An appraisal of methods and data used by CALM to estimate wood resource yields for the South-West Forest Region of Western Australia

A REGIONAL FOREST AGREEMENT FOR WESTERN AUSTRALIA

An appraisal of methods and data used by CALM to estimate wood resource yields for the South-West Forest Region of Western Australia

by

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FOREWORD

This report is by Dr Brian Turner of The Australian National University. It is the product of a consultancy for the Bureau of Resource Sciences, Department of Primary Industries and Energy, based on the terms of reference that are included at the end of this report. The terms of reference were prepared by project officers of the Commonwealth and Western Australian Department of Conservation and Land Management.

The project officers were:

- Dr Martin Rayner, Department of Conservation and Land Management, who provided presentations and written information, arranged access to other CALM staff and to forest resource systems and provided comment on the draft report.

- Mr Karl Rumba, Bureau of Resource Sciences, who managed the consultancy, provided advice on the Commonwealth's requirements on the project, and commented on the draft report. In addition Dr Oliver Chikumbo, Bureau of Resource Sciences was engaged in an advisory capacity, and provided comment in the development of the terms of reference and the draft report.

The Commonwealth and Western Australian governments wish to acknowledge the effort and diligence of Dr Turner in the report he has provided.

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EXECUTIVE SUMMARY

An appraisal of the methods and data used by the Western Australian Department of Conservation and Land Management (CALM) to estimate wood yields has been conducted for the South-West Forest Region of Western Australia. This is part of the Comprehensive Regional Assessment process leading up to the Regional Forest Agreement for this Region.

In order to estimate sustainable yields for the jarrah and karri forests of the south-west a system has evolved which has a number of components which can be grouped into: land information, inventory, growth and yield projection, and harvest scheduling and yield regulation.

Land information

A basic requirement of all forest management is that the land be mapped accurately and yield estimation begins with the definition and accurate quantification of areas of forest available for timber production.

CALM uses a number of GISs to manage their spatial information. These include the CALM-built Forest Management Information System (FMIS) which is used for rapid overlaying and area calculation and the commercial Microstation and Arc/Info systems. Another commercial system, Map-Info, is used in the Hardwood Integrated Planning System (HIPS). SILREC is used to update FMIS and HIPS records. All these systems are required to interchange data and where appropriate are attached to the corporate database.

Cadastral information can be presumed to be highly accurate, but information derived from air photos despite the best error control will have errors when examined in detail. The mapping of the forest vegetation characteristics was done by aerial photograph interpretation (API) in the 1950s-60s. It is updated as information comes to hand, principally now through the Silvicultural Recording System (SILREC). Areas of severe jarrah dieback are mapped out as non-production zones. Floristics data have been extensively checked in the recent publication of Forest Association maps. An accuracy assessment at an opportune time would seem wise.

All area estimation is via one of the GISs, so is dependent on the accuracy of the original mapping and its digitising. CALM has indicated that its 1:25000 mapping has an accuracy of 12.5 metres of ground position 85% of the time. The net area of coupes is determined by aerial photography in conjunction with differential geographic positioning system (DGPS) data. CALM staff believe that the logging histories of high wood-yield areas are now reliably mapped but more work is needed to check the poorer quality areas. From the combination of frequent photography, DGPS and extensive use of GIS it has to be concluded that area statistics are likely to be quite accurate and certainly sufficient for the accurate estimation of sustainable yields.

The management of all these systems which deal with spatial forest management data is a large and complex task and is the responsibility of the Forest Management Branch. Systems have been developed to allow ready interchange of data so that it has been possible to select the most appropriate software and hardware for the task.

Inventory

The process of collecting information about the current status of the forest is known as inventory. The accuracy of the estimates collected in the inventory process is dependent on the intensity of sampling and the care with which measurements are taken. Care is taken in the training of CALM measurement crews and their work is monitored by field checking of a sample of measured plots.

The most recent inventory of the mature karri forests was a management level inventory (MLI) conducted from 1973 to 1984. The basic design was a systematic stripline sample with a sampling rate of 2.5%. Because of this design, it is not possible to estimate meaningful sampling errors; however this is a high sampling intensity for strategic information. Models have been developed to estimate bole volume from tree dbhob and bole height. The MLI has been kept current through detailed monitoring of the products removed from the forest. Despite this, consideration should be given to a new strategic-level inventory in the near future.

The most recent inventory of the jarrah forest was completed in 1991. It was an innovative design, a two-phase system in which the first phase gave estimates of merchantable volumes of individual trees in photo-plots taken from helicopters. In the second phase a subsample (about 10%) of the photo-plots were located on the ground and were carefully measured. The boles of trees were described in quality segments to allow computerised product specifications to estimate utility of log segments. Sampling errors for volume for the jarrah inventory were designed to be of the order of less than 20% for areas of 20 000ha. Actual errors may be somewhat higher and should be continually monitored.

A comprehensive utilisation monitoring study was done in connection with the jarrah inventory. This showed that the inventory overestimated the proportion of the gross bole volume that was actual sawlog by up to 6% and indicates the need for the correction of inventory data against actual removals, as is done in the CALM system. Continued attention to monitoring this relationship is essential.

Most of the ground plots which are logged are re-measured to monitor removals. Sawing trials have been conducted periodically to monitor internal log defect. The Quality Sorting computer program is driven by user-defined product priorities, and could be improved so that it determines log assortments optimally to provide comparison and learning.

CALM has been able to use its commercial accounting procedures through its Logging Operations Information System (LOIS) to check actual removals against previous estimates and to update inventories. This appears to be a highly effective component of the inventory system and it is obviously important that this procedure be continued.

Growth estimation and projection

Past growth of forests is generally determined by the re-measurement of permanently marked plots. Over a thousand permanent sample plots (PSPs) have been established in the south-west forests. The process of developing models of the future growth of the forests using information about past growth is dependent on the availability of suitable data and analysts who not only have modelling skills but also have an excellent understanding of the forest. CALM is fortunate in having a few such people.

The karri forests have had a varied utilisation and silvicultural treatment history. There are at least three types of forest and growth estimates differ among these. The mature forest is considered to have zero net increment. The growth of the two-tiered forest is based on the assumption that it consists of a mix of mature forest and regrowth growing at a reduced rate. Plots established in the regrowth stands around 1980 and other experimental plots have provided sufficient information for an individual tree model to be developed. Intensive investigation has revealed no long-term negative impact of controlled burns on the stand growth rate provided fire is not introduced before the regrowth is aged about 20 years. The regrowth models have been incorporated into a deterministic simulator called KARSIM.

The jarrah forest has also gone through some changes in silvicultural treatment which impact on growth rates and the ability to model them. Mostly it has been harvested under various forms of the selection system. Since the mid-1980s, larger gaps have been created to encourage development of lignotubers, with a shelterwood system being used where lignotubers are absent. Single tree selection methods are used in dieback stands. Some 650 permanent sample plots have been established in the jarrah forest. Unlogged jarrah forest and trees remaining following selection cutting are assumed to have zero net increment.

There is a shortage of long-term plots representing current silvicultural regimes. In general it is probable that the current set of plots, if carefully maintained and augmented as the regrowth estate increases, will be adequate for future growth modelling. The representation of species other than karri and jarrah needs to be evaluated. Some trials have been done of measuring past diameter growth of karri through ring analysis and further work should be encouraged. The assumption of zero net increment growth for unlogged stands of jarrah and karri and partially logged jarrah residuals seems reasonable but should continue to be monitored through the LOIS and PSP re-measurements.

The heart of any yield prediction and regulation system is the growth modelling component. The karri regrowth models are the result of intensive investigation and review, including internationally. Further improvements are now possible with newly available thinning data. The models would need modification if the silvicultural system departs significantly from a clearcutting regime.

A matrix modelling approach has been used in the past to predict the growth of jarrah stands under selection management, the goal being to preserve the current distribution of size classes. This method is not very robust for long-term forest-level projections. The development of strategic-level growth models for the jarrah regrowth forests should be given high priority. Cohort models, as currently under investigation, are a reasonable approach for stands which are managed as uneven-aged stands, but since the gaps of the recent silvicultural methods are tending to be large enough to be mapped, it may be possible to model the growth of regrowth within the gaps as even-aged stands.

Yield regulation and scheduling

The next step in predicting the future supply potential of the forest is to apply the growth models to the existing inventory statistics over a long period of time. Commonly external demand and other operational constraints are applied at this stage and often an attempt is made to "smooth" the irregularities in the predicted production from the forest so that the effects of major sudden changes in supply are reduced. Alternatively or in addition the process may be driven by a desire to create a forest of a certain structure at the end of the planning period. This is the process called "Regulation". There may also be an attempt to optimise production over time. Because of the importance of spatial relationships in forest planning, acceptable solutions may be further tested for spatial feasibility.

In the jarrah Forest Scheduler, FORSCHED (and KARSCHED for karri), appropriate growth models are applied to user-defined forest strata and the inventory statistics are projected while imposed simulated harvesting patterns produce wood yields. Constraints may be imposed to adjust the patterns of yields or the structure of the forest to meet specified strategic criteria. Simulations are typically run for 100-200 years. Commonly a large number of scenarios is produced and a subset of these is selected for further consideration. The exact process used by analysts in judging the relative merits of scenarios is not well defined and needs written description for reasons of transparency and reproducibility. It is suggested that some optimisation procedure be investigated to assist the selection of the "best" scenario.

The spatial feasibility of selected scenarios can be tested through HIPS which uses GIS-defined "stands"; contiguous stands are aggregated into coupes by logging year. A major value of HIPS has been in spatially examining the relationship between the fire protection plans and the timber production plans.

Plantation inventory and yield regulation systems

The methods and systems developed for pine and eucalypt plantations follow similar procedures to those for native forests. The review of these has been cursory but they are included here for completeness and to identify any major causes for concern.

Summary

Results indicated that the datasets, models, systems and methodologies used by CALM to assess sustainable yields from the karri and jarrah forests are appropriate, internally consistent and contain adequate safeguards on the quality of the data through the use of competent staff and the incorporation of monitoring and calibrating procedures.

The reliability of the predictions can be evaluated only through consideration of the reliability of the components that go into the prediction. Error estimates are generated at some stages of the process. In other cases errors are either small, known from the regression analysis used to construct the growth models, or unknown. Because of the checks and balances built into the system it is probable that estimates of current growing stock statistics are quite reliable and that karri growth is reliably estimated except perhaps for low site quality or mixed species stands. Jarrah growth estimation in the short term is likely to be fairly reliable but in the long term, less so with the current modelling approaches. Product outturns are again probably reasonably reliable in the short term. Strategic planning outcomes are checked for spatial feasibility.

In the course of this review a number of opportunities for improvements to the various systems have been identified, but on the whole it is concluded that the systems and procedures developed by CALM staff for estimating sustainable yields from the jarrah and karri forests of the South-West Forest Region are adequate and appropriate. They certainly rank among the best in Australia in terms of comprehensiveness of the data base, monitoring arrangements and growth modelling. The complex computerised systems and production of scenarios for estimating future yields are largely the result of the efforts of a dedicated few and the Department needs to ensure that the skill base is disseminated through documentation, training and transparency of decision procedures.

1 INTRODUCTION

An appraisal of the methods and data used by the Western Australian Department of Conservation and Land Management (CALM) to estimate wood yields has been conducted for the South-West Forest Region of Western Australia. This is part of the Comprehensive Regional Assessment process leading up to the Regional Forest Agreement for this Region.

In this appraisal the basis of CALM's calculation of native forest wood yields has been reviewed to determine the reliability of yield forecasts for use in the RFA process. The appraisal builds on previous reviews of methods and systems relevant to the south-west, including those by Spencer (1992), Turner and Wood (1993) and Meagher (1993).

Specific aspects addressed include:

- methods and data used to derive yield forecasts (including calculation of net harvestable area, inventory, growth and yield models, simulators, schedulers, assumptions and constraints, the capacity of the models to predict different management scenarios and loss of productivity due to dieback, and the format of yield forecasts).

- relative accuracy of predictions, strengths and weaknesses and scientific validity of the methods/systems used for data collection and modelling of growth and yield, generation of management prescriptions and harvest scheduling.

- the overall expected reliability (which incorporates sensitivity) of the yield forecasts for use in the RFA.

In this review possible improvements in the methods, calculation of yield and scheduling of harvest have been identified. The nature and completeness of the system used by CALM for pine plantation yield forecasting from information provided by CALM are also commented upon.

2 BROAD METHODOLOGY OF THE REVIEW

This report documents an evaluative review of the appropriateness of the datasets, models, systems and methodology used in the calculations of the sustainable yield of wood products from public native forests and exotic plantations in south-west Western Australia, including the capacity of models to accommodate different management systems. The appraisal has been conducted through a review of a number of documents, maps and publications (listed at the end of this report) and interviews with those responsible for making the yield calculations in Western Australia (acknowledged later in this report).

My approach has been to review all relevant documentation and results of data analyses, then to request verbal explanations where information is found to be missing or obscure and then to evaluate each component against my knowledge of current best international practices. Where necessary, I have requested that further information be provided. Strengths and weaknesses of the various components of the yield prediction systems are indicated in this report and the expected reliability of the estimates are commented upon.

Because the management of the karri and jarrah forests differ appreciably and systems of management have evolved in divergent ways, it is frequently necessary in this report to subdivide discussion between these two management systems.

Following is a listing of items considered in this appraisal.

2.1 Datasets

The following datasets have been evaluated:

- Forest area estimation and means of stratification, including aerial photograph interpretation (API) procedures for the native forests
- Current growing stock statistics - as derived from forest inventories or other means
- Estimates of past growth of forests as derived from permanent plot measurements and perhaps other methods
- Measurements of actual removals from forests and comparisons with standing volume estimation

2.2 Models

Mathematical models evaluated for their applicability and accuracy include:

- Models for estimating volumes of standing trees
- Models for predicting growth and mortality of forests under various conditions
- Models for estimating product outturn from predicted gross volumes

2.3 Systems

Computer and other systems critically reviewed include:

- Computer systems used to project forest statistics into the future and to take into account constraints on the predictions
- Systems set up to verify and validate predictions from growth models

2.4 Methodology

The methodology used in various parts of the sustainable or continuing yield calculation process have also been evaluated. These include:

- Sampling methods used to gather data for input to the systems, including growing stock information, growth information and removals information
- Actual methods used to calculate sustainable yields including an evaluation of the underlying assumptions
- Methods used to estimate the reliability of the predictions

3 OVERVIEW OF THE YIELD PREDICTION SYSTEM

In order to estimate sustainable yields for the jarrah and karri forests of south-west Western Australia a system has evolved which has a number of components. The major components and their linkages are shown in Figure 1[1]. They can be grouped according to the type of function they perform or information they provide into: land information, inventory, growth and yield projection, harvest scheduling and yield regulation.

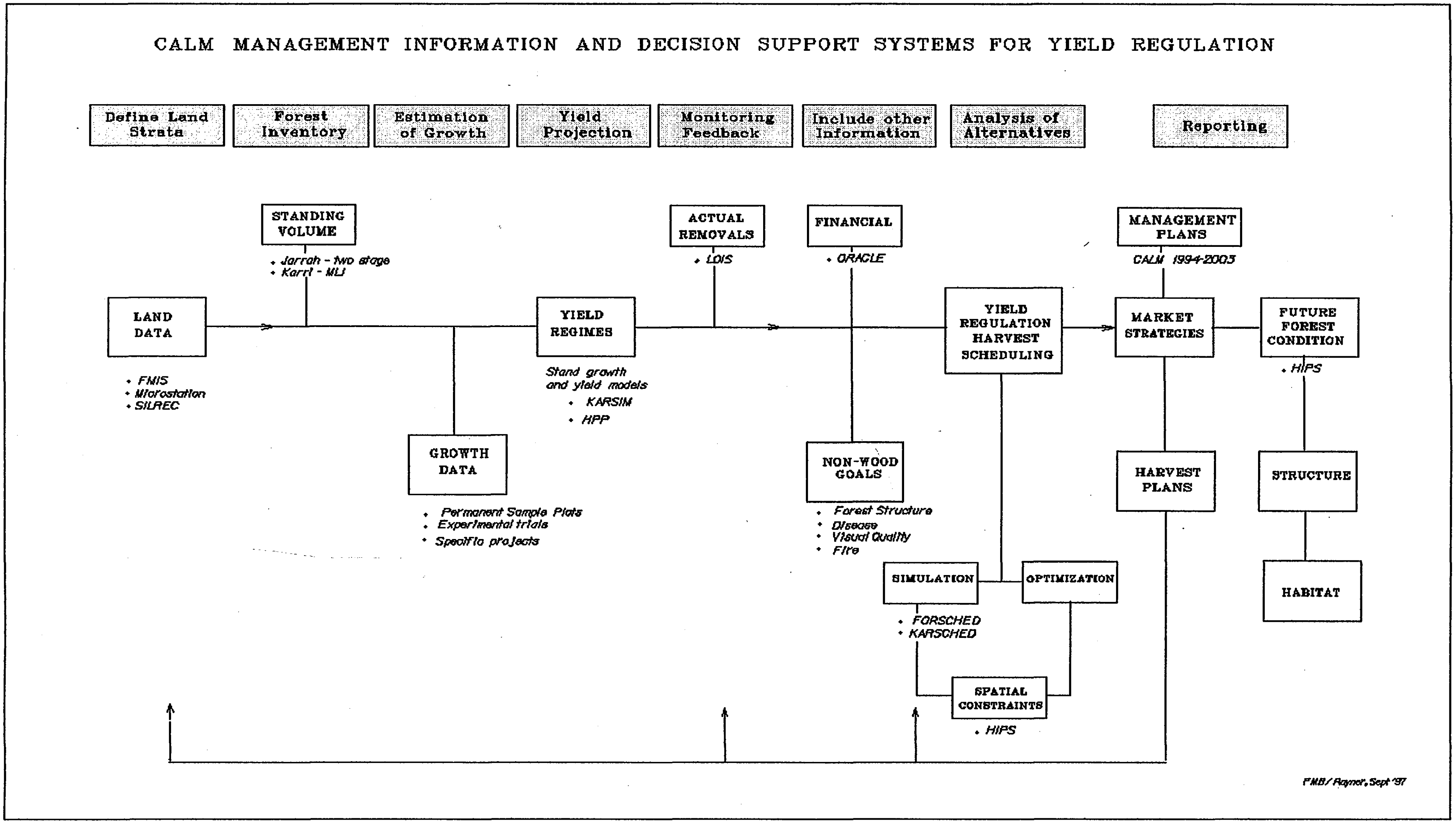
3.1 Land information

A basic requirement of all forest management is that the land be accurately mapped and yield estimation begins with the definition and accurate quantification of areas of forest available for timber production.

3.1.1 Base layer

Base tenure maps as geographic information system (GIS) layers are obtained from the state land information department, the Department of Land Administration (DOLA). Cadastral information can be presumed to be highly accurate, but information derived from air photos despite the best error control will have errors when examined in detail, e.g. rural or forest roads being on the wrong side of streams and creeks flowing uphill (since the digitising of roads, streams and contours are usually separate activities).

[1] M. Rayner, CALM, pers comm.



CALM MANAGEMENT INFORMATION AND DECISION SUPPORT SYSTEMS FOR YIELD REGULATION
Define Land Strata
Forest Inventory
Estimation of Growth
Yield Projection
Monitoring Feedback
Include other Information
Analysis of Alternatives
Reporting
STANDING VOLUME
• Jarrah - two stage
• Karri - MLI
ACTUAL REMOVALS
• LOIS
FINANCIAL
• ORACLE
MANAGEMENT PLANS
CALM 1994-2003
LAND DATA
• FMIS
• Microstation
• SILREC
YIELD REGIMES
Stand growth and yield models
• KARSIM
• HPP
YIELD REGULATION HARVEST SCHEDULING
MARKET STRATEGIES
FUTURE FOREST CONDITION
• HIPS
GROWTH DATA
• Permanent Sample Plots
• Experimental trials
• Specific projects
NON-WOOD GOALS
• Forest Structure
• Disease
• Visual Quality
• Fire
HARVEST PLANS
STRUCTURE
SIMULATION
OPTIMIZATION
HABITAT
• FORSCHED
• KARSCHED
SPATIAL CONSTRAINTS
• HIPS
FMB/Rayner, Sept '97

3.2.1 CALM GIS

CALM uses a number of GISs to manage its spatial information. Historically the first was a raster-based system called Forest Management Information System (FMIS) originally developed in the late 1970s by the former Forests Department. It has been regularly upgraded since then and is used for rapid overlaying and area calculation. The capture pixel size was originally 2ha (now 0.5ha) which makes it very suitable for storage of forest level data. FMIS layers have been registered geographically with data in the more line-accurate vector-based commercial systems, Microstation and Arc/Info. The Microstation Intergraph system is convenient for digitising new information from maps and Arc/Info is used by DOLA for cadastral mapping and it is therefore useful to have this system available as well. In addition the precision of vector systems for buffer generation makes Arc/Info useful for this and similar purposes. In addition Map-Info (a smaller-scale vector GIS suitable for PC platforms) is used in the CALM-developed Hardwood Integrated Planning System (HIPS) for harvesting planning. All these systems are required to interchange data and where appropriate are attached to the corporate database, currently Oracle.

Another system which handles spatial data is the Silvicultural Recording System (SILREC) which keeps track of silvicultural activities on logged coupes and shows future treatment requirements with expected timings. It thus interfaces with other systems, such as the Logging Operations Information System (LOIS) and the Oracle database. It uses Microstation to record coupe progression (including the calculation of net areas) from 1:12500 air photos twice yearly and is used to update FMIS and HIPS records.

The management of all these systems which deal with spatial forest management data is a large and complex task and is the responsibility of the Forest Management Branch. CALM has had a longer history of managing GIS than any other state forestry organisation resulting in a range of systems developed on different platforms. Systems have been developed to allow ready interchange of data so that it has been possible to select the most appropriate software and hardware for the task.

3.1.3 Forest vegetation data

An important input to any forest information system is a mapping of the forest vegetation characteristics in particular of the dominant canopy. In CALM as in most forestry organisations this is done by aerial photograph interpretation (API). This was carried out over the whole forested estate to a 2ha minimum polygon in the 1950s-60s. Species present by more than 20% are indicated and dominant heights are classified into three to five classes (Bradshaw et al, 1997). The accuracy of this mapping was stated as "good" with respect to the species typing and "not as good" with respect to the height information. Nevertheless it forms the baseline historical data on these attributes and is updated as information comes to hand, principally now through the SILREC system.

3.2 Inventory

The process of collecting information about the current status of the forest with respect to its timber production at least is known as inventory. If there are easily mapped differentiations in the volume on the forest (in particular differentiating between degrees of past logging) it is convenient and efficient to consider for sampling purposes that these are different strata.

The accuracy of the estimates collected in the inventory process is dependent on the intensity of sampling and the care with which measurements are taken. In some forestry organisations inventory is a part-time job of field staff, sometimes it is done largely by students, sometimes by contract consultants and sometimes by specialist inventory crews. Accuracy will vary among these; the best situation is probably the specialist teams as has been the case in Western Australia for many years. It was claimed that crews receive careful training and take professional pride in their work which is monitored by some field checking of measured plots. It was also claimed that because those supervising the crews had a significant role in all aspects of the determination of sustainable yields up to the point of recommendations to the Minister, it was to their advantage to produce creditable results.

3.2.1 Karri inventory

The most recent inventory of the mature karri forests was a management level inventory (MLI) conducted from 1973 to 1984. Field procedures have been outlined in training manuals (CALM, 1980). The basic design was a systematic stripline sample with the lines spaced 400m apart. This gave a sampling rate of 2.5% over the forest. The design was considered efficient in that the dense understorey is a considerable impediment to access, and the stripline sample meant that all walking time was spent in gathering data, not in finding a plot location. The heavy karri canopies precluded any use of air photos for estimating tree heights (in contrast to the jarrah inventory). It is noted that the manual recommends that lengths of products in the tree be ocularly estimated and only checked regularly with a clinometer. Data collected in another state indicate log lengths based on ocular estimates can be seriously biased.

The relatively high sampling rate meant that information was collected at an intensity suitable for operational as well as strategic planning. The MLI has been kept current through detailed monitoring of the products removed from the forest. Estimation factors and utilisation factors based on removals data for an annual sample of 10-12 logged coupes are used to calibrate the MLI data by strata (based principally on past logging/silvicultural history). It was claimed that this procedure is very effective in ensuring that inventory data are current and accurate.

3.2.2 Jarrah inventory

The most recent inventory of the jarrah forest was completed in 1991. It was an innovative design, a two-phase system in which the first phase gave estimates of merchantable volumes based on large-scale stereo-pairs of air photos taken from a helicopter with boom-mounted cameras (Spencer, 1992; Biggs, 1990; Biggs, 1991).

This phase resulted in over 32 thousand photo-plots located by GPS scattered systematically over the unstratified forest (Biggs, 1989). Stratification was not used because the variation in merchantable volume over the mature forest is not closely related to any mapped layer, it would have caused major difficulties in locating plots from the air and because of the perceived need for different types of post-stratification. In the first phase the volume of individual trees was estimated from measurements of their height on the stereo pairs. In the second phase a subsample (about 10%) of the photo-plots were located on the ground and were carefully measured. Merchantable trees were described fully with respect to their visible defects and size so that accurate estimates of volumes by product classes (sawlog grades, etc) could be obtained. A further subsample of the ground plots had felled plots established nearby to relate standing and felled volumes. Field and data management procedures are described by Spencer (1992).

An Inventory Resource and Information System (IRIS) was developed to manage the inventory data and subsequently to keep it current. The inventory process has been repeated a few times over recently logged areas to maintain up-to-date information. Most of the ground plots which are logged are re-measured to monitor removals and re-establish current condition.

3.3 Growth estimation and projection

Past growth of forests is generally determined by the re-measurement of permanently marked plots. Over a thousand permanent sample plots (PSPs) have been established in the south-west forests, a few dating back to 1916 and are re-measured every three to 10 years depending on rates of growth. A manual detailing the considerable amount of data collected on PSPs and measurement standards has been produced (CALM, 1991). There are also experimental research plots which have contributed data for the construction of growth models. Some recent work has suggested that it is possible to estimate ages of karri and to some extent, jarrah, by tree ring analysis (Rayner, 1992). Further insights into tree growth are possible through this means.

The process of developing models of the future growth of the forests using information about past growth is dependent on the availability of suitable data and an analyst who not only has modelling skills but also has an excellent understanding of the forest and its dynamics under management. CALM is fortunate in having a few highly skilled analysts who have been with the organisation and working in management roles in the forests for some time.

3.3.1 Karri forest

The karri forests have had a varied utilisation and silvicultural treatment history. In the late 1930s a form of group selection silviculture replaced the previous clearfelling regime and remained the dominant management system for almost 30 years. In 1967 clearfelling was re-instituted due *inter alia* to the difficulties associated with the selection method of carrying out a second cutting cycle without destroying what little regeneration resulted from the first cycle. This has meant that at least three types of forest can be found and growth estimates differ among these: the mature essentially unlogged forest, the so-called two tiered forests resulting from selection management and the regrowth forests resulting from recent clearfelling (Bradshaw, 1985).

The mature forest is considered to have zero net increment. This simple assumption has been validated by comparison of the removals (via the LOIS) with the inventory estimates and is monitored from re-measurement of about 50 PSPs in the mature forest.

The growth of the two-tiered forest is based on the assumption that it consists of a mix of mature forest (zero net increment) and regrowth growing at a reduced rate (dependent on degree of overstorey). There are about 20 PSPs in these stands to monitor these assumptions.

A stratified arrangement of 230 plots was established in the regrowth stands around 1980. Detailed measurements have been made on each plot. In addition thinning and espacement trials and other experimental plots have provided sufficient information for an individual tree model to be developed. This followed the well-known structure of the Victorian STANDSIM models after exhaustive testing of alternative structures. It formed the substance of a PhD thesis (Rayner, 1992).

The controlled burning regimes might be assumed to have some impact on the growth of karri. However intensive investigation has revealed no long-term negative impact of controlled burns on the stand growth rate provided fire is not introduced before the regrowth is aged about 20 years.

The regrowth models have been incorporated into a simulator called KARSIM (CALM, 1995). This is a deterministic growth model except for a probabilistic function for mortality.

3.3.2 Jarrah forest

The jarrah forest has also gone through some changes in silvicultural treatment which impact on growth rates and the ability to model them. Mostly it has been harvested under various forms of the selection system, with follow-up treatment prior to the 1940s, and without since then (Stoneman et al, 1989). Since the mid-1980s, larger gaps have been created to encourage development of lignotubers, with a shelterwood system being used where lignotubers are absent. Single tree selection methods are used in dieback stands.

Some 650 PSPs have been established in the jarrah forest; more than a third of these were established 30 or more years ago and have been periodically measured since. About 40 plots are in unlogged areas.

Unlogged jarrah forest and remaining trees following selection cutting are assumed to have zero net increment. This is being monitored through the LOIS.

A matrix modelling approach has been used in the past to predict the growth of jarrah stands under selection management, the goal being to preserve the current distribution of size classes. This method is reasonably successful for medium-term stand projection but because of the many in-built assumptions, not very robust for long-term forest-level projections. An attempt to build individual-tree models foundered mostly because of lack of crown data in the early plot measurements. Current work is focussing on building cohort models which will stratify the tree population of a logging-history stratum according to their size and then project these size-cohorts separately, in recognition that only the co-dominant cohort shows any appreciable growth.

3.4 Yield regulation and scheduling

The next step in predicting the future supply potential of the forest is to apply the growth models to the existing inventory statistics over a long period of time. Commonly external demand and other operational constraints are applied at this stage and often an attempt is made to "smooth" the irregularities in the predicted production from the forest so that the effects of major sudden changes in supply are reduced. Alternatively or in addition the process may be driven by a desire to create a forest of a certain structure at the end of the planning period. This is the process called "Regulation". There may also be an attempt to optimise production over time. A byproduct of the regulation process may be a strategic-level schedule of where and when harvesting operations should occur in the long-term future (Turner, 1995). Because of the importance of spatial relationships in forest planning, acceptable solutions may be further tested for spatial feasibility.

3.4.1 FORSCHED/KARSCHED

Although CALM uses different computer systems for projecting the karri and jarrah forests, they both follow the same methodology so will be described together here. The two systems are respectively called KARSCHED and FORSCHED, and will be referred to here collectively as FORSCHED (see also CALM, 1997).

FORSCHED is an Oracle-based system which operates on CALM's VAX mainframe. It is a relatively simple (conceptually) simulator which applies appropriate growth models to user-defined strata and projects the inventory statistics derived from the Oracle database over time (after first bringing them to a common starting point in time, usually now), and imposing simulated harvesting patterns which produce wood yields. Constraints may be imposed to adjust the patterns of yields or the structure of the forest to meet specified strategic criteria. Commonly a large number of scenarios are produced and a subset of these is selected for further consideration at higher organisational levels. The process by which these scenarios are selected is dependent on the experience of the analysts and is not by any explicit decision rule. According to the Manual (CALM, 1997, p.3) "a solution...is obtained by iteratively adjusting operations' parameters and viewing the resultant output. The impact of the proposed regime is then analysed using a combination of graphical and tabular output. Subsequently adjustments are made to the operations' parameters (e.g. the number of years to complete an operation on a strata); the yields are recalculated, etc." FORSCHED does not apply any optimisation for example to maximise wood yields over the planning period. Output is often passed to a SAS package to produce graphical displays (see Figure 2 as an example). Standard graphical outputs are prediction of sawlog yields by year, area cutover by year and age structure of the forest at 10-yearly intervals.

3.4.2 Hardwood Integrated Planning System (HIPS)

The spatial feasibility of selected scenarios can be tested through HIPS, a Map-Info based system with links to almost all other GIS, databases and simulators. HIPS uses a subdivision of the forest into about 183 000 " stands" formed by overlaying of appropriate GIS coverages. Contiguous stands are aggregated into coupes by logging year as determined by FORSCHED or some other means. A major value of HIPS has been in spatially examining the relationship between the fire protection plans and the timber production plans. Complex rules were developed in the 1970s for protecting regrowth by buffers which are subjected to a regime of prescribed burning until the regrowth reaches 15-20 years old. Then the buffers may become available for harvesting and be protected by burning of the former regrowth stands. For the first time it is now possible to follow these plans through time by examining maps of the simulated logging and prescribed burning patterns every five years. Non-timber attributes such as heritage areas can also be overlayed to ensure protection of special values. HIPS can produce a harvest planning map for any coupe.

3.5 Monitoring

At various points in the above description mention has been made of methods used by CALM to monitor their data collection and analysis systems to ensure that the quality of the information produced is high. In some cases the monitoring information is used to calibrate or adjust previous estimates. While this may elicit unease about the accuracy of the original data, it is sound and common practice in production systems to have feedback control. CALM has been able to use their commercial accounting procedures to do this to a very effective degree through their Logging Operations Information System (LOIS).

3.5.1 LOIS

LOIS is a computerised process that was introduced in 1986 to track the source, destination, amount and type of all truckloads of forest products emanating from CALM lands. It is the basis of all sales invoicing and thus has a high degree of credibility and accountability. This has been used to check actual removals against previous estimates and to update inventories through calculation of Estimation Factors (ratio of actual to estimated removals), Product Proportion Factors (ratio of volume removed to total volume) and Product Utilisation Factors (ratio of actual to estimated product proportion factor). For karri forests, the Estimation Factor has remained relatively constant at about 1.17, but the Utilisation Factor has been

Annual first + second grade sawlog supply (volume in cubic metres)

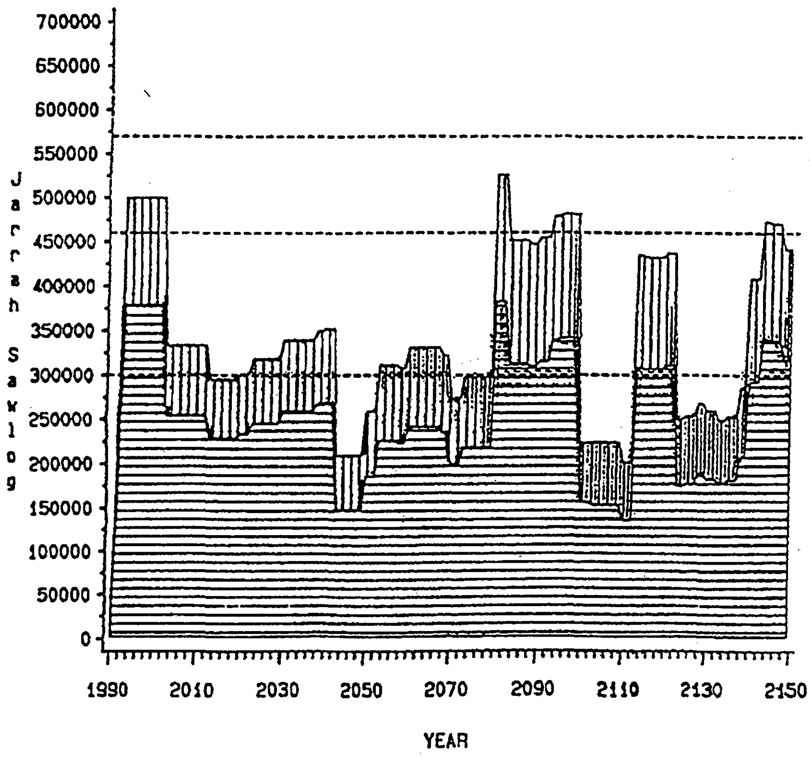


Fig. 2. Example of graphical output from FORSCHED showing one scenario of production of jarrah sawlogs over time.

decreasing over time since the MLI, attributed to improved utilisation of wood considered in the inventory as non-sawlog.

3.5.2 Other forms of monitoring

CALM has from time to time carried out other forms of monitoring. A good example is the utilisation monitoring study carried out in conjunction with the jarrah inventory and which is continued periodically as other measured inventory plots are logged. See 4.1.4.

3.6 Fire and disease considerations

Two major factors of the ecological environment of the south-west forests require comment in terms of their effect on estimating future yields.

Prescribed burning has been fundamental component of forest management in the south-west for decades. Its greatest impact in terms of the yield prediction is on the spatial arrangement of areas to be logged and thus the scheduling of harvesting must take into account the need to buffer regenerated areas for 10-15 years after logging. This severely constrains the yield regulation options and makes difficult the use of more automated scheduling procedures such as linear programming. Prescribed fire does not appear to have a deleterious effect on the growth of mature forests. It is assumed that the burning program is successful in reducing the potential impact of wildfires, so their effects are not built in to growth models except at a low frequency for lightning strikes.

The most significant disease by far in the region is jarrah dieback. Mapping of dieback has developed into a sophisticated process which is closely monitoring the progress of the disease. Areas of severe dieback are mapped out as non-production zones, areas of low dieback attack are assumed to be of low future productivity. Growth models take account of the reduced productivity of these areas.

4 EVALUATION OF THE COMPONENTS

4.1 Datasets

In the time available for this consultancy it has not been possible to examine more than a casual sample of any datasets. Rather the evaluations have been based on how the data have been collected, managed and used and then comparisons have been made with similar operations in other states.

4.1.1 Forest area estimation and stratification

All area estimation is via one of the GISs, so is dependent on the accuracy of the original mapping and its digitising. CALM has indicated that its 1:25000 mapping has an accuracy of 12.5 metres of ground position 85% of the time and a worst case of 50 metres. This is well within the 2ha cell size of FMIS. FMIS has been in operation since the late 1970s, so it is likely that any gross inaccuracies will have been detected by now. The frequency with which datasets are overlayed would suggest also that discrepancies would have been detected, particularly as those carrying out those procedures are also responsible for data quality. Base maps are derived from DOLA which established a reputation for high standards of mapping in the early days of GIS. A minor concern is that the 2ha cell size of most of the FMIS data leads to some imprecision, especially in the estimation of small areas. This has prompted the recent adoption of a 0.5ha cell size and the use of a vector system where a large cell size might lead to problems, e.g. in buffer generation (with subsequent transfer back to FMIS).

The net area of coupes is determined by six-monthly aerial photography in conjunction with differential GPS (DGPS). CALM was one of the first organisations in Australia to use DGPS (for the Jarrah Inventory) and has gained extensive experience in its use. Net areas exclude streamside buffers, areas too steep to log and other mappable operational constraints. These are mapped from the 1:12 500 air photos taken after the logging. From the combination of frequent photography, DGPS and extensive use of GIS it has to be concluded that area statistics are likely to be quite accurate and certainly sufficient for the accurate estimation of sustainable yields.

Although the original forest type maps are somewhat dated, the simplicity of the overstorey floristics (compared to east coast forests) facilitates API and floristics data have been extensively checked in the process of publication of Forest Association maps (Bradshaw et al, 1997). However no mention of quantitative estimates of accuracy is made in that publication. Structural attributes are updated by ground-based observation. CALM has built up a cadre of skilled photo interpreters through the dieback surveys and the jarrah inventory and it is unlikely that major discrepancies are undetected. However given the criticism of forest typing that is occurring in other states, an accuracy assessment at an opportune time would seem wise.

Reliable applications of inventory and growth information requires appropriate stratification. This is usually based on a combination of forest types and past logging history. While the latter may be obtainable from past records, in most forestry organisations these have not proved very reliable especially in the spatial detail. Significant effort has been recently put into checking the veracity of logging history maps and CALM staff believe that the high wood-yield areas are now reliably mapped but more work is needed to check the poorer quality areas.

4.1.2 Current growing stock statistics

Current growing stock statistics are derived from the karri MLI of 1978-84 and the jarrah inventory completed in 1992. Through the LOIS and other updating procedures such as the SILREC system these records are adjusted for current utilisation standards and for changes due to harvesting operations, etc. In addition the jarrah inventory is periodically updated with new plot measurements.

Because of the systematic stripline nature of the karri inventory, it is not possible to estimate meaningful sampling errors; however a sampling intensity of 2.5% is high for strategic inventories. Sampling errors for volume for the jarrah inventory were designed to be of the order of less than 20% (95% confidence level) for areas of 20 000ha and 10% for areas of 50 000ha or more. The IRIS automatically generates a summary of sample statistics for every analysis. An example showed for an area of 15 500ha the ratio standard error for total bole volume of sawlog species as 14.1 with a mean of 80.3 m^3. This translates into a sampling error of about 34% at the 95% level which is somewhat higher than the design level of about 22%. It's not uncommon for actual sampling errors to be higher than the design. It's not known whether this was an outlier but obviously it needs monitoring.

The karri inventory is now 15 years old. It would seem prudent to be thinking about a new inventory of the karri resource in the near future. It should be possible to design an inventory using new technologies at a fraction of the cost of the previous one. This would provide a necessary check on the correction factors which have been applied to the inventory data over the years.

4.1.3 Estimates of past growth

Past growth of regrowth stands has largely been obtained from permanent sample plots which are subjected to normal management practices. There is a representative set of permanent sample plots (PSPs) in both forest types but there is a shortage of long-term plots representing current silvicultural regimes. The slow growth of the jarrah also is an inhibiting factor. In general it is probable that the current set of plots if carefully maintained and augmented as the regrowth estate increases will be adequate for future growth modelling. The representation of species other than karri and jarrah needs to be evaluated; while it appears they grow similarly to the more common species there does not seem a lot of quantitative evidence to support this assumption.

Some trials have been done of measuring past diameter growth of karri through ring analysis. Although this can provide only part of the information required about growth (e.g. provides no information about mortality) and is expensive, it can be quite useful in particular for gaining information on long-term growth rates. Further work should be encouraged.

The assumption of zero net increment growth for unlogged stands of jarrah and karri and partially logged jarrah residuals seems a glib but reasonable assumption. An inquiry into this assumption in Tasmania revealed that veteran ash were in fact growing at a significant positive rate externally, begging the question as to whether internal defects were increasing at the same rate. Of course the importance of the question diminishes as the area of mature stands reduce. In due course data from the PSPs should be able to answer the question.

4.1.4 Comparison of actual removals with standing volume estimates

As indicated above, a number of approaches have been devised to use the data on removals in the LOIS to check estimates of standing volumes obtained during inventories. This information is actually used to calibrate the inventory results.

It appears that this is a systematic and sophisticated approach to controlling the inventory for change and is probably the most advanced use of removals data for this purpose in Australia.

In addition a comprehensive utilisation monitoring study was done in connection with the jarrah inventory. The volumes removed from the 56 inventory plots that were cutover in 1993-94 were carefully compared with assessed volumes. *Inter alia*, this showed that the inventory overestimated the proportion of the gross bole volume that was actual sawlog by up to 6%. A degree of overestimation in inventories in native forests in Australia is not uncommon and indicates the need for the correction of inventory data against actual removals, as is done in the CALM system. Continued attention to monitoring this relationship is essential.

4.2 Models

The CALM approach to estimating sustainable yields from the karri and jarrah forests involves the development, maintenance and use of a large number of mathematical models. These have been constructed mostly by regression analysis from data specifically collected for that purpose, from general-purpose surveys or from data from experiments. For example data from the re-measurement of thinning experiments have contributed to the construction and testing of growth and mortality models. In addition data are often used from a different source to test the models. Some of the more important models involved in yield prediction are reviewed here.

4.2.1 Models for estimating volumes of standing trees

Models have been developed to estimate from tree dbhob and bole height, the bole volume of mature and pole-size karri (WAFD, 1981; WAFD, 1983). In the jarrah inventory and on all PSPs, the boles of trees are described in quality segments to allow computerised product specifications to estimate utility of log segments. In this case relatively simple geometric models are adequate to compute utilisable bole volumes. These are periodically calibrated against felled tree measurements when ground plots are logged as was done in 1993-94 (see 4.1.4). It can be expected with these methods that the actual saleable volumes are accurately estimated.

4.2.2 Models for estimating product outturn from predicted gross volumes

The quality assessment procedure used in plot measurement is able to account for defects which have some external manifestation but not those which are internal such as rot and termite attack. Sawing trials have been conducted periodically to improve the ability to predict internal defects from external indicators. The Quality Sorting computer program is driven by user-defined product priorities, and could be improved so that it determines log assortments optimally to provide comparison and learning. Again the LOIS records are invaluable for relating actual product outturns to estimated volumes by products and allowing the calculation of calibration coefficients.

4.2.3 Models for predicting growth and mortality of forests under various conditions

The heart of any yield prediction and regulation system is the growth modelling component. The karri regrowth models are the result of intensive investigation and review, including internationally through peer-reviewed publication and must be considered reputable. Plots used in their generation and testing were deliberately chosen such that they contained no overstorey trees to restrict growth; the models would need modification if the silvicultural system departs significantly from a clearcutting regime. In addition there are now new data available from recently measured thinning trials which should be used to calibrated and perhaps extend the existing KARSIM model.

The models used to predict the development of jarrah forests are less robust and satisfying. The approach used to model the development of the selection-managed stands is acceptable for short-term (up to a few decades) modelling but questionable for long-term forest-level prediction. The science of modelling uneven-aged stands is however considerably underdeveloped. With the change in silviculture to small gaps and shelterwood methods, new models are under construction for which the cohort approach seems appropriate.

The development of strategic-level growth models for the jarrah regrowth forests should be given high priority. Cohort models, as currently under investigation, are a reasonable approach for stands which are managed as uneven-aged stands, but since the gaps of the recent silvicultural methods are tending to be large enough (2-10ha) to be mapped, it may be possible to model the growth of regrowth within the gaps as even-aged stands.

4.3 Systems

The connection between field data and the prediction models is usually a computer system. CALM uses a number of computer systems to accomplish management information tasks and these have already been mentioned. Two of the most important in the CALM yield regulation process and which are appropriate for critical review for different reasons are the forest projection system, FORSCHED and the monitoring system, LOIS.

4.3.1 Computer systems used to project forest statistics into the future and to take into account constraints on the predictions

The FORSCHED system is a simulation program which takes forest statistics for a defined stratum, applies growth, harvesting according to a fixed schedule of operations to appropriate cohorts, and mortality, and produces tables and graphs of the production of defined product classes over time. Operational constraints are built into the model. However the simulator does not do any adjustment of yields to compensate for high or low productions - these adjustments have to done externally and the system rerun to see the effects of changes to regimes on the outputs. The implication is that as far as possible the optimal stand regimes should not be varied.

A number of forestry organisations have found it useful to recognise that the set of regimes which are optimal at the stand level are not necessarily optimal at the estate level where system-wide constraints such as a need to produce an even flow of products over time may dictate the use of a mixture of regimes not all of which can be stand-optimal. In this case it is useful to have a computer system which can accommodate a range of acceptable regimes for each cohort and then choose between them using some priority rule (e.g. oldest first) or according to some optimisation procedure such as linear programming. Having such a tool should reduce the number of iterations of reviewing outputs to get an acceptable sustainable yield, without necessarily losing transparency. It also provides an increased flexibility of outcomes. Of course all solutions would need checking spatially through HIPS or the optimiser would need built-in spatial feasibility.

4.3.2 Systems set up to verify and validate predictions from growth models

An appropriate feedback mechanism to monitor and correct for bias in inventory or growth models is a fundamental component of a system which relies on sampling for its estimates. The LOIS is a system for tracking in detail the removals from the forest, providing an outstanding opportunity to compare assessed volumes by products with the volumes actually removed. This is a considerable strength of the yield prediction system and allows the calibration and monitoring of inventory data. Any deficiencies or datedness in the inventory data can be compensated for by this process and it is obviously important that it be continued.

4.4 Methodology

The methodology used in various parts of the sustainable or continuing yield calculation process have also been evaluated. These include:

4.4.1 Sampling methods used to gather data for input to the systems

Growing stock information has essentially been collected in two inventories of the forest, one in the karri and one in the jarrah. The karri resource was estimated by a systematic stripline inventory which provided a relatively high intensity sample, making possible the use of the information at the operational level, but no valid way of estimating the sampling error. More efficient and cost-effective methods are now available particularly for strategic-level inventory. The bias which exists in the utilisable volumes is corrected by LOIS data.

The jarrah inventory on the other hand used state-of-the-art technology and sampling design. Although the systematic plot selection strictly speaking again mitigates against the correct calculation of a sampling error, in practice the plot locations are selected in an unbiased fashion so conventional sampling theory can be applied with the minor caveat that the sampling error may be slightly underestimated. The design was such that forecast sampling errors were of the order of 10% at the 95% confidence level for forest strata of more than about 50 000ha.

The karri regrowth plots have been located in a stratified manner to sample over the geographic and age range. However the low SQ sites are not very well represented by the 200+ plots and more plots are being installed in these areas as they become available. There are PSP plots in the unlogged and two-tiered forests as well. With these additions it is probably true that the distribution of PSPs in the karri is satisfactory. For modelling purposes it is more important that the plots cover the range in variables rather than being a random sample of the population.

The 650 plots in the jarrah forest also seem to be located to cover a range of conditions of the forest. About two thirds of them are 20-30 years old, the rest older. Given the long rotations being proposed for jarrah it is clear that the longer term data need to be evaluated for their value in building improved jarrah growth models. New plots will be needed to represent the new styles of silviculture being carried out in these forests.

The methods used to select samples for monitoring estimated and actual harvestable volumes is opportunistic, depending on where operations are in progress. Obviously this method requires cutting of the trees and this is best done in conjunction with harvesting operations, although during the jarrah inventory a systematic selection of plots were destructively sampled. In balance, this seems a practical solution to a potentially expensive problem.

4.4.2 Actual methods used to calculate sustainable yields

The methods used to calculate sustainable yields have been briefly described above as an iterative process using FORSCHED to produce scenarios which are examined for acceptability, then either rejected or accepted as an option for further consideration. Further scenarios are usually generated as alternatives after input parameters are adjusted. Criteria for rejection include declining yields or increasing areas harvested indicating a depletion of the resource over time. Options may be generated to show different ways of reducing fluctuations in the predicted flow of products over time. Simulations are typically run for 100-200 years. The exact process used by analysts in judging the relative merits of scenarios is not well defined and needs written description for reasons of transparency and reproducibility.

A major assumption behind the predictions is that the silvicultural treatments are carried out according to the schedule used in the simulator. In the case of the jarrah forests in particular this means that thinning of the regrowth will have to be carried out as planned, even though it will mean the market will have to adjust to a substantially smaller sawlog size in some areas. Thinning of karri regrowth is also critical for realising the growth potential as estimated by the simulator.

4.4.3 Methods used to estimate the reliability of the predictions

The reliability of the predictions can be evaluated only through consideration of the reliability of the components that go into the prediction. Error estimates are generated at some stages of the process, for example as a standard output from LOIS runs. In other cases errors are either small (e.g. for mapping accuracy), known from the inventory although updating through the LOIS calibration procedures affects that, known from the regression analysis used to construct the growth models, or unknown. Because of the checks and balances built into the system it is probable that estimates of current growing stock statistics are quite reliable and that karri growth is reliably estimated except perhaps for low site quality or mixed species stands. Jarrah growth estimation in the short term is likely to be fairly reliable but in the long term, less so with the current modelling approaches. Product outturns are again probably reasonably reliable in the short term. Strategic planning outcomes are checked for spatial feasibility through the use of HIPS. The whole system and individual components are periodically reviewed to ensure that the system is working according to design. Further effort could be put into methods for estimating system-wide reliability but experience suggests that this is a difficult research area with not too much reward.

5 PLANTATION INVENTORY AND YIELD REGULATION SYSTEMS

The methods and systems developed for pine and eucalypt plantations follow similar procedures to those for native forests. The review of these has been cursory but they are included here for completeness and to identify any major causes for concern. As well as the State-owned plantations, CALM manages a large number of joint venture plantations (mostly eucalypt).

5.1 Land information

The plantation estate has recently been remapped using 1:10 000 photography with boundaries validated against digital orthophotomaps. Boundaries are then digitised and incorporated into CALM's Arc/Info database where it can be overlayed with cadastral, management and topographic data. A resource stratification, based on top height and stocking, has also been extracted from the photography. This information has been used to review the net productive areas of plantation, as well as for inventory stratification. This level of photographic detail in conjunction with the use of GIS to validate the digitising should ensure accurate statistics of net areas.

Stand history records are being transferred to GIS and linked to the Oracle database. This new system is now known as the Plantation Management Information System. The transfer provides the opportunity to check the veracity and accuracy of the information previously recorded only on paper maps.

5.2 Inventory

In the past, inventories have been by stratified variable radius permanent plots at an intensity of 1 per 2-4ha. This has now been varied to a system of temporary plots at variable intensities on an as-needed basis. Tree measurements vary depending on purpose of the inventory. While the cost of maintaining a permanent plot system of the previous intensity is no doubt prohibitive and that intensity unnecessary, the current system seems to be imposing a risk that inventories will be relinquished completely. The need to continuously monitor the plantation estate for a variety of reasons should not be ignored.

5.3 Growth estimation and projection

The primary growth projection system used by CALM for pine plantations is the Plantation Operations Thinning Schedules (POTS) system which simulates a regime over a rotation using growth models derived from permanent plot data. The method is described by Vanclay (1994). This has recently been augmented by the Plantation Inventory Product Determination system which grows and thins individual trees which can be subdivided into product classes. New measurement data is acquired as necessary to incorporate new species, sites and silvicultural regimes. Wood flows can be generated from a combination of POTS and actual removals data obtained through the LOIS.

Eucalypt plantations growth is estimated using the *Eucalyptus globulus* Growth Simulator based on the PhD work of Inions (1992).

5.4 Yield regulation and scheduling

Harvest scheduling is performed with the Pine Scheduling System (PINESCHED) which is an Oracle-based simulator similar to FORSCHED. It can generate short-term logging plans or strategic plans and can be linked to the GIS. Although linear programming has been used in the past for pine plantation scheduling it is not currently used. Because of the financial importance of the pine estate, it would seem that an optimisation approach should remain as an option for choosing regimes which maximise present net worth or some other financial criterion.

A similar simulator named BLUEPLAN is used for yield regulation of the hardwood plantations.

5.5 Monitoring

The LOIS is used to monitor all removed product volumes and regime data are reviewed annually. It is assumed this is as useful for this purpose as it is with the native forests.

6 SUGGESTIONS FOR IMPROVEMENT

In the course of this review a number of opportunities for improvements to the overall systems have been identified. Briefly, these are:

- New growth models for jarrah forest regrowth to reflect changes in silviculture are needed, covering the full range of sites
- Karri regrowth growth models should be re-examined to ensure they can meet any requirements to consider varied silvicultural approaches arising from ESFM considerations and to incorporate new measurement data for the full range of sites
- The desirability of a strategic-level re-inventory of the mature karri forest should be evaluated with consideration being given to modern efficient designs
- The way in which sustainable yield strategies are selected and evaluated should be made more explicit so that the process can be replicated by following stated rules
- Serious consideration should be given to the extension of FORSCHED to automate the iterative process of selecting acceptable solutions, either by some heuristic process or by an optimisation approach, for which the US Forest Service's Spectrum, augmented for spatial feasibility, is highly recommended.

7 SUMMARY

Results indicated that the datasets, models, systems and methodologies used by CALM to assess sustainable yields from the karri and jarrah forests are appropriate, internally consistent and contain adequate safeguards on the quality of the data through the use of competent staff for its collection and analysis, and the incorporation of monitoring and calibrating procedures throughout the system. Areas of forest are accurately mapped to a refined level using the modern technologies of large-scale aerial photography, Global Positioning Systems and a GIS which originated as the first in a forestry organisation in Australia.

The jarrah inventory procedure is an innovative world-acclaimed system, delivering acceptably accurate data and is acceptably monitored and updated. The jarrah growth models are inappropriate for long-term growth projection and currently used silvicultural methods, and new models should be given high priority.

Estimates of the karri forest resource derive from an inventory completed in 1984 and although the data are updated through a sophisticated tracking and feedback system, a new inventory should be under consideration since the data will soon be 20 years old.

Growth data are collected from re-measurements of over 1000 permanent plots, and growth models developed for the estimation of future growth of regrowth stands appear to deliver reliable forecasts under current management strategies.

Computerised systems are used to investigate a large number of future (100-200 years) scenarios in order to produce recommendations of sustainable yield from the two forest types. The interpretation of these scenarios requires experience and comprehensive understanding of the forests. Despite this there is a need for a more transparent explanation of this part of the process. The management feasibility of these scenarios is checked through a new computerised tool which translates the strategic solutions into maps of the future forest condition. It is noteworthy that most of the systems have been documented as technical reports at least at the user level, and many of the components are the result of PhD research and have been subjected to international scrutiny through examination and refereed journals.

It is concluded that the systems and procedures developed by CALM staff for estimating sustainable yields from the jarrah and karri forests of the South-West Forest Region are adequate and appropriate and certainly rank among the best in Australia in terms of comprehensiveness of the data base, monitoring arrangements and growth modelling. The complex computerised systems and production of scenarios for estimating future yields are largely the result of the efforts of a dedicated few and the Department needs to ensure that the skill base is disseminated through documentation, training and transparency of decision procedures.

8 ACKNOWLEDGMENTS

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APPENDIX

Appraisal and accreditation of wood yield methods and data used by CALM for the South-West Forest Region of Western Australia

Terms of reference

For the South-West Forest Region of Western Australia, the terms of reference for the consultant to undertake an appraisal are:

1. Work with the Bureau of Resource Sciences and the Western Australian Department of Conservation and Land Management to develop a works program for an appraisal of wood yield methods and data.

2. The consultant will be provided with relevant information and supervised access in Western Australia to relevant systems. All information provided to the consultant remains the property of the providing agency and may not be used by the consultant for any purpose beyond the scope of the project, nor may the consultant retain a copy of the data after conducting the work.

3. The appraisal shall build on previous reviews of methods and systems relevant to south-west Western Australia including CALM (1992), Turner and Wood (1993) and Meagher (1993).

4. The consultant will review the basis of CALM's calculation of native forest wood yields to determine the reliability of yield forecasts for use in the RFA process. Specific aspects to be addressed include:

- methods and data used to derive yield forecasts (including calculation of net harvestable area, inventory, growth and yield models, simulators, schedulers, assumptions and constraints, the capacity of the models to predict different management scenarios and loss of productivity due to dieback, and the format of yield forecasts).

- relative accuracy of predictions, strengths and weaknesses and scientific validity of the methods/systems used for data collection and modelling of growth and yield, generation of management prescriptions and harvest scheduling.

- the overall expected reliability (which incorporates sensitivity) of the yield forecasts for use in the RFA.

5. Indicate possible improvements in the methods, calculation of yield and scheduling of harvest.

6. A separate written summary of the system used for pine plantation yield forecasting will be provided by CALM. The consultant will discuss and comment on the nature and completeness of this system.

7. Provide a written report to an agreed standard in draft form to Mr Karl Rumba and Dr Martin Rayner by 10 October 1997. The final reporting date will be 31 October 1997.

R F A

Regional Forest Agreement

AUSTRALIA

THE GOVERNMENT OF WESTERN AUSTRALIA

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