstorey. This is supported by the work of Mcchesney, Koch and Bell (1991) who found that the retention or absence of an overstorey significantly influenced moisture availability and the extent of diurnal temperature fluctuations. Overall there was no difference in emergence between low and high quality forest sites.

Ward and Koch (1993) showed that jarrah readily establishes from seed on bauxite mined areas. They suggested that differences in the densities of jarrah seedling emergence within their experiment could have been due to climatic and soil conditions, differences in the timing of rehabilitation procedures, and the high incidence of dieback on one study site. Stoneman and Dell (1994) suggested that predator populations may be lower in areas being actively mined or rehabilitated because of the soil disturbance and reduced cover.

The work of Grant et al (19979) also highlighted the significance of prescribed fire application, particularly in autumn in assisting jarrah seedling establishment.

Mortality of Seedlings

Stoneman et al. (1994) found that mortality of seedlings was greater with an overstorey retained than where the overstorey had been removed, on low quality sites compared to high quality sites and on undisturbed and lightly disturbed seedbeds as compared to heavily disturbed seedbeds. Fertilisation and grazing by large vertebrates did not significantly influence seedling mortality in the experiment.

The experiment clearly showed that water deficits caused by the onset of summer was a major cause of mortality and this was exacerbated by a retained overstorey. It was suggested that some mortality also resulted from pathogenic fungus in the early weeks following emergence.

The greater mortality on low quality sites was also attributed to higher levels of water stress than was experienced by seedlings on high quality sites.

The improved survival of seedlings on the more disturbed sites was attributed to a number of reasons such as water retention capacity, an increase in soil volume which could be explored by roots, greater rooting density, improved populations of beneficial bacteria in the soil, increase in nitrogen mineralisation, increase in soil nutrient concentrations and reduced density of competing vegetation.

The research concluded that mortality of seedlings could be minimised by reducing the density of the overstorey and so reduce water stress placed on seedlings and by seeding into a seedbed which has had litter and groundcover removed and the soil disturbed.

This is supported by Ward and Koch (1993) who suggested seedling mortality was influenced by understorey competition, the greater the competition the higher the mortality. They also found that more than half the deaths of planted jarrah seedlings occurred in the first 8 months after planting. This supports the contention that the first summer drought period is critical to seedling survival.

Growth of Seedlings

Stoneman et al. (1995) found that the presence or absence of an overstorey was clearly the most important factor affecting the growth of jarrah seedlings. The results of the experiment showed that after one year's growth seedlings on sites without an overstorey had approximately eight times the growth of those on sites with an overstorey. Site quality and fertiliser had little effect on growth in the presence of an overstorey but a significant effect on growth of seedlings on sites where the overstorey had been removed. Thus site quality and application of fertiliser were found to be of secondary importance to the role of the overstorey.

It was concluded that light availability, soil temperatures and availability of water were the critical factors being influenced by a retained overstorey. Availability of water was consistent to be the most important factor.

The results of the above field study is supported by other controlled environment studies completed by Stoneman et al. (1993) and (1994) and by the review paper on establishment of eucalypt seedling by Stoneman (1993).

Ward and Koch (1993) also found that jarrah plants grew faster and developed into saplings earlier than jarrah seedlings growing in unmined forest. Growth was influenced by competition and availability of resources. For example, establishing a vigorous understorey decreased growth, application of DAP fertiliser to base fertiliser application increased growth.

Other Research and Operational Experience into Regeneration of Jarrah

Stoneman (1994) in an internal CALM memo predicted the required spacing of retained shelterwood trees to ensure complete seed coverage.

To augment the above work a further research project was initiated by CALMScience in 1993. This was Science Project Plan (SPP) 93/94 titled "Establishment of jarrah (*Eucalyptus marginata*) in shelterwood logged areas and on dieback 'graveyard' sites". This SPP is referred to by the EPA Advisory Committee (EPA 1998).

The aims of the SPP with respect to shelterwood were to expand on the earlier work particularly with respect to factors influencing jarrah seedfall as well as to examine the effect of fire and disturbance on various parameters.

This SPP has not been completed. Data on seedfall has been collected but has not been fully examined. The remaining areas of the SPP need to be reconsidered in the light of operational experience gained since 1993 when the SPP was originally proposed.

Operationally, a large amount of experience has been gained over the last few years on the implementation of the shelterwood treatment and its outcomes. Some of the early concerns regarding successful establishment of regeneration, although not fully researched, have been resolved. For example, the coordination of seed crops, time of burn and intensity of burn are critical to achieving a successful regeneration result.
Seed forecasting of coupes in advance of treatments is a task that has only recently become a standard operation. The timing and intensity of burns has been addressed through improved training of staff. Unfortunately, completion of burns is now severely constrained by smoke issues over Perth. While Perth has seen less smoke, this has been at the expense of achieving optimum conditions for jarrah establishment in some shelterwood treatments.

When the correct application of requirements is achieved outstanding success can result. There are a number of examples now where 'wheatfield' regeneration has been achieved. In general, lower rainfall areas presents greater difficulties for establishment of jarrah seedlings than higher rainfall areas, particularly if drier than normal seasons occur and these have been highlighted in the research (Stoneman et al. 1994)

Additionally, operational trials of alternative regeneration establishment techniques using direct seeding and planting of nursery raised seedlings beneath a retained shelterwood have been implemented in several areas where establishment surveys have shown seedling establishment to be sub-optimal. Early observations of these trials suggest planting may be superior to direct seeding and may also be a more cost-effective option.

Regeneration Surveys

The effectiveness of regeneration treatments within shelterwood areas is monitored through regeneration surveys (CALM Silvicultural Guideline 4/97). Ideally this is in the first summer following the winter of establishment.

For example, in the summer of 1998/99 approximately 4 800 hectares of establishment surveys were completed in Dwellingup district, 1 250 hectares in Mornington district and 1 050 hectares in Mundaring district. The results by district and coupe are summarised in Appendix 2.

The results of the surveys include an assessment of all stages of regeneration found to be present from seedlings to saplings. In the summarised form in Appendix 2 they do not reflect success or failure of establishment, but simply provide an indication of total stocking levels for each coupe following harvesting and post-harvest silvicultural treatment. In practice, the survey results are also mapped to show the spatial distribution of stocked and unstocked points.

Where regeneration establishment does not meet stocking targets the current strategy is to time further prescribed burning with future seed cycles. It may be unrealistic to expect that full establishment of regeneration will be achieved in one cycle of operations, particularly in harsher sites such as the low rainfall zone. It is far more realistic to plan on recruitment of regeneration over time from a number of establishment events.

Accounting for Variation in Site

The EPA (1998) states:

"The EPA is of the view that more work is needed to develop or adapt forest management systems to ensure that silvicultural prescriptions can be applied in a more flexible and adaptive manner to take account of variations in forest type and site conditions, such as landform, vegetation, slope, climate and other factors."

It is CALM's contention that this flexible and adaptive approach is inherently provided by the jarrah silvicultural prescription and is exemplified by the increase in area being harvested to shelterwood. The use of the one generic prescription results in the application of a range of silvicultural objectives and treatments depending on the structure and regeneration status of the forest. The structure and regeneration status of the forest is in turn a reflection of forest type and site conditions such as landform, vegetation and climate.

In many cases this results in a mosaic of different silvicultural treatment down to a patch size of 0.2 hectares (2 tree heights). Additionally, post-harvest treatments may be varied depending on the particular conditions of the site. For example, in gaps there may be a need to coppice poorly formed stems to supplement the regeneration. In shelterwood areas the degree and type of disturbance varies according to site conditions. Prescribed burning regimes vary according to the particular requirements of the silvicultural objective and site (refer Silvicultural Guideline 1/97). For example, this may be reflected in a range of season of burns and intensity of burns.

Bradshaw (1999) indicated that in his opinion the pattern of harvesting objectives over the period of time in question:

" reflects the sensitivity of the current prescription to the requirements of the site."

The EPA (1998) states

"It appears likely that soil types, climate and location will prove to be key elements in the regeneration of the forest under these new silvicultural prescriptions."

CALM agrees with the above statement by the EPA. This is also supported by the research findings summarised above. However, this does not mean that different silvicultural 'prescriptions' are required for these different sites. Rather, it means that the silvicultural prescription should contain sufficient flexibility to allow for the appropriate silvicultural 'treatment' to be used, depending on the forest and site conditions. CALM believes that the current silvicultural guidelines allow for this flexibility in application.

Future Research

Future research in the following areas would assist the ongoing development of silvicultural practices:

- Clearer definition of an adequate seed crop to provide for successful establishment and design of an efficient sampling method to measure this objectively.
- Determination of the optimal basal area retention in shelterwood treatments, to achieve adequate seed coverage, adequate reduction in competition, maintenance of forest values and control of ground coppice.
- Optimum timing and intensity of soil disturbance and prescribed burning in shelterwood treatments.

Implications for Forest Yield Predictions

Projections of current and future yield from the forest must reflect the silvicultural system applied to the species. Within the jarrah forest, different yield regimes have been developed for each silvicultural objective. These yield regimes incorporate differences in site quality, stand structure, timing and intensity of log removal, and hence the sequence of wood flows.

The data, method, and systems used to calculate the jarrah sustainable yield have been previously reviewed and endorsed by independent expert panels (Turner 1998, Turner et al. 1999). The shelterwood regimes were examined during this process. The review of calculation of sustainable yield concluded:

"*...the scheduling has been carried out in an objective, professional (scientifically appropriate) and operationally realistic manner. We can also confirm that the whole-of-forest yield of jarrah, karri and marri sawlogs for the period 1999 to 2018 for the analysed reserved design is consistent with the data, assumptions and methodologies adopted in the scheduling*" (Turner et al., 1999).

The shelterwood yield regimes specifically provide for a prolonged period of establishment between the initial partial removal of the overwood and the subsequent harvest for creation of the gap. The scheduled timing of the second gap release operation varies across the geographic and site quality strata, from a minimum of 15 years on high quality sites west of the 900 mm rainfall isohyet, to a nominal 25 years on the lower quality sites east of the 900 mm isohyet. Such a gradation recognises that a longer period is likely to be required in some areas to establish adequate lignotuber / advance growth prior to the removal of the shelterwood.

An example of this range in a sample of shelterwood yield regimes is presented in Appendix 3.

Because the exact timing of the shelterwood removal cannot be consistently predicted in advance, a precautionary approach is adopted in the yield scheduling by assuming no future merchantable growth accrues on the retained shelterwood trees. In practice, future monitoring of the status of the recruitment within such stands will refine such predictions.

The jarrah forest yield predictions must also incorporate estimates of the relative area of each stratum to be cut to shelterwood. The jarrah forest available for harvest has been stratified into 522 strata of varying site, productivity, and silvicultural history (past cutting and treatment history). Within each stratum, cohorts are scheduled to be harvested to the various silvicultural objectives, including shelterwood. The area of each stratum projected to be cut to shelterwood varies according to past silvicultural history, geographic location and site quality. In the long term (100 + years) an average between 15% to 33% by area has been scheduled to be cut to shelterwood. This covers all climatic zones.

As has been emphasised elsewhere in this report, it is difficult to predict in advance the relative proportion of shelterwood treatment in any one year. From a yield prediction perspective, the proportions will vary on a short-term and medium term as different strata are accessed in different periods, and will also be subject to natural variation within each stratum. These effects are not significant for long-term yield scheduling as the effects of such fluctuations can be harmonised over time.

The robust nature of the yield scheduling approach also means that any variation in the proportions of shelterwood are self-compensating. If the area of shelterwood is under-predicted, and more forest is harvested using shelterwood treatment in early years of the schedule, then additional resource becomes available when the shelterwood is harvested 15-25 years later.

Conversely, if the area of shelterwood is over-predicted, then larger proportions are likely to be cut to gaps, yielding a higher volume per hectare but a smaller cut-over area in the early years. This leaves the remaining area available to supply resource in subsequent years.

If new evidence shows that the values used for any stratum need revision, then such estimates can be incorporated in each revision of the sustainable yield.

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Appendix 1

Development of Silvicultural Prescriptions

The first principle of any successful silvicultural system is that it must provide for the regeneration and development of the forest through its growth stages from seedling to maturity at the local level. If a silvicultural system fails to meet this criteria the long term growth and development of a forest will be seriously impaired as will its productivity with respect to sawlog production.

From 1940 to 1985 most of the jarrah forest was harvested under a single tree selection system. Regeneration that was able to develop in small patches was inhibited by retained cull trees and protection of it in later felling operations was difficult. Little or no protection for regrowth was considered from prescribed burning operations due to its dispersed nature throughout the forest. With the emphasis on removal of the best jarrah, the forest was becoming dominated by cull jarrah trees and marri trees. If this silvicultural system was continued then the future of the jarrah forest for timber production looked bleak. It was this concern that initiated the review of silviculture in the multiple use jarrah forest in 1985 (see Bradshaw 1999).

Jarrah Regeneration

To develop a silvicultural system an understanding of the regeneration process of the species concerned is required.

The characteristics and growth of jarrah regeneration are well described by Abbott and Loneragan (1986). More recently a number of papers have been published on related issues by Stoneman et al.

The establishment growth and development of jarrah seedlings is summarised as follows.

Flowering

Jarrah reproduces from seed. The flowering cycle from bud initiation to complete seed fall spans 4 years. Flowering occurs from mid spring to early summer and from the time of flowering, mature seed takes approximately 1 year to develop. Seed shed commences in the ensuing summer period, but may not be complete until a further summer has elapsed.

The extent of flowering and subsequent seed crop development varies from year to year across the jarrah forest and between individual trees in the same locality. Heavy consistent flowering of most trees in any one year occurs on a 4 to 6 year cycle. Several seed crops of varying extent and different stages of development may be present on any one tree.

Seed Dispersal, Germination and Initial Seedling Establishment

Following seed maturity seed is dispersed from tree crowns following the release of seed from capsules as they dry over summer. The dispersal distance from the parent tree depends on three factors. These are tree height, wind speed and crown diameter. Under average conditions the area over which seed will disperse is estimated to be up to 1.5 times tree height.

Germination of seed occurs during the early months of the first winter following seed shed. Most germination will occur after the first good rains of winter while the soil is still warm.

Germination is best on disturbed seed beds, where litter has been removed. The presence of an overstorey encourages germination, however, later survival and growth of seedlings is reduced with increasing overstorey retention.

Development of a well established root system before the onset of summer is the seedlings greatest challenge. A combination of ground disturbance, ashbed and minimal overstorey providing the most ideal conditions for seedling growth and development(personal observation). The greatest loss of established seedlings occur when seedlings experience their first summer drought period. Losses during this period are heaviest from seedlings that have germinated late and have not had time to develop a strong root system; and for those under strong competition from retained overstorey and understorey. Conditions are particularly harsh in lower rainfall areas where the duration of the winter establishment period is reduced, total available moisture is less and the summer drought period longer and more intense.

Seedling Development

Under natural conditions developing jarrah seedlings are characterised by shrubby foliage growth and the development of what is called a "lignotuber" at ground level. The lignotuber is a woody swelling at the base of the stem of seedlings and has two functions. It provides for a store of nutrients and it contains many dormant buds. This renders the young jarrah plant virtually indestructible to fire or grazing. If the aerial parts of the plant are removed or damaged, the lignotuber is capable of rapid new growth.

As each flowering cycle may result in some seedling establishment, a patch of forest may contain regeneration in varying stages of development. This progressive regeneration process eventually develops a significant 'lignotuber pool'. The density of this pool varies with site and reflects the ease with which regeneration can become established. Regeneration can also be achieved through stump coppice.

Under natural conditions the jarrah seedling retains its shrubby appearance while the lignotuber and root structure develop. Once the lignotuber has developed to what is called the 'ground coppice' stage, and this may take many years (20 years), the jarrah seedling is capable of rapid development into a sapling when conditions are appropriate. The condition required for a response to occur is a reduction in overstorey competition. If the reduction in overstorey is adequate and permanent the sapling will continue to develop. However if the reduction in overstorey competition is only temporary, for example following a fire, ground coppice may initially respond to the reduction, then as the crown cover redevelops their development will be arrested, though they seldom die. If the overstorey is removed before the lignotuber has developed to the ground coppice stage, no immediate growth response will occur. The lignotuber will continue development until it reaches the ground coppice stage at which point it will then develop into a sapling. The rapidity with which seedlings develop to a stage where they will respond to overstorey removal is strongly influenced by site.

If overstorey removal occurs in the absence of jarrah regeneration the usual consequences are that the dominant vegetation layer will be replaced with another species. This may be other tree species eg (marri) or understorey species such as Banksia grandis or Allocasuriana fraseriana (Sheoak). There are examples in the northern jarrah forest where harvesting earlier this century of jarrah dominant stands without consideration for regeneration has resulted in extensive stands of banksia or sheoak with little or no jarrah regeneration except for some stump coppice.

The Jarrah Prescription

In 1985 Bradshaw, by applying the knowledge of the above process of regeneration and the lessons available from approximately 100 years of practical application of harvesting and silviculture in the jarrah forest, developed a revised silvicultural prescription. (Bradshaw 1985) In essence this was little different to the silvicultural prescription first applied by the Forest Department soon after its formation earlier this century. Foresters Manual (1927).

In simple terms Bradshaw identified three primary silvicultural objectives to be applied to the jarrah forest subject to timber harvesting. These were ;

Where the overstorey was mature and regeneration on the forest floor was present and adequate both in numbers and stage of development for release, remove the overstorey and allow the regeneration to develop. (**Gap**)

Where the overstorey was mature but regeneration on the forest floor was inadequate (in numbers or stage of development or both) for release, remove part of the overstorey and encourage regeneration to establish and develop. (**Shelterwood**)

Once regeneration was developed to a stage suitable for release a second harvesting operation would remove remaining commercial trees to create a gap.

Where past disturbance had provided for a vigorous stand of young developing trees, remove some to favour the growth of identified crop trees. (**Thinning**)

On any patch of forest only one silvicultural objective should apply at any one time. As the jarrah forest contains a mosaic of structure from both natural and man induced disturbance, the result of applying the revised silviculture was a corresponding mosaic of silvicultural objectives. The composition of the mosaic with respect to each silvicultural objective varies across the forest depending on the site and disturbance history. To maintain the integrity of each silvicultural objective it is very important where they occur in mixture to ensure that each is applied over at least a minimum area in extent. Bradshaw defined this as 2 tree heights although recommended this minimum should be extended to 4 tree heights where ever possible.

As the forest is highly variable and the application of the three objectives changes accordingly, ensuring the objectives are applied correctly requires each patch of forest to be individually assessed in the field. Implementation of the objectives was provided for through trained CALM staff systematically assessing regeneration status and forest structure followed by physically treemarking the required trees for retention prior to harvesting. In some cases pre harvesting regeneration surveys were also applied to assess regeneration status prior to treemarking.

Selective and Selection Silvicultural Treatments

Two other silvicultural descriptions are used to describe the silvicultural outcome achieved following harvesting in the jarrah forest.

The term "selective harvesting' is applied to forest which following harvesting remains fully stocked with non- commercial trees (culls). The forest is not suitable for thinning as there are no crop trees and does not require regeneration as it is still fully stocked. Sufficient culls could be removed to achieve regeneration through non commercial methods such as chemical

notching treatment, however this would be costly and more importantly would result in a significant waste of potential resource. Silvicultural treatment of these areas are deferred until more resource can be removed commercially. Silvicultural Guideline 1/95 also refers to these as "extensively managed areas".

The term "selection harvesting" is applied to forest harvested in the northern jarrah forest infested with *Phytophthora cinnamomi* (jarrah dieback disease). In this forest the intent is to maintain a full forest cover of healthy trees following harvesting to minimise potential escalation of disease impact. (Refer to Silvicultural Specification 3/89) Where adequate healthy trees exist this in effect results in a thinning of the forest although the retained trees do not necessarily meet crop tree standards.

Prescription Implementation and Review

The prescription developed by Bradshaw was implemented in stages across the jarrah forest from 1985. The change was a major departure from the established practice of selection harvesting. Selection harvesting simply meant selecting trees for removal based on some set criteria eg a certain circumference or girth, without any thought given to the future of the particular patch of forest being harvested. Staff involved needed to develop new skills and knowledge and interpretation and application on the ground was initially variable. In 1989 the prescription was revised with the release of Silvicultural specification 7/89 titled Treemarking and Silvicultural Treatment in Multiple Use Jarrah Forest. This specification supplemented the CALM leaflet Treemarking and Silviculture in the Jarrah Forest 1987 and provided staff with more detail on application. A greater emphasis was also placed on correct field implementation. This resulted in a more uniform application of the silvicultural prescription across the forest.

In 1991 the prescription was again reviewed and silvicultural Specification 2/91 "Treemarking and Silvicultural Treatment in the Jarrah Forest" was released in October of that year.
In essence this was little different than 7/89 with respect to application of the three silvicultural objectives. This revised specification included more allowance for maintenance of non-timber values and in particular amalgamated Silvicultural Specification 7/89 with Silvicultural Specification 5/89 " Maintenance of Habitat for Hole Nesters in Timber Production Areas of the Jarrah Forest'.

In 1995 the jarrah prescription was again reviewed with the release of Silvicultural Guideline 1/95 "Silvicultural practice in the Jarrah Forest". This Guideline again was little different to Silvicultural specification 2/91 with respect to the three primary silvicultural objectives. There were however clearer guidelines on the maintenance of habitat values.

As can be seen from the above, the silvicultural prescription applied to the jarrah forest has been regularly reviewed at about 4 yearly intervals since 1985. This has allowed for regular updates in the applied silviculture based on best information at hand either developed from research findings or from practical application. This is clearly within the requirements of Ministerial Condition 3, Precautionary and adaptive management.

Appendix 2

Seedling establishment survey summary 1998/99

DISTRICT	COUPE	AREA (ha)	% STOCKED	RAINFALL ZONE
DWELLINGUP	BOMBALA 2A	260	44	Intermediate
	BOMBALA 2B	215	32	Intermediate
	BOMBALA 3A	430	60	Intermediate
	BOMBALA 3B	300	47	Intermediate
	BOMBALA 4A	200	61	Intermediate
	HAKEA 1A, 1B	660	89	Intermediate
	HAKEA 1C	430	83	Intermediate
	HAKEA 1D	350	82	Intermediate
	HAKEA 2A	150	26	Intermediate
	HAKEA 2B	470	64	Intermediate
	HAKEA 2C	460	87	Intermediate
	HAKEA 2D	200	76	Intermediate
	HAKEA 3C	350	17	Intermediate
	HAKEA 3D	200	24	Intermediate
	TAREE 4A	122	40	Intermediate
TOTAL		**4797**		
MORNINGTON	BELL 1	140	56	Low
	BELL 2	85	48	Low
	BELL 3	320	52	Low
	BELL 4 & 5	385	47	Low
	BELL 6	210	55	Low
	TUMLO	110	85	Intermediate
TOTAL		**1250**		
MUNDARING	LESLIE 1	150	85	Intermediate
	LESLIE 2	650	90	Intermediate
	RANDALL 1	150	80	Intermediate/ Low
	RANDALL 3	100	85	Intermediate/ Low
TOTAL		**1050**		

Appendix 3

Examples of the range in timing of operations and projected yields for jarrah shelterwood yield regimes applied in the determination of sustainable harvest levels.

Shelterwood Regime	Year of operation	Operation Type	Sawlog Yield (m^3 ha^{-1})
Swan Region, East, Moderate quality, Varied cutting history	0	Shelterwood	6
	20	Shelterwood removal	6
	40	Thinning	0
	70	Thinning	6
	150	Thinning	18
	170	Thinning	18
	220	Gap	30
Central Region, West, Moderate quality Limited previous cutting	0	Shelterwood	18
	20	Shelterwood removal	18
	40	Thinning	0
	65	Thinning	0
	110	Thinning	14.4
	155	Thinning	12
	220	Gap	24