


CALCULATING THE SUSTAINED YIELD FOR THE SOUTH-WEST NATIVE FORESTS[1] OF WESTERN AUSTRALIA

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[1] Cover photos: from top left clockwise: uneven-aged jarrah, even-aged jarrah, two-tiered karri, even-aged karri

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EXECUTIVE SUMMARY

1. Introduction

In summary, the terms of reference for the Panel were to confirm whether:

1. the structure, operation and outputs from the woodflow models are robust and flexible enough for computing the sustained yields and other wood availability figures included in the proposed FMP;
2. the uncertainty associated with a drying climate has been adequately factored into the sustained yield calculations;
3. the level of provision for other risks and uncertainty associated with the volume estimates are appropriate; and
4. the calculations incorporate suitable adjustments for the operational feasibility of obtaining the strategic woodflows.
   The Panel was also consider the issues raised in the public consultation process when undertaking its work.

This report deals with a work that is still in progress, pending some decisions by the Conservation Commission, completion of dependent computations and completion of computations relating to changes the Panel has requested. However, the structure and detail of the calculation of sustained yield has largely been completed.

2. Identifying net productive areas

The identification and verification of the net productive area of forest is a fundamental component of the inventory system because all subsequent volume estimates relate to the boundaries so identified.

A large number of other 'informal reserves' have been established through objectives and actions in the current FMP. These reserves were set aside to protect local or specific mature conservation, soil, water, heritage or other specified values, such as old-growth forest.

Although the information in the GIS and FMIS is of a high degree of accuracy, from time to time adjustments are needed to accommodate changes to a particular Theme or minor past misclassifications. The process involved in making changes is flexible, robust and indicative of a mature system that has integrity and security of process.

The DFMP proposed changes to net productive area and changes in some informal reserves. All old-growth forest is unavailable for timber production, and the boundaries have been mapped to a minimum area of 2 hectares and those areas excluded from harvest. Further reductions were applied within the total areas of each Forest Type available for timber harvesting to take account of local landform and vegetation conditions that are unsuitable for timber harvesting.

Recommendation 2.1, Area database: The processes used in maintaining and adjusting the GIS and FMIS databases are mature, flexible, robust and documented well. The Panel is satisfied that the identification and verification of net productive area meets best practice standards.

3. Estimating the 2014 standing sawlog and other volumes

Forest inventory inevitably involves errors through the use of plot sampling, various measurement techniques, and statistical estimation of tree volumes. The critical properties of those errors can be measured and summarized using two criteria – bias and precision.

DEC staff have a tendency to take the conservative option at every step: the danger of this approach is that these many small conservative assumptions all accumulate in one direction, and may contribute a substantial hidden bias. It is preferable to make best estimate whether it is conservative or not, knowing that the final estimate will be 'on the edge' and then to make an overall adjustment for any desired redundancy, informed by comprehensive monitoring.

Recommendation 3.1, Best estimates: Government agencies involved in calculating the sustained yield should empower staff to take the 'best' and not a conservative path of action in estimating the sustained yield to avoid accumulating a substantial hidden bias. Any adjustment by way of a safety margin is a policy decision to be taken after the sustained yield has been estimated.

Even-aged regrowth has been assessed using stratified random sampling. Two-tiered karri forest is more variable and aerial photography was used to inform inventory. Jarrah forests were assessed with two-stage inventory, following a procedure instituted during the 1980s. In preparation for FMP14, some of the original jarrah ground plots were re-measured. A significant number of other long established permanent plots within silvicultural and fire research trials have been used in growth model development, validation, or yield table checking.

Gross bole volume is estimated by integrating stem cross-sectional areas between the recorded breast height (1.3 m) and the observed stem diameter at crown break. In current calculations, the former is adjusted for growth, the latter is not.

Recommendation 3.2, Cross-sectional adjustment: The Panel believes that the upper stem cross-sectional area should be adjusted for growth in proportion to the adjustment of that at breast height.

One important step in quality control of models and their prediction is to reconcile predictions against reality and so remove, as far as is possible, any bias. Some anomalies were evident in data collected by DEC that required further analysis.

Recommendation 3.3, Further UMA analyses: The Panel has requested that further work on the UMA data be undertaken to establish the reasons for these differences and obtain the best correction possible. It also believes that routine monitoring along the lines of this study is essential and should be given high priority.

4. Predicting future yields

The estimation of growth and prediction of future yields is carried out separately for the (1) mature two-tiered karri forest, (2) even-aged karri forest (3) uneven-aged jarrah forest (including mixtures) and (4) even-aged jarrah forest.

Because deliberate conservatism is not best practice, the incremental growth from the 2002-12 re-measurement should be used to predict yields for two-tiered karri forest.

Recommendation 4.1, Two-tiered incremental growth: The Panel believes that best practice requires that the incremental growth from the 2012 re-measurement should be used to predict yields for two-tiered karri forest in the proposed FMP14.

The Panel has inspected summaries of the yield tables for stands in excess of 10,000 ha. It notes the attention given by DEC in comparing predicted sawlog volumes against actual volumes. Subject to the corrections above, the Panel believes the present set of yield tables represent best practice.
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Recommendation 4.2, Continuing data collection and analysis: The Panel believes that, subject to some revised analyses yet to be completed, the present set of yield tables represent best practice but notes the need for continuing data collection and analysis to maintain that position

5. Adjusting for future climate change

Adjustments for climate change and similar potentially predictable changes need to focus on applying the best estimates to remove biases. Any adjustment by way of a safety margin is a policy decision to be taken after the sustained yield has been estimated.

Clear distinctions need to be drawn between the impact of (1) the long-term trends in climate to 2070 and beyond, specifically those in average annual rainfall and temperature; (2) the short-term trends and variability that occur in those variables over ten to 30 years or so; and (3) the changes in seasonal characteristics that may be associated with the latter.

(1) Long-term trends: In calculating the long term sustained yield, the DEC team has estimated progressive adjustments to the yield tables for jarrah and karri, based on data from a series of regrowth jarrah and karri permanent plots. Statistical analyses were carried out for relative change of mean tree diameter and stand volume. Initial results did not show a geographic difference in jarrah growth rates between different rainfall zones. At the request of the Panel, further work by DEC indicated that the average rainfall had a weak but statistically significant effect on jarrah tree increment, in addition to the statistically significant effects of site quality (canopy top height) and tree DBHOB.

No significant differences were found in the relative change of karri growth rates between different groups of PSPs that represented different soil types and annual rainfall.

Recommendation 5.1, Further climate change analyses: The Panel endorses the research done to develop adjustments for climate change for jarrah and karri forests for FMP14. The Panel recommends that further research on the impact of climate change of the productive forest estate should be pursued in the course of the next Plan, noting that any refinements to the approach need to be consistent with the processes used in monitoring and scheduling of yields.

(2) Medium term trends and variability: The Panel concluded that although there was good evidence of drought events over the past decade in the jarrah forest, the impact on crown condition was restricted to limited parts of the forest where factors such as shallow soil depth predispose the forest to water deficit in years of well below average rainfall. The level of tree mortality remains relatively low. Notably, jarrah in the lower rainfall zones has not experienced as much drought impact, relative to extant area, as jarrah in higher rainfall zones.

(3) Seasonal characteristics: Changes in the seasonal growth of jarrah associated with climate change could have further implications but these are beyond the level of resolution that could be credited to this analysis.

Recommendation 5.2, Remote sensing and permanent monitoring plots: DEC should extend their remote sensing of vegetation change over the next FMP and should establish large permanent monitoring plots within which individual tree canopy responses can be monitored in the long term. These plots should also be available to researchers outside DEC facilitating greater integrated research, as well as being used by DEC to investigate tree water use and other attributes using the 3-PG model.

6. Adjusting for pests, diseases and fire

(1) *`Pests and diseases: Phytophthora cinnamomi* is a major threatening process in the South-west Botanical Province of WA. A previous sustained yield review Panel recommended developing a capacity to model the introduction of new infection sites rather than simply the extension of existing occurrences but this work has not proceeded. Regrettably, the Panel believes that the DEC conclusion completely misses the point of long term monitoring, which is not about the short term fluctuations of climate that occur.

The Panel believes that the impact of *Phytophthora* on growth is still very uncertain. It accepts that DEC has acted on the best current data available but does not believe them to provide the best estimate of impacts because of an imbalance in numbers on infested areas.

Recommendation 6.1, Best estimates for *Phytophthora*-infested jarrah sites: Notwithstanding the recent changes in short-term climate, the Panel recommends jarrah growth on *Phytophthora* -infested high impact sites be reduced by 20%, and by 5% on moderate impact sites, as used in FMP04.

Recommendation 6.2, Further dieback and disease research: The Panel strongly urges that further work be undertaken to develop a Phytophthora and Climate Change model that has the capacity to model a wide range of scenarios including disease outbreaks of *Phytophthora cinnamomi* (and other *Phytophthora* species if they are shown to be having an impact on the forests) and new infection sites following extreme weather events such as unseasonal storms.

The Panel supports the approach adopted with respect to *Armillaria* but and believes it should be extended to later rotations.

Recommendation 6.3, *Armillaria* degrade sites: Although having a negligible effect on sustained yield, the next and later rotations on *Armillaria* sites should repeat the degrade adjustment of sawlog used in the current rotation in the calculation of sustained yield.

Gumleaf skeletonizer, jarrah leafminer and *Phoracantha* are episodic pests that have caused localized forest damage and whose past impacts are reflected in the inventory data.

Recommendation 6.4, Other pests and diseases: The Panel supports the approach adopted by DEC in making adjustments to reflect karri and jarrah pests and diseases other than *Phytophthora*. It notes that future seemingly unpredictable episodes of infestation are best taken account through the safety margin to be applied to the final calculated sustained yield, although it believes that this source would be quite a very small contributor, given their nature and likely extent.

(2) *Fire:* The DEC methods of adjusting for fire through area adjustments developed for the previous Plan are unsatisfactory in the light of the improvements that the current Panel propose in dealing with risk and uncertainty. The inventory data already reflect the impact of past fires.

However, future fire is episodic and seemingly unpredictable in a deterministic model such as DEC has developed.

Recommendation 6.5, Fire adjustments: The Panel recommends that DEC drop the previous area adjustments, for fire, thereby avoiding deliberate conservatism. DEC should develop adjustments to aggregate standing volumes of sawlogs based on available data. This would enable the approximate adjustments to sustained yield to be calculated and so inform later determination of the safety margin to be applied to the calculation of sustained yield.

7. Scheduling future woodflows

Woodstock software is used to select a set of woodflows for the various Forest Types that will aggregate to best meet the constraints whilst, as far as is possible, providing the most volume possible for utilization over the planning horizon. It computes the best aggregate schedule of woodflows, while meeting the considerable array of market, legal and operational constraints.

A systematic approach in documenting and running the scenarios is important, as is the checking of the specification of the scenario and the sensibility of the outcomes. Outcomes are checked by running the simulation models used in scheduling the current FMP, as well as checking the sensibility of outcomes by other experts.

The Panel endorses the view of the leading scientist of Remsoft that best practices are mostly employed by DEC throughout, although the number of variables could be reduced to advantage.

(1) *.Strategic planning:* Preliminary karri scheduling resulted in a continuing mixture of smaller logs from harvesting even-aged regrowth, together with a mix of larger sizes from the harvesting of remaining two-tiered karri stands. From an industry perspective, a more economically viable solution may be to constrain the to see a step change to a smaller average log size but one exhibiting lesser variability in size. This would enable the successful purchaser to better adapt to the log mix with appropriate technology and scale.

Changes in the mix of sawlog grades and sizes are inevitable as a consequence of the history of past cutting. As far as possible, these impacts need to be taken into the process of simulating the allocation of allowable harvest levels to individual sawmills or processors in terms of location and scale, rather than assuming that a particular level of sustained yield is immutable and an automatic solution for all times.

Recommendation 7.1, Strategic planning and step changes in scheduling: Analyses of sustained yield should be based on strategic planning by DEC and FPC to assist the future development of economically viable timber processors and dependent communities. This may necessitate step changes in scale and timber grade and size, in contrast to a long-term static sustained yield.

(2) *Specifying constraints:* The Panel believes that while non-declining even-flow and sequential flow constraints can be useful, they should be used sparingly.

(3) *Simplifications:* In earlier Sections, the Panel has recommended a review of Themes and pooling or simplification of Silvicultural Status categories for jarrah forest to reduce complexity and/or improve precision. The Panel is also skeptical of the frequency/intensity of the thinning schedule for re-afforested minesites that is applied more generally to even-aged jarrah regrowth.

Recommendation 7.2, Pooling and/or simplification of jarrah strata for scheduling: The Panel recommends that, where practicable in the time available, the pooling and/or simplification of the jarrah Silvicultural Status used in scheduling be pursued for the proposed FMP14. Further research on this should be pursued in the next plan.

Woodstock is not suited to analysis of the impact of fire or drought because they are episodic events, whose future occurrence cannot be predicted with any precision. Other forms of analysis can be used to gauge the sensitivity of the sustained yield to such events.

Recommendation 7.3, Adjusting for fire and drought: The potential impact of fire and drought on sustained yield should be analyzed by means other than Woodstock and adjustment for them incorporated in the safety margin to be applied to the final sustained yield calculated from Woodstock.

The harvests of wandoo and marri sawlogs are small and the resource so dispersed that their sustained yields are better calculated by other means.

Recommendation 7.4, Wandoo and marri: The sustained yields for wandoo and marri should be calculated by means other than Woodstock.

(4) *Scenarios*: Each additional scenario represents a substantial demand in terms of staff and computing time, so the sooner decisions on some of the outstanding options in the DFMP can be resolved, the better.

Mine sites re-afforested with jarrah pose an additional and serious problem with respect to thinning. Being mainly in high rainfall areas, thinning would probably provide a significant marginal net social benefit in terms of water production. Research on the responses to thinning on re-afforested minesites and on native jarrah regrowth forest provides sufficient data to gauge initial responses in terms of additional water production and timber production.

For adequately stocked areas, an initial thinning and treatment of stumps, as early as is practicable, represents a make or break decision for future timber production as well as the immediate impact on water production and therefore represents 'best practice' in terms of restoring productive capacity. Re-afforested minesites that are left unthinned and untreated will produce negligible volumes of large sawlogs over a proposed rotation of 200 years.

Recommendation 7.5, Re-afforested minesites: The Conservation Commission should ascertain the intentions of the mining companies and Government in relation to thinning of re-afforested minesites and draw their attention to best practice. If this issue cannot be resolved in time for the calculations in the proposed FMP14, this resource will have to be treated as an unresolved option, involving two alternative scenarios (one thinned and the other omitting the resource) for sustained yield. In any event, further research is needed on the frequency and intensity of thinning and the associated economics.

8. Specifying safety margins

The Panel is satisfied that, as far as is practicable given the data available, any material biases in the estimating and predictive functions involved in calculating the sustained yield have been removed. Any prediction of this kind embodies some inherent variability (imprecision) due to the sampling base and statistical procedures involved. So what safety margin is needed in the sustained yield, if any, to protect DEC and/or FPC against imprecision? For a large commercial

State-owned entity, there is a valid argument for a risk-neutral or, at least, only a very small amount of risk aversion in setting a safety margin. The choice of a safety margin is a pragmatic choice that aims to minimize the maximum risk, especially of breach of contract or insolvency. The risks pertaining to pests and diseases have already been noted to be of minor magnitude, given the provisions already made in calculating the sustained yield.

Recommendation 8.1, Safety margins: The Panel recommends that safety margins of 10% and 15% be applied to the calculated sustained yields of jarrah and karri respectively to allow for the impacts of seemingly unpredictable events such as fire, cyclones, drought, and pests and diseases.

9. Implementing the Sustained Yield

The sustained yield, after adjustment for a safety margin, becomes the ceiling for the allowable cut, which is then allocated in contracts or licenses to individual processors, generally through transparent and competitive processes. The legislation dealing with sustained yield reflects a mode of thinking that warrants reconsideration in relation to future industry development and environmental management. Being trade exposed, the timber industry, in common with most others, has to ride the cyclical waves of the global economy. To do that successfully, it needs some flexibility in its production levels to take advantage of the upside of the cycle by selling more and by reducing the cut in the downside. Flexibility also needs to be reflected in the way the sustained yield is monitored and regulated- not as a fixed and immutable target but in terms of the future capacity to sustain, hence the strong preference for the use of the term 'sustainable yield'.

The Panel believes that the 10-year period of FMP is too long and that a five-year period would be more appropriate to enable the plan to adapt to shocks, such as major fires, cyclones or pest or disease outbreaks and global trade and economic change. Some of this greater flexibility also needs to be reflected in the translation of the present 'sustained yield' into operations on the ground.

Technology can assist this process if Silvicultural Guidelines and like information, 3-year and other harvest plans, and the strategic 5-year FMP are available on the web[2], reducing the costly production process involved in a 10-year plan . The Panel notes that some testing has been carried out of the Remsoft's tactical planning software, 'Stanley', to complement the strategic scheduling and planning by Woodstock.

Recommendation 9.1, Use of Stanley and dual prices: The Panel recommends that harvest planning be migrated to the Stanley platform following completion of the proposed FMP14. For reasons discussed in Section 7.2, it also recommends that calculation of dual prices be carried out as a matter of course for any penultimate run of the Woodstock scheduling software.

The proposed FMP14 will represent a considerable step forward from its predecessor but some characteristics merit further consideration in addition to the earlier plea for greater flexibility. The present scheduling of the sustained yield extends annually to 100 years. Such detail beyond about 50 years lacks credulity because of our limited capacity to predict so far in the future precisely and without bias. Beyond about 50 years, planning should reduce to applying broad trends in growth and harvest levels that enable the sustainability goal of a steady state to be assessed at, say 100 years. Once a steady state 'normal' forest has been achieved, the yield will remain constant. This is the essence of sustainability in terms of maintaining or improving productive capacity. For future generations

Recommendation 9.2, Planning horizon and sustainability goals: The Panel recommends that future planning beyond the proposed FMP14 should focus on a planning horizon for scheduling of about 50 years. Beyond about 50 years, planning should reduce to applying broad trends in growth and harvest levels that enable the sustainability goal of a steady state to be assessed at, say 100 years.

In the FMP that follows the proposed FMP14, greater attention needs to be given to monitoring and reporting of the status of broader environmental goals on biodiversity, fragmentation, connectedness, water production and salinity predicted at the end of the 50-year scheduling period. The Panel is confident that these goals are generally being met, based on present data and research. This proposal does not imply a uni-directional change – while some additional local informal reserves may well be required, some existing ones may be deemed unnecessary when the opportunity costs in relation to timber production are weighed against their contribution to environmental values.

Recommendation 9.3, **Environmental goals in next plan:** The Panel recommends that greater attention be given to monitoring and reporting of the broader environmental goals on biodiversity, fragmentation, connectedness, water production and salinity at the end of the 50-year scheduling period of the next Plan, using metrics that can be informed by existing data and processes.

New technologies are continually being developed that can improve forest inventory and planning and DEC needs to maintain its monitoring and testing of these. Two stand out as being technologies that are now well-developed and whose costs are declining rapidly as additional contractors enter the market with new or improved equipment.

Recommendation 9.4, LiDAR and multispectral imagery: The Panel recommends that DEC continue to monitor and test the use of new technologies and, in particular, develop a department-wide plan for the purchase of LiDAR and multispectral imagery for the South-west forest region.

Consideration should be given to developing the scheduling based on an objective of maximizing the discounted net revenue to FPC in the next FMP following FMP14. This would (1) enable the economic issues of location to be better reflected in the analyses and enable the associated Stanley software to be better used for tactical harvest planning and integrated with the scheduling, and (2) be consistent with the planning needed to underpin valuation of the production forest estate for accounting and certification purposes.

Recommendation 9.5, Change to economic objective: The Panel recommends that consideration should be given in the next FMP to developing the scheduling based on an objective of maximizing the discounted net revenue to FPC, to enable better integration of economic factors into the planning and to provide a basis on which estate valuation for accounting purposes could be based.

10. Conclusions

The Panel believes that, subject to the implementation of earlier recommendations regarding improvements or changes to the processes involved in calculating the sustained yield, that the processes involved in calculating the sustained yield meet the Terms of Reference.

1. INTRODUCTION

1.1 Terms of reference

The terms of reference for the Panel were as follows:

> Having due regard to the previous independent reviews of sustained yield, and within the context of determining an allowable cut for the period of the FMP, the expert panel will provide a written report to the Department of Environment and Conservation and the Conservation Commission, based on the settings adopted for the proposed FMP, that confirms whether:

5. the structure, operation and outputs from the woodflow models are robust and flexible enough for computing the sustained yields and other wood availability figures included in the proposed FMP;
6. the uncertainty associated with a drying climate has been adequately factored into the sustained yield calculations;
7. the level of provision for other risks and uncertainty associated with the volume estimates are appropriate; and
8. the calculations incorporate suitable adjustments for the operational feasibility of obtaining the strategic woodflows.

> The Panel will be informed of issues related to the calculation of sustained yields raised in the public consultation process for the draft FMP and will consider these issues when undertaking its work.

1.2 The Process

With the assistance of DEC staff, published research and a large number of submissions in response to the DFMP, the Panel systematically reviewed the process involved in calculating the sustained yield. While references to published literature are cited in this report, it is not practicable to cite individual submissions, such was the number and diversity of content.

This report deals with a work that is still in progress, pending some decisions by the Conservation Commission, completion of dependent computations and completion of computations relating to changes the Panel has requested. However, the structure and detail of the calculation of sustained yield has largely been completed.

The review involved a sequence of major steps reported in detail in subsequent sections but which can be summarized thus:

- Identifying net productive areas
- Estimating the 2014 standing sawlog and other volumes
- Predicting future yields
- Scheduling future woodflows
- Adjusting for future climate change
- Adjusting for pests, diseases and fire
- Specifying safety margins

- Implementing the Sustained Yield

The calculation of sustained yield is based on a planning horizon of 100 years and uses annual planning periods.

2. IDENTIFYING NET PRODUCTIVE AREAS

2.1 Introduction

The identification and verification of the net productive area of forest is a fundamental component of the inventory system because all subsequent volume estimates relate to the boundaries so identified.

The basic data were derived from well-established cadastral maps that have a high degree of accuracy. These were further informed by formal tenure maps, forest type maps based on photogrammetry, and various special silvicultural and other maps prepared by DEC.

A large number of other ‘informal reserves’ have been established through objectives and actions in the current FMP. These reserves were set aside to protect local or specific mature conservation, soil, water, heritage or other specified values, such as old-growth forest. In addition, about 52,000 hectares have been also been set aside in patches of at least 200 hectares in a roughly systematic manner throughout the native forest as Fauna Habitat Zones.

The boundaries of all such informal reserves need to be identified in the Geographic Information System (GIS) so that the net productive area of forest that is available for wood production can be established.

2.2 GIS and FMIS databases

Area maps are stored in a GIS. A subset of 14 different layers, called Themes, are used in calculating the sustained yield.

Map 1 is a 1:500,000 map (in sleeve inside back cover) showing the complexity of the area breakup within the Availability Theme 9 alone. Availability is a field and desk-based classification of areas scheduled for harvest in the years to 2014, those are potentially suitable for economically viable harvesting in each of the following three decades, those not available until after 2060, and two classes not available for harvesting. The complexity of the subdivision of the forest is apparent even for this single theme and map scale.

Some 13 other Themes are overlaid on it to define the patches of forest for area determination and yield prediction creating a mosaic of fine detail and great complexity. This complexity is both the strength of system, in being able to address differences in condition, yield and management; and its weakness in complicating the calculation of sustained yield through the later scheduling process.

This complexity defies a comprehensive and concise summary but mention must be made of some particular Themes and resulting cross-classifications for later reference in this report.

Jarrah Forest Types

The GIS database includes detailed delineation of a Forest Type theme by aerial photo-interpretation into various well-known species mixtures (e.g. jarrah, jarrah-marri, etc). The classification of these species or mixtures is broadly reliable but local variability does occur. Variability also occurs within many other Themes and is the reason why detailed sampling and measurement of plots in the field and by aerial photo-interpretation is necessary in the inventory process.

The Silvicultural Status theme classifies jarrah forest types into six main categories based on aerial photo-interpretation, informed by other records :

- Thinned forest,
- Gap creation (regeneration release) forest,
- Shelterwood (regeneration establishment) forest,
- Selectively harvested forest and
- Dieback (selection) forest
- Temporary exclusion areas,

These reflect an important change in Silvicultural guidelines implemented during the current and FMP (1994-2003) following the recommendations of the last ESFM review (Ferguson *et al.*, 1997). The subdivision into gap creation, shelterwood, selective logging and (for some cases) thinned has greatly improved silvicultural practice in the field with respect to tailoring appropriate silviculture to the site but complicated yield prediction – a matter to which we return in Section 7.2. Each is further classified into three Site Quality categories, based on mature canopy height.

Karri Forest Types

In the karri Forest Types, various species mixtures are also recognized but the classification of Silvicultural Status is simpler:

- Two-tiered forest, and
- Even-aged forest

Both are further classified by four Site Quality levels, including one of predominantly senescent forest and Even-aged forest is also classified by the age of the regeneration..

Spatial datasets derived from the GIS used for the calculation of sustained yield and operational harvest planning are maintained in a Forest Management Information System (FMIS). The GIS and FMIS are robust, flexible and well-established and documented systems.

In preparing the net productive area database for later use in scheduling and the calculation of sustained yield, the overlaid array of relevant themes have to be integrated into one map. Because of the number of categories in each Theme can vary from about 4 to 20, the effect is to fragment the productive forest area into many small patches, some of highly irregular shape and small size. Given the pixel-based (i.e. square 0.5 ha units) nature of the GIS, this imposes many joining points and hence complexities in the later Woodstock scheduling system.

2.3 Adjusting for Unproductive or Unavailable Areas and Other Changes

Process

Although the information in the GIS and FMIS is of a high degree of accuracy, from time to time adjustments are needed to accommodate changes to a particular Theme (e.g. new dieback areas) or minor past misclassifications.

Take for example, the informal reserve associated with a protective buffer strip around a stream. A recent field inspection (see Figure 2) prepared in the course of drawing up a harvest plan has shown that the stream shown on the plan did not exist beyond a particular point going upslope under the defined criteria for a stream.

In order to make a change removing that upslope part of the informal reserve, an Informal Reserve Amendment Request had to be filed with the Forest Management Branch who then checked the plan and aerial photo information and arranged a field inspection by the Regional SFM coordinator. His report concurred but required that the 30m buffer be extended around the (new) top of the stream, and extending it up to a track. That revision was reconsidered by Forest Management Branch and once approved, passed to the Data Custodian for action. She then changed the buffer strip boundaries accordingly, such that the revised plan is available immediately for field use. Any contingent changes to other Themes, would also be made at this time. The DEC database for Woodstock is not necessarily updated immediately but the proposed amendment is parked securely and the amendment made at an appropriate time, involving a complete rebuild of the FMIS database.

The same process is applied for any change that affects the area base, whether the addition of a new previously undiscovered patch of old growth forest, a request from the Department of water to impose some restriction on harvesting, or changes imposed on Silvicultural Status and other Themes by fire or cyclone.

The process involved is flexible, robust and indicative of a mature system that has integrity and security of process.

Changes undertaken in DFMP

The DFMP proposed changes to net productive area and changes in some informal reserves. The net productive area available for timber harvesting has been reduced to account for some operational constraints and for the old-growth forest that must be excluded from harvest.

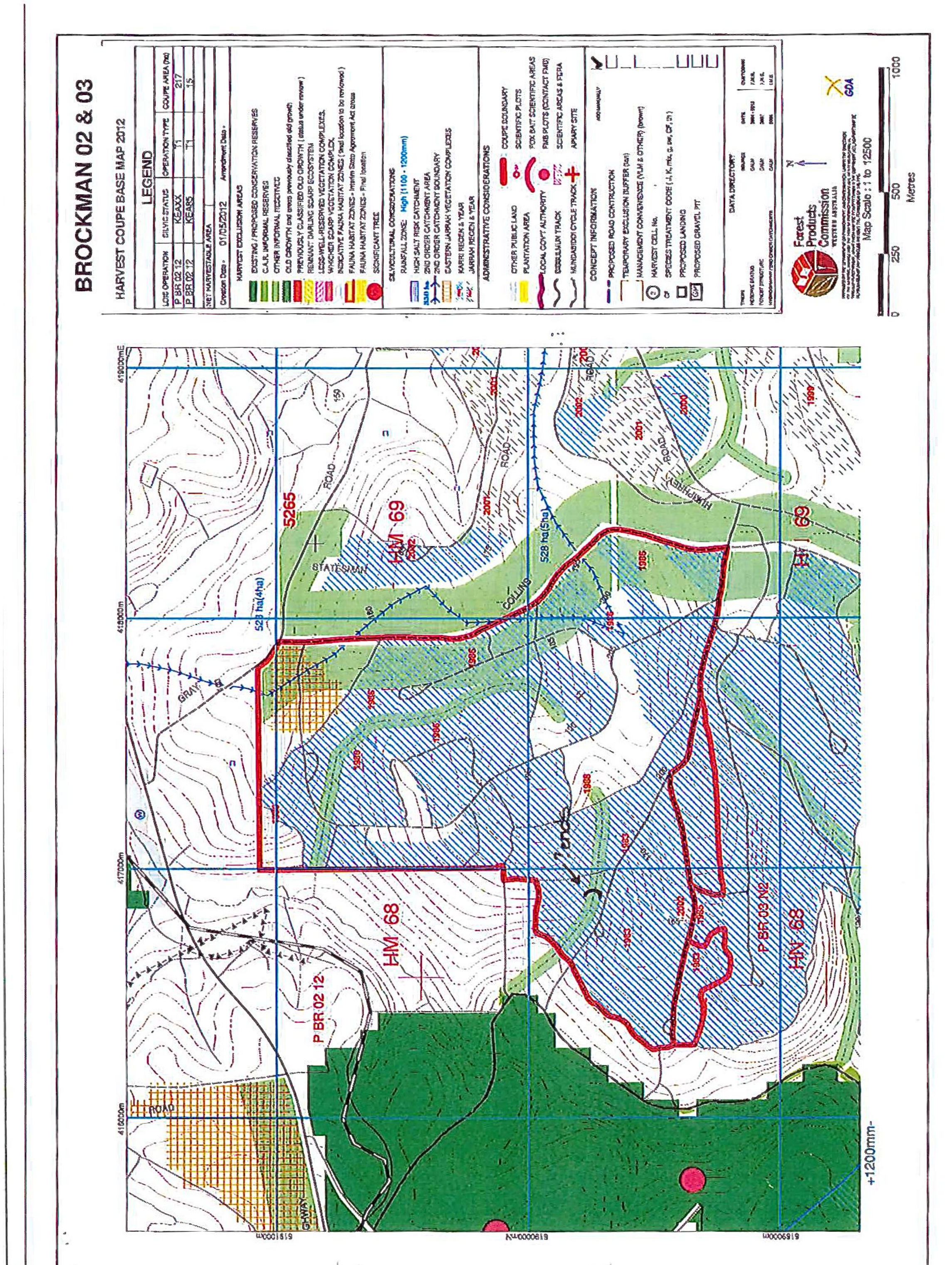

Figure 2.2: Amendment of an informal reserve; note arrow & 'ends'

(1) When calculating sustained yields, further reductions were applied within the total areas of each Forest Type available for timber harvesting to take account of local landform and vegetation conditions that are unsuitable for timber harvesting, such as areas too steep for harvest machinery to access or areas mapped as not economically viable. A terrain model calculation of steep forest was used to define areas to be removed in the net area adjustment along with other contingent exclusions (such as roads and basic raw material pits).

Within the last 25 years almost 60,000 hectares of forest has been classified as uneconomic (at the current harvest) and over 1,000 hectares as too steep. This includes over 2,000 hectares of two-tiered karri forest, which is a substantial proportion of the two-tiered karri available and reflects the small patch size and isolation of the remnants from past harvesting.

(2) All old-growth forest is unavailable for timber production, and the boundaries are mapped to a minimum area of 2 hectares. Many small forest areas were designated for review as to their old-growth forest status under the current FMP04. Field inspections confirmed that 230 hectares were not old-growth forest. Conversely, a separate process that requires the field checking of all harvest operations for the presence of old-growth forest identified 1,390 hectares of previously unmapped old-growth forest within the jarrah and karri two-tiered forests.

An adjustment for future unmapped old-growth forest that might be identified in future pre-disturbance surveys was computed based on the proportion of the area of each forest type that had been identified during the current FMP. This proportion was then used to reduce the area available for timber harvesting.

Recommendation 2.1, Area database: The processes used in maintaining and adjusting the GIS and FMIS databases are mature, flexible, robust and documented well. The Panel is satisfied that the identification and verification of net productive area meets best practice standards.

2.4 Summary of Areas available for Timber Harvesting

The following table summarizes the availability for timber production by dominant forest type of the total area of land within the DFMP at the time of writing:

TABLE 2.1: Summary of net productive areas

Classification	Forest type				
	Jarrah (ha)	Karri (ha)	Wandoo (ha)	Non forest/ other (ha)	TOTAL (ha)
Land vested in the Conservation Commission within FMP boundary	**1,577,750**	**175,440**	**144,290**	**626,370**	**2,523,850**
Area excluded from timber production					
Existing/proposed formal reserves and FCA	644,940	93,390	98,400		
Informal reserves	128,890	21,360	9,530		
Fauna habitat zones	48,640	1,040	1,920		
Sub-total	822,470	115,790	109,850		
Area available for timber production	**755,280**	**59,650**	**34,440**		**849,370***
Percentage of total area of each forest type available for timber production	**48**	**34**	**24**		

*This area comprises 34 per cent of the total land area, or 45 percent of the total forest area, on land vested in the Conservation Commission, plus freehold land held in the name of the CALM Executive body, within the FMP boundary.

3. ESTIMATING THE STANDING SAWLOG AND OTHER VOLUME IN 2014

3.1 Introduction

Forest inventory inevitably involves errors through the use of plot sampling, various measurement techniques, and statistical estimation of tree volumes, complete measurement of every tree being impossible. The critical properties of those errors can be measured and summarized using two criteria – bias and precision.

Bias and precision are illustrated in Figure 3.1.

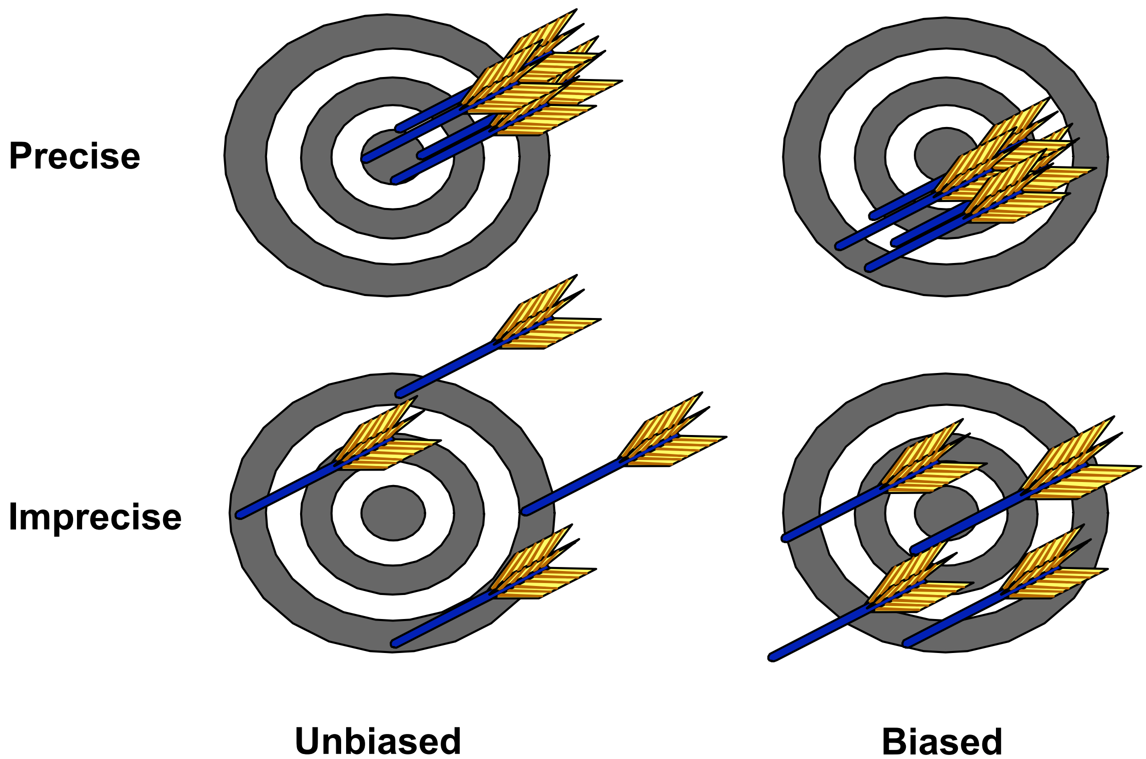

Figure 3.1: Illustration of bias and precision relative to a known target

Unlike Figure 3.1, we cannot see our target in forest inventory, so the task of estimation is somewhat more difficult. Figure 3.2 illustrates the dilemma.

Because we cannot see the centre or target, it is very important that we try to avoid biases by taking every opportunity to test estimates against other data and to correct any biases.

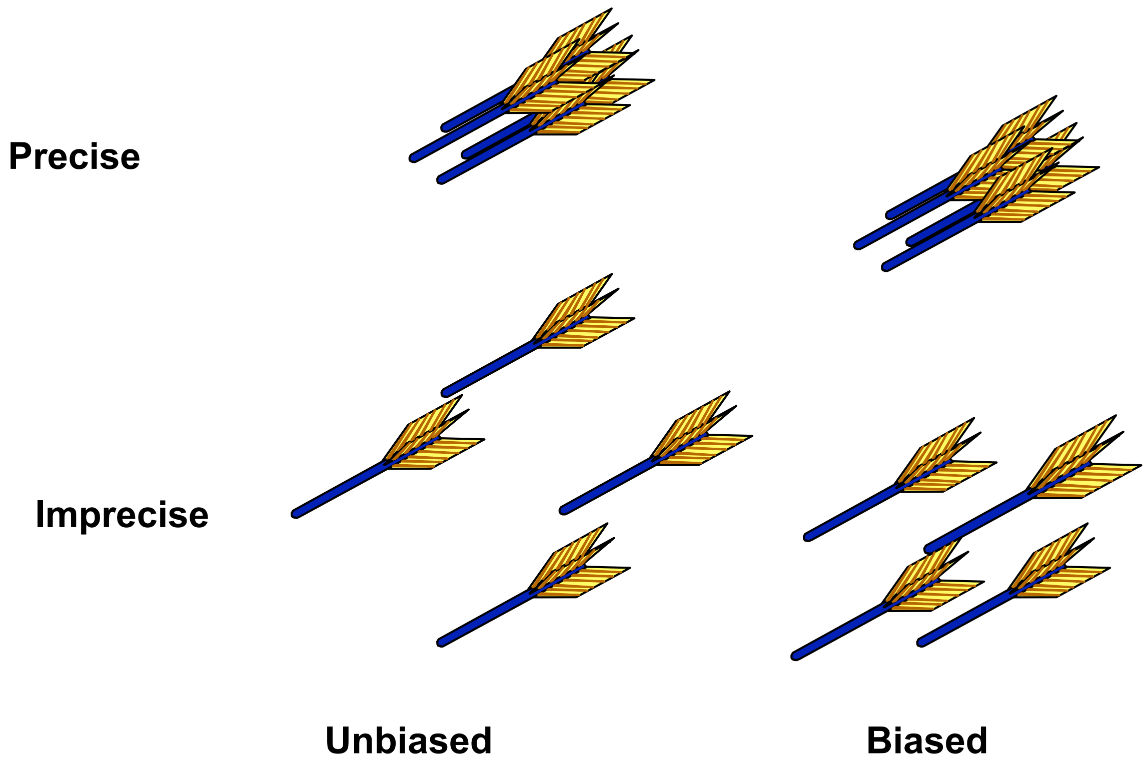

Figure 3.2: Illustration of bias and precision relative to an unknown target

DEC staff have a tendency to take the conservative option at every step: the danger of this approach is that these many small conservative assumptions all accumulate in one direction, and may contribute a substantial hidden bias. DEC staff should avoid this temptation: it is preferable to make best estimate whether it is conservative or not, knowing that the final estimate will be 'on the edge' and then to make an overall adjustment for any desired redundancy, informed by comprehensive monitoring. In practice, such an adjustment may be small, because the commitment to an allowable cut is for 10 years, a modest fraction of the planned 100 to 200-year rotation.

To empower DEC staff to take the 'best' and not the conservative path of action, there needs to be institution-wide recognition that such an approach will lead to periodic overestimates as well as underestimates, and that these are a perfectly normal part of resource estimation. Indeed, if monitoring reveals consistent underestimation, if may be indicative not only of a practice of taking conservative options, but also of missed opportunities to derive the best socio-economic outcome from the sustained yield.

Recommendation 3.1, Best estimates: Government agencies involved in calculating the sustained yield should empower staff to take the 'best' and not a conservative path of action in estimating the sustained yield to avoid accumulating a substantial hidden bias. Any adjustment by way of a safety margin is a policy decision to be taken after the sustained yield has been estimated.

While better precision is always a desirable goal, it is not so critical as freedom from bias because, as we shall show later, there are simple ways of protecting against imprecision in the penultimate estimate of sustained yield,

3.2 Forest assessments

Forest assessments in Western Australia's forests draw on three different techniques appropriate for the diversity of the forests involved, with different procedures for karri even-aged regrowth and two-tiered forest, and uneven-aged jarrah forest.

Even-aged regrowth tends to be relatively uniform within well-defined stands, and has been assessed using stratified random sampling (Anon 2012). Two-tiered karri forest is more variable and aerial photography was used to inform inventory. Jarrah forests were assessed with two-stage inventory with a total 29,000 photo plots (including some outside the current production estate), sub-sampled using 3,000 ground plots, following a procedure instituted during the 1980s (Spencer 1992). In preparation for FMP14, some of the original jarrah ground plots were re-measured to create the database indicated in Table 3.1.

TABLE 3.1: Plots within the productive forest estate that contributed to the calculation of sustained yield.

	Jarrah	Karri	Wandoo	Other	Total
Aerial photography plots	17,805	604	851	1,416	20,676
JI ground plots	1,685	35	75	88	1,883
JI ground plots re-measured	434	4	25	6	469
Permanent plots	320	48	15	10	393
Regrowth plots	59	445	0	1	505

JI denotes Jarrah Inventory (Spencer, 1992)

A significant number of other long established permanent plots within silvicultural and fire research trials administered by DEC's Science Division have been used in growth model development, validation, or yield table checking (e.g. 82 + plots at various thinning and espacement trials for jarrah and karri were used in the 3-PG work, and yield table checking; 48 FORESTCHECK plots across 12 sites were used to compare predicted increments etc).

All trees within the circular ground inventory plots were individually identified and measured, and their data entered into the computerized database known as IRIS (Integrated Resource Information System) to inform yield calculations.

3.3 Inventory plot database

Inventory data are stored and managed in an on-line database implemented using a well-documented version of Oracle. IRIS offers access to stored data in a format similar to that used for field acquisition (Anon. 2011) to facilitate data entry and verification. The data recorded for each tree includes a series of measurements and observations that allows the utility of the tree to be assessed on the basis of existing or alternative specifications. In some plots, spatial coordinates of individual trees have also been recorded (distance and direction from plot centre), allowing spatial analyses when simulating thinning and selective harvest.

3.4 Estimating whole bole volume and sawlog grades

While the estimation of that part of gross bole volume between stump height and breast height is appropriate, that above is not. The part of gross bole volume above breast height is estimated by integrating stem cross-sectional areas between the recorded breast height (1.3 m) and the observed stem diameter at crown break (Spencer 1992). However, whereas adjustment for growth to 2014 or beyond is made to the cross-sectional area at breast height, no adjustment is made to the final upper cross-sectional area. This constitutes a deliberate source of bias, by underestimating volumes a small amount, and should be corrected. This gross volume is then reduced to adjust for observed defect and the volumes of grade 1 and 2 sawlogs are estimated. Specifications (Spencer 1992) including the minimum length, top diameter and quality (maximum sweep and defect) guide the classification of logs into various grades. The system is flexible and capable of estimating alternative log specifications, such as those involving a change in small end diameter.

Recommendation 3.2, Cross-sectional adjustment: The Panel believes that the upper stem cross-sectional area should be adjusted for growth in proportion to the adjustment of that at breast height.

The scheduling of woodflows in the proposed FMP14 is concerned primarily with grade 1 and 2 sawlogs, the current specifications for which require logs of at least 2.4 metres in length, with a small-end diameter of at least 200 mm, and which are estimated to be at least 30% millable on their worst face. These grades are the critical grades for sawmilling and thus the primary basis of the calculation of sustained yield, even though sales to sawmills are, with one exception, based on whole bole volume at prices suitably adjusted to reflect the various grades contained

3.5 Reconciling estimated against actual volumes harvested

One important step in quality control of models and their prediction is to reconcile predictions against reality and so remove, as far as is possible, any bias. Whilst conceptually easy, this step is complicated by the various components of model predictions. Thus a discrepancy between the predicted and actual harvest may relate to differences in the area involved, the assumed size of the trees, growth of trees between initial measurement and time of harvest, compliance with guidelines and product specifications by the harvesting crew, volume estimation procedures – or a combination of these factors. Because of natural site-to-site variation, it is important that any reconciliation involve sufficient samples to allow meaningful inferences to be made.

A study of discrepancies between predicted and actual yields during 2004-07 attributed differences to conservative assessment of defects, growth of trees, and retention of habitat trees (Anon 2009). Although the discrepancies varied according to silvicultural objective of the harvest, the overall discrepancy across 98 plots was 9%, within one standard error of the true value. Subsequently, the Utilization Monitoring Assessment (UMA SouthWest) project examined the predicted and actual yields from 148 plots across three regions (South-West, Swan, Warren), revealing that actual yields varied from 60-90% of the predicted in the three regions. Figure 3.3 shows data from the South West region and the fitted regression used to correct the bias. In Figure 3.3, a single (rightmost) point has a strong effect on the adjustment that has been factored into the sustained yield calculation. Further investigation at the request of the Panel has revealed some anomalies with this plot that warrant further refinement of the approach. Routine monitoring along the lines of this study is essential and should be given high priority.

Recommendation 3.3, Further UMA analyses: The Panel has requested that further work on the UMA data be undertaken to establish the reasons for these differences and obtain the best correction possible. It also believes that routine monitoring along the lines of this study is essential and should be given high priority.

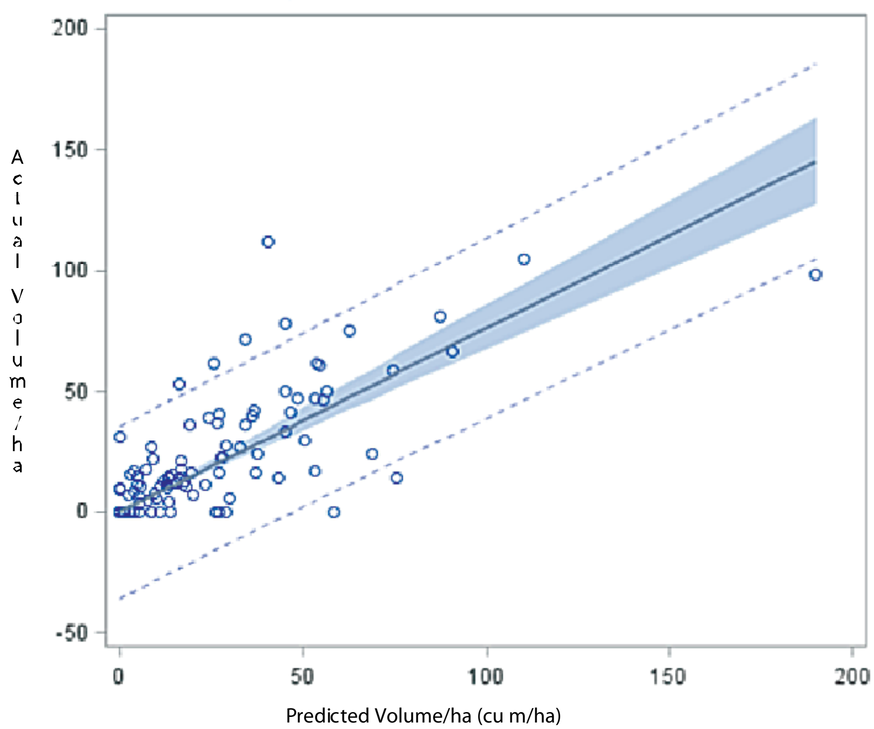

FIGURE 3.3. Utilization Monitoring Assessment data and fitted correction and confidence intervals

Future volumes are estimated via the application of a yield table. In effect, the many ground plots and tree measurements are distilled into a series of yield tables, with each 'patch' of forest assigned one of these tables and a nominal age.

3.6 Demonstrating precision

Whilst it is possible to compile error budgets for calculations of this kind (Rennolls *et al.,* 2007, Güneralp *et al.,* 2007), the task is complex, and the effort could be invested more productively in other ways. In any event, the estimates of precision derived directly from the field inventory work provide a sufficient guide.

Because sustained yield calculations are concerned with long-term averages, it is critical to reveal possible sources of bias, and less important to address unbiased variation associated with short-term and small-scale variability (the primary focus of typical error budgets). Furthermore, there are two approaches that may be used in applying models to complex systems: a model may be made increasingly complex to deal with every eventuality, or the model may be implemented in a way that encourages fast feedback and adjustment. Whilst both approaches in conjunction are desirable, it is usually preferable to direct limited funds towards the fast feedback approach, and in the present case the potential uncertainties (e.g., possible wildfire) strongly favour the fast feedback approach that will enable tracking of field performance and corrective actions to align sales with the allowable cut. In practice, this should involve regular and on-going monitoring of predicted versus observed yields and reconciling discrepancies to clearly establish the relative influence of contributing factors (areas, standing volumes, growth projections, product estimation, compliance, etc.).

4. PREDICTING FUTURE YIELDS

The estimation of growth and prediction of future yields is carried out separately for the (1) mature two-tiered karri forest, (2) even-aged karri forest (3) uneven-aged jarrah forest (including mixtures) and (4) even-aged jarrah forest.

4.1 Two-tiered karri forest

A relatively small area remains of available karri two-tiered forest. A small number of the 2002 measured plots were re-measured in 2012. However, since most of this strata will be harvested and regenerated over the next plan period, DEC determined that the growth component, although significant, would not be of consequence in calculating sustained yield for the proposed FMP14 given the small volume relative to the regrowth estate. Figure 4.1 shows the results of the original measurement, the re-measurement, and the increment from 2002 to 2012.

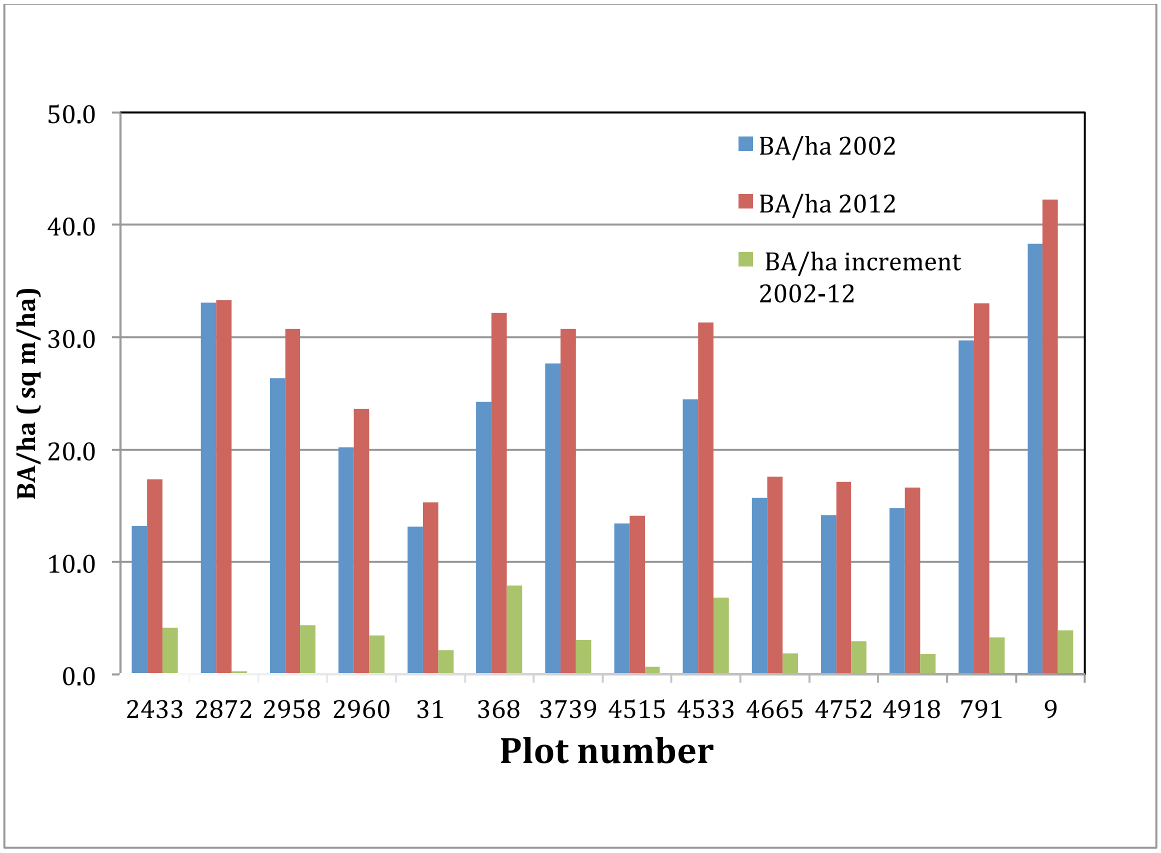

FIGURE 4.1 Basal areas per hectare for two-tiered karri plots

As noted earlier, the Panel believes that deliberate conservatism is not best practice. The incremental growth from the 2002-12 re-measurement should be used to predict yields for two-tiered karri forest.

Recommendation 4.1, Two-tiered incremental growth: The Panel believes that best practice requires that the incremental growth from the 2012 re-measurement should be used to predict yields for two-tiered karri forest in the proposed FMP14.

4.2 Even-aged karri forest

The original design and structure of KARSIM is an adaptation of the STANDSIM model originally developed by Opie (1972) for mountain ash forests in Victoria. The STANDSIM model has been comprehensively described elsewhere (Incoll, 1974; Campbell *et. al.,* 1979).

KARSIM is a distance-independent, individual tree level growth model that comprises a series of integrated modules to predict the development of stand and tree attributes on an annual time step. Individual trees in a stand are represented by their diameters within an array. Only stems greater than 10 cm DBHOB are simulated. All growth, mortality, and stand treatment are updated to adjust the diameter array. Model components are deterministic, with the exception of the mortality component. Details of the biometrics and operation of KARSIM, and the growth characteristics of regrowth karri have been documented in Rayner (1991, 1992).

Since 2003 the KARSIM application has undergone redevelopment to enhance the functionality of the volume estimation and utilization components, as well as the simulation of multiple species within the plot.

Yield tables

Yield regimes were generated by DEC for pre-defined development types reflecting combinations of forest types, site qualities, silvicultural status and management objectives. Stand simulations were initialized from tree distributions generated from permanent sample plots (PSP's). A total of 252 PSP's listed karri presence as significant and 12 plots were selected from these as suitable for simulating the various development types required for the proposed FMP14. One particular management type, karri partial clearfell (Kpar) used an input file created by merging a regrowth PSP with a SILVIA plot to represent the mix of overstorey and regrowth components created with this type of harvesting.

All of the PSP's in each development type were simulated using KARSIM, with an average sawlog volume calculated for each thinning event. The final Woodstock yield table were generated from the plot that most closely produced average sawlog thinning yields, with a preference for plots representing the more dominant vegetation types, given the correlation of the site quality categories and vegetation types.

During the simulation, the timing and intensity of the initial thinning operation applied was in accordance with the draft silvicultural guidelines, whilst the subsequent thinning events were guided by general biometric principles (i.e. to maximize stand BA increment). Product utilization factors derived from inventory plot analysis and by analyzing operational removals (LOIS) were applied to the recovered volumes at each harvesting event, so constraining KARSIM predicted volumes with realized empirical evidence. Figure 4.2 compares the simulated sawlog volumes and those measured on PSPs for one development type.

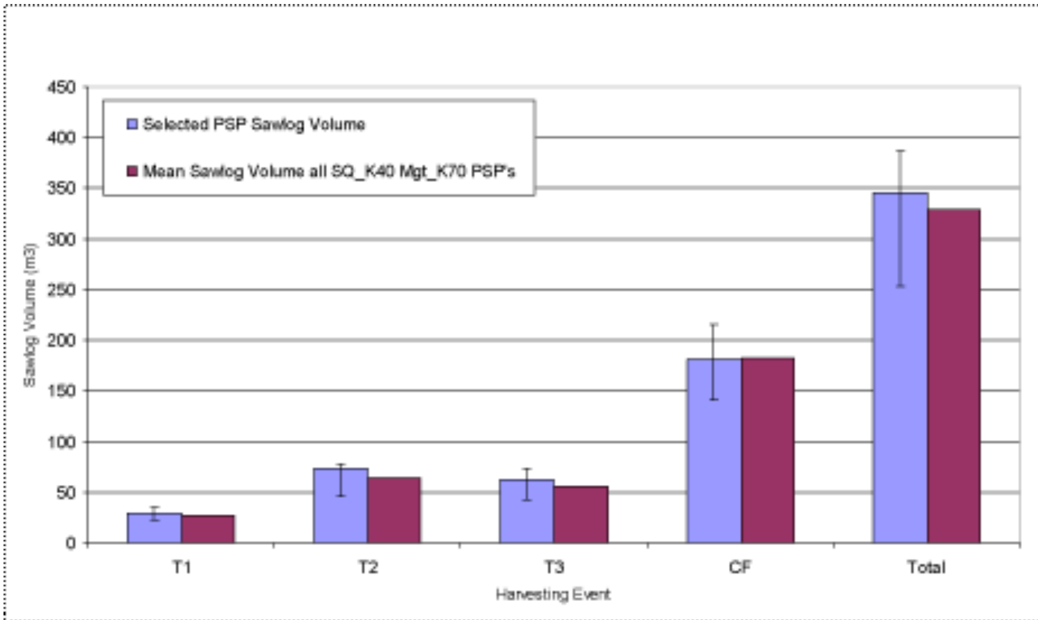

FIGURE 4.2: Comparison of simulated and measured volumes for one karri development type.

Karri even-aged regrowth yield tables for a range of products for periods of up to 120 years were created by DEC for all required development types and incorporated in the Woodstock model. Figure 4.2 shows basal area development for a particular yield table.

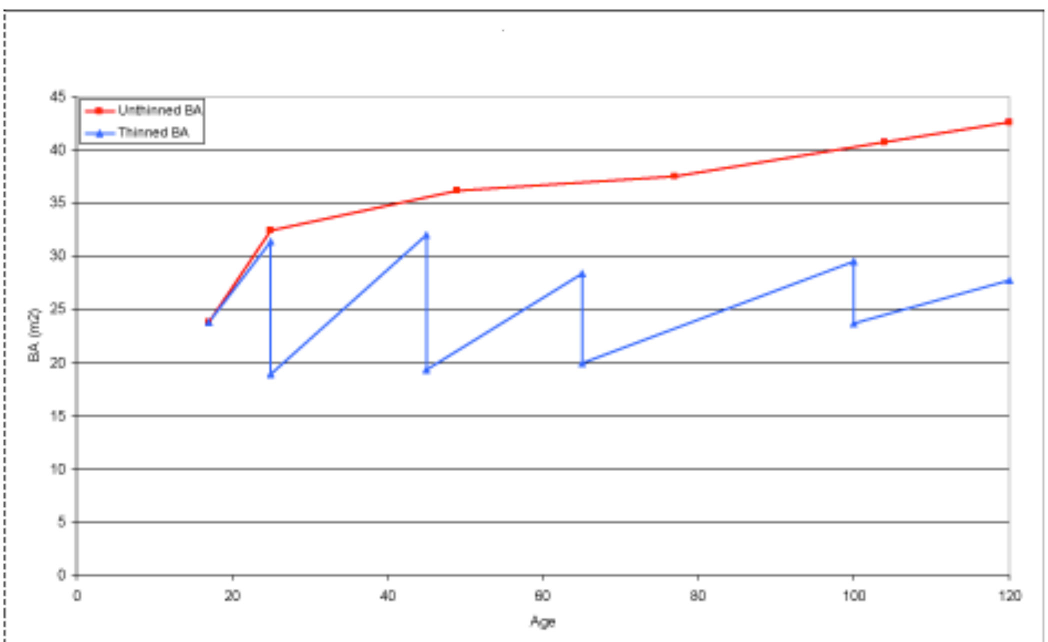

FIGURE 4.3: Predicted standing live basal area over time, both thinned and unthinned.

4.3 Jarrah uneven-aged forest

The distribution of plots by rainfall zone used in the analysis is illustrated in Figure 4.4. There are sizeable gaps in the distribution due to large areas of mining, harvest and large reserves. Further plots have been measured and will be used to refine later models.

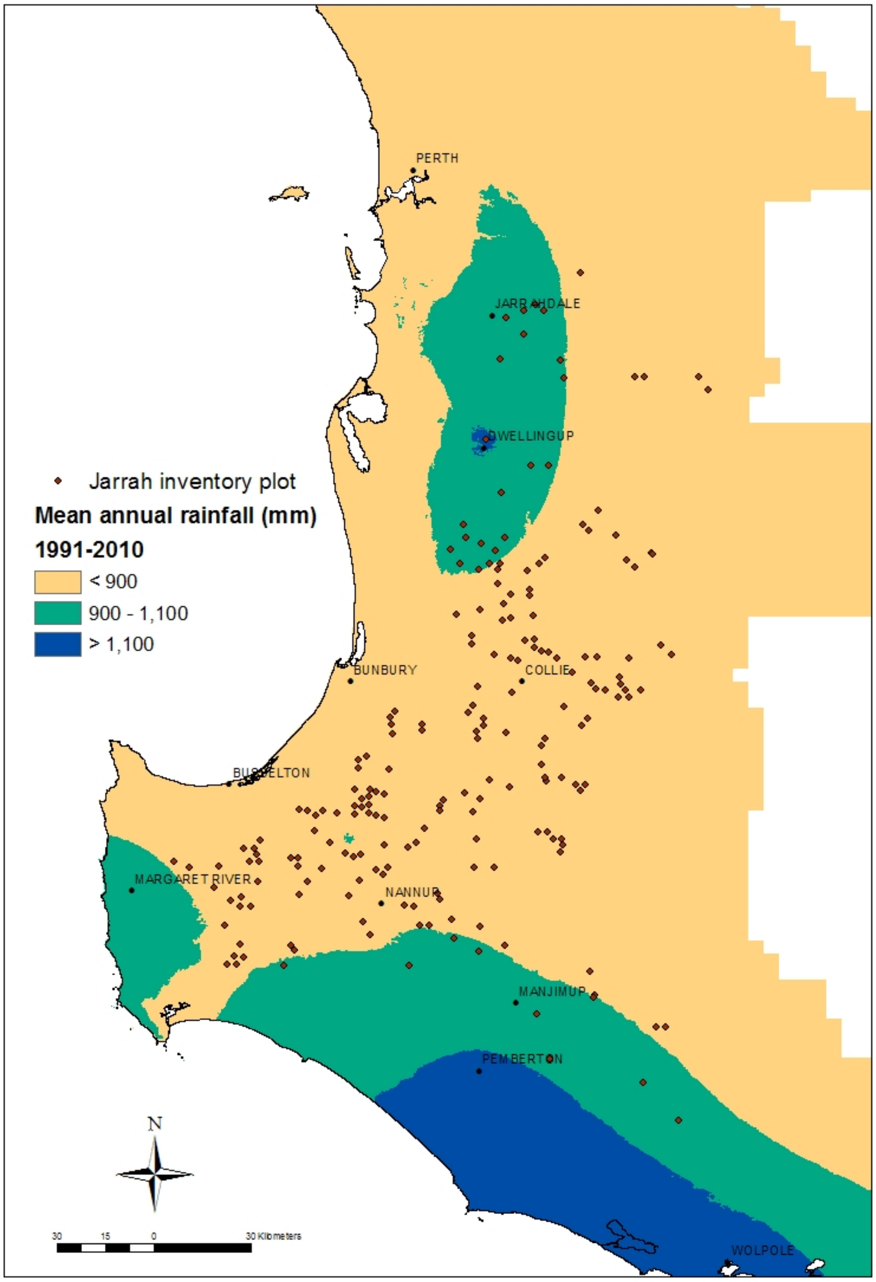

FIGURE 4.4: Location of PSPs by annual rainfall zone

Diameter increment

Analysis of variance was undertaken by DEC to examine which attributes were useful in model formulation. These analyses provided separate diameter increment functions for both jarrah and marri. The Panel had some concerns that the use of rainfall categories in the three broad classes in Figure 5.3 may mask the effect of rainfall, although mindful of the likely correlation of interpolated rainfall at the plot site and top height. In view of the importance of this matter to climate change, the Panel requested that this analysis be re-run both using interpolated rainfall at the plot site and using incremental DBHOB as the dependent variable, with suitable weighting for heterogeneity. The results are discussed in Section 5 because they are especially apposite to the possible impact of climate change.

Natural mortality

Recent re-measurements of 5284 trees on 105 plots were analyzed by DEC to explore mortality relationships in uneven-aged stands and the results were clear and consistent across the range of diameter class and site quality. Little mortality was observed in the low site quality plots representing the eastern jarrah. Figure 4.4 shows the mortality rates by DBHOB class and site quality.

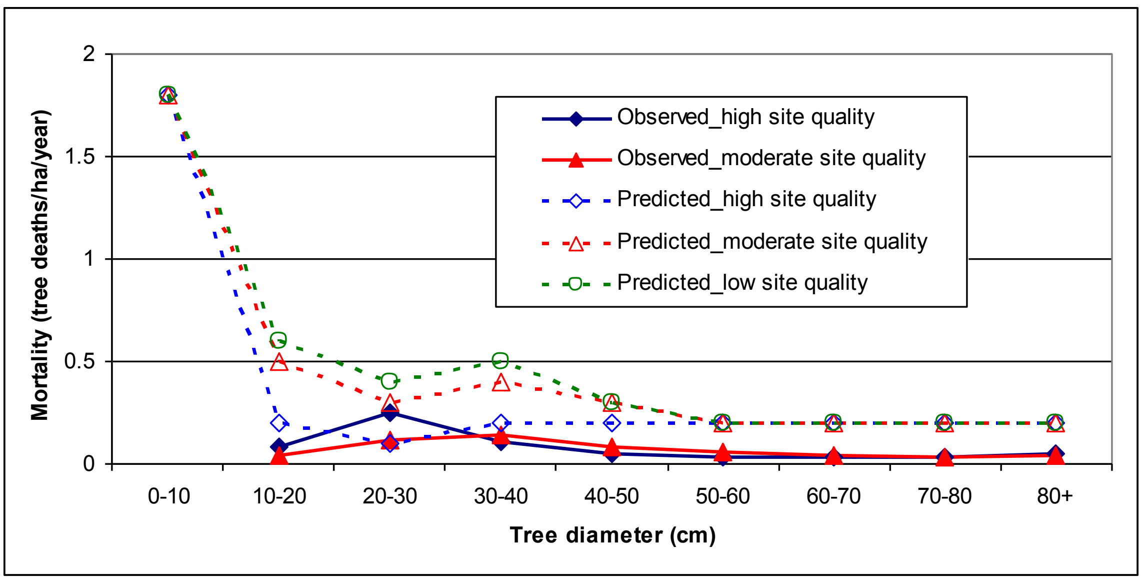

FIGURE 4.5: Uneven-aged jarrah mortality rates by diameter class

As expected, mortality of trees below 15cm DBH was quite high as expected but from 15 – 45 cm DBHOB, the rate was fairly steady at approximately 0.2 trees per hectare per annum. Above 45 cm DBHOB, the rate stabilized at 0.1 trees per hectare per annum (predicted rates are those used in JARSIM). Jarrah accounted for three quarters of the mortality compared with 15% for marri and 9% for other species.

The very low rate of mortality of jarrah is a matter to which later reference will be made.

4.4 Yield tables

The preceding diameter increment and mortality functions were used in SILVIA, described earlier, to predict the yields associated with harvesting and follow-up treatment based on the various silvicultural guidelines for jarrah, karri and wandoo. The ground plots from the jarrah inventory were processed within the relevant strata and the associated yield regimes applied in scheduling. The processing of the jarrah data through SILVIA involved the iterative assessment of around 7,000 plot/prescription combinations that simulated treemarking the equivalent of 729,000 trees. This was used to determine the operational yields for 22 separate silvicultural outcomes across 59 different strata, a total of 756 distinct yield and stand descriptions. The more complex treemarking rules used in the proposed FMP14 will involve even greater numbers. This process was used to determine the operational yields for 378 separate generic strategies for 840,000 ha of stands represented in the database at the start of the Woodstock simulations commencing in 2014. In addition, a further 264 yield tables for stands are not represented at that point in time but constitute future stands that will result from thinning or combinations of site quality and future harvesting. Another 44,000ha of stands do not have yield tables at commencement of simulation. These include:

- Stands (approx. 8,000ha) omitted because they would have zero volume
- Stands (approx. 10,000ha) involving mixed silviculture that are converted to stands with standard yield tables by a special transfer function at the start of planning period one.
- Stands excluded (1,400ha) because they cannot be cut,
- Stands in Temporary Exclusion Zones (approx. 23,000ha) that are time-linked to a later second rotation stand and yield table.

The Panel has inspected summaries of the yield tables for stands in excess of 10,000 ha. It notes the attention given by DEC in comparing predicted sawlog volumes against actual volumes. It believes the present set of yield tables represent best practice but notes the need for continuing data collection and analysis to maintain that position.

Recommendation 4.2, Continuing data collection and analysis: The Panel believes that, subject to some revised analyses yet to be completed, the present set of yield tables represent best practice but notes the need for continuing data collection and analysis to maintain that position

5. CLIMATE CHANGE

5.1 Introduction

As noted earlier, the DEC team involved in calculating sustained yield tend to take the conservative option at every step of the process from inventory to scheduling, raising the danger that these may accumulate in one direction, and may contribute a substantial hidden bias (see Section 3.1). Adjustments for climate change and similar potentially predictable changes need to focus on applying the best estimates to remove biases. Any adjustment by way of a safety margin is a policy decision to be taken after the sustained yield has first been calculated.

The sections that follow deal in turn with the consideration of adjustments relating to exogenous changes that cannot be readily incorporated in the preceding process of calculating the sustained yield and for which, adjustments by way of recognition in a safety margin, may be needed.

5.2 Adjusting for climate change

The terminology and impacts of climate change and drought in relation to the South-west forests warrant some clarification before dealing with how climate change was taken into account in calculating sustained yield. Climate change is, as well known, an extremely complex process. For the purposes of this review, the Panel believes it is essential to draw clear distinctions between the impact of (1) the long-term trends in climate to 2070 and beyond, specifically those in annual average rainfall and temperature; (2) the short-term trends and variability that occur in those variables over ten to 30 years of so, and (3) the changes in seasonal characteristics that may be associated with the latter.

Long-term trends

South-western Australia experiences a Mediterranean-type climate, with cool, wet winters and warm, dry summers. Trends in climate for this part of Australia are influenced by variability in the Indian Ocean dipole (IOD) and the southern annular mode (SAM) (Feng *et al*., 2010). In addition, the poleward-flowing Leeuwin Current is influenced remotely by El Niño–Southern Oscillation (ENSO) events (Weller *et al*., 2012). The relative extent to which these and other synoptic systems explain climate in the region will remain a matter of discussion for some time into the future (see, for example, Hope *et al*., 2006; Indian Ocean Climate Initiative 2012).

Regional projections for future climate change using a range of Global Climate Models and IPCC emission scenarios all indicate further increases in temperature and decreases in rainfall by 2030 (Bates *et al*., 2008). Increases in the frequency and severity of extreme climate events have been projected (CSIRO and BoM 2007). These include longer-duration heat waves, elevated maximum temperatures, and increased frequency of droughts and frosts.

Potential effects of climate change on Australian forests have been examined in a number of reports (e.g. ABARES 2011; Medlyn *et al*., 2011) and parallels have been observed globally (e.g. Allen *et al*., 2010). In 2009, DEC established an internal Expert Advisory Group to report on the vulnerability of forests in South-western Australia to timber harvesting under the influence of climate change. The Panel examined three climate change scenarios as follows: (1) low impact model MIROC-H combined with the B1 emission scenario and low climate sensitivity; (2) moderate impact model MIROC-M combined with the A1B emission scenario and medium climate sensitivity; and (3) high impact model CSIRO Mk 3.5 combined with the A1F1 emission scenario and high climate sensitivity. These climate scenarios have been discussed more fully elsewhere (e.g. Gordon *et al*., 2010; Charles *et al*., 2012). The Panel's report (Maher *et al*., 2010) concluded that the area of jarrah forest predicted to fall below 600 mm annual rainfall by 2030 increases from 1.3% for the low climate change severity scenario to 5.1% for the high severity scenario. The area of karri forest predicted to fall below 900 mm annual rainfall by 2030 increases from 0.1% to 6.1% for the same two scenarios.

In calculating the sustained yield, the DEC team has taken a different but not inconsistent path by estimating progressive adjustments to the yield tables for jarrah and karri. This was based on data from a series of regrowth jarrah and karri permanent plots, regrowth being chosen because it enables the otherwise confounding influence of the age of the tree to be taken into account.

Averaged data of climatic variables and tree growth rate in the period of 1991-2010 were used to establish climatic and tree growth baselines. A series of regrowth permanent sample plots (PSPs) were selected from jarrah and karri forest to cover the range of stand conditions (site quality, rainfall zone and stand age) and measured at least twice. Their last measurement times were variable but chosen as close to 2010 as possible for baseline tree growth development to be consistent with the climate data. The periodic annual increments (PAI) of diameter at breast height (DBHOB) and stand volume (SV) were calculated from 1991 to the last measurement time for selected PSPs as a baseline. Each PSP was linked with the nearest weather station to get historical climate data required for simulation until the end of 2010. The averages of climatic variables in 1991-2010 were used as a climate baseline to compare with the future climate conditions.

The 3-PG tree growth model (Landsberg and Waring 1997; Landsberg 2003) was then used to estimate the effects of the changes in climate predicted in the CSIRO and BoM (2007) study for 2030, 2050 and 2070. This model has been widely used for various plantation species across a range of site conditions (e.g. Paul 2007). It has also been used for mixed species stands of varying age such as tropical rain forest (Nightingale *et al.* 2008). The model was calibrated for jarrah and karri separately using data from thinning trials with a range of stand densities and different site conditions to build the growth-climate relationship.

The performance of the calibrated 3-PG model was tested using simulated data against observed data collected from selected PSPs. The model was initialized with the first measurement data and simulated tree growth up to the last measurement time using monthly climate data observed during the growth period. The simulation results were compared with the true data of the last measurement for model validation.

The 3-PG software was at first run with climate of the past 20 years to develop the forest growth baseline and then the previous climate was replaced with the two scenarios (the medium and high severity climate change scenarios discussed in Maher *et al.* (2010) to project forest growth under a changing climate. According to these scenarios, average mean temperature continued to rise, reaching 1.1^{o}C and 4^{o}C higher than the baseline and annual rainfall declining by 17 and 29% by 2070.

Relative changes of periodic annual increment (PAI) were used for tree diameter at breast height and standing volume to define the forest growth change on average from the last 20 years to the future since the absolute estimates are very dependent on local stand age and structure.

Statistical analyses were carried out for relative change of mean tree diameter and stand volume. Analysis of variance (ANOVA) was used to examine forest growth in relation to geographic variation (rainfall zone) and partial correlation analysis was used to examine the statistical significance of different climatic variables on growth.

(1) Jarrah forest results

Under the medium severity climate change scenario of climate change, the PAIs of jarrah did not reduce significantly from 2010 to 2030 but reduced by 7% and 14% in 2030-50 and 2050-70, respectively. In contrast, high severity climate change scenario reduced PAIs significantly by 10%, 30% and 45% in 2010-30, 2030-50 and 2050-70 respectively, compared with the trees growth in last 20 years. According to the simulation results, most reduction in stand volume increment in the jarrah forest occurred in dry summers as an result of interaction of rainfall decline and temperature increase, with most jarrah growth occurring in winter and spring.

These results are summarized in Figure 5.1.

Initial ANOVA results did not confirm a geographic difference between different rainfall zones. Partial correlation analysis indicated close relationships of individual climatic variables and a weak effect on forest growth. The Panel had some reservations about this result and asked that some further analysis be done using interpolated average rainfall at each plot.

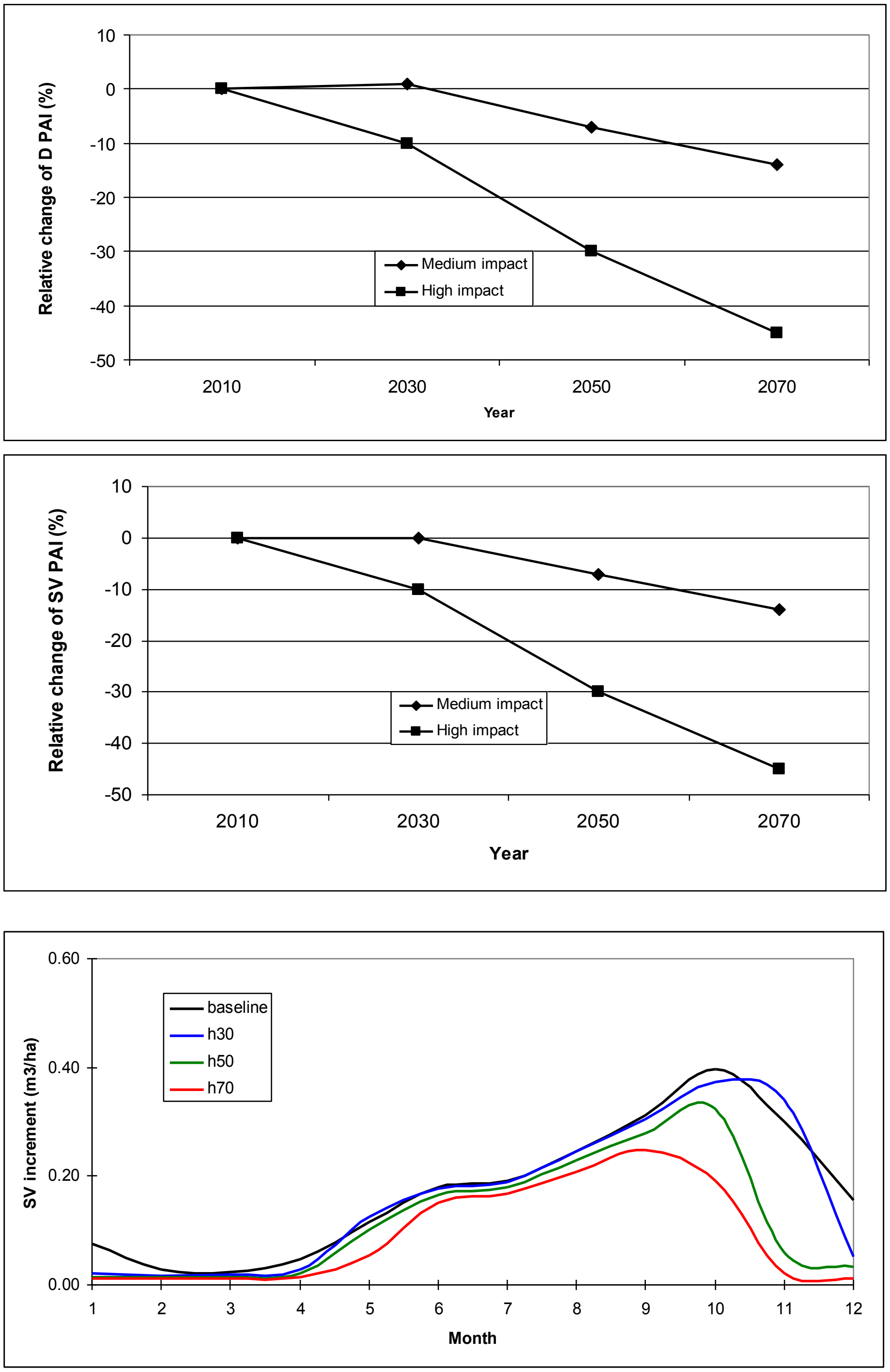

FIGURE 5.1: Relative changes for jarrah forest in (a) mean diameter and (b) stand volume and (c) mean seasonal change in stand volume under medium and high climate change scenarios.

Further analysis by DEC of tree growth recorded in the inventory plots for the period 1990 to 2010 indicated that the average rainfall during that period had a weak but statistically significant effect on tree increment, in addition to the statistically significant effects of site quality (canopy top height) and tree DBHOB. The 3-PG model has been used to simulate the effect of predicted reductions in future rainfall (CSIRO and BoM, 2007) on tree growth and yield. The adjustments were applied to yield tables (and hence through the woodflow schedules) and involved progressively 'scaling back' the future site quality or productivity of forests over time to 2100. Existing site quality is strongly correlated with past rainfall patterns and hence this approach captures the historic effects on site quality of the progressive reduction of rainfall east to west in the jarrah forest. It also utilizes the detailed site quality mapping that is available across the forest and so provides consistency with implementation of the silviculture guidelines. Other approaches to apply scaling adjustments were explored but created difficulties and inconsistencies with yield monitoring and scheduling processes.

(2) Karri forest results

Based on the 3-PG simulation, karri growth under the medium impact scenario of climate change did not decline significantly from 2010 to 2070. In contrast, the high climate change scenario resulted in significantly reduced PAIs of mean diameter and stand volume by 24% in 2030-50 and 40% in 2050-70 respectively, compared with the baseline tree growth of the last 20 years. Neither the medium nor high impact scenario produced a significant change from current growth rates in the period 2030-50.

There were no significant differences in relative change of growth rates between different groups of permanent sample plots that represented different soil types and annual rainfall. In comparison with obvious impact of climate change on the tree growth rate at different times, karri forest was more likely to have a similar growth pattern response to climate change. The results are summarized in Figure 5.2.

The results of the partial correlation analysis did not support a significant linear relationship between relative changes of stand volume increment and individual climatic variables. The high correlation coefficient of multiple climatic variables indicated a strong linear correlation between compound climatic effects and karri growth. These results also demonstrated a high correlation between different climatic variables.

Recommendation 5.1, Further climate change analyses: The Panel endorses the research done to develop adjustments for climate change for jarrah and karri forests for FMP14. The Panel recommends that further research on the impact of climate change of the productive forest estate should pursued in the course of the next Plan, noting that any refinements to the approach need to be consistent with the processes used in monitoring and scheduling of yields.

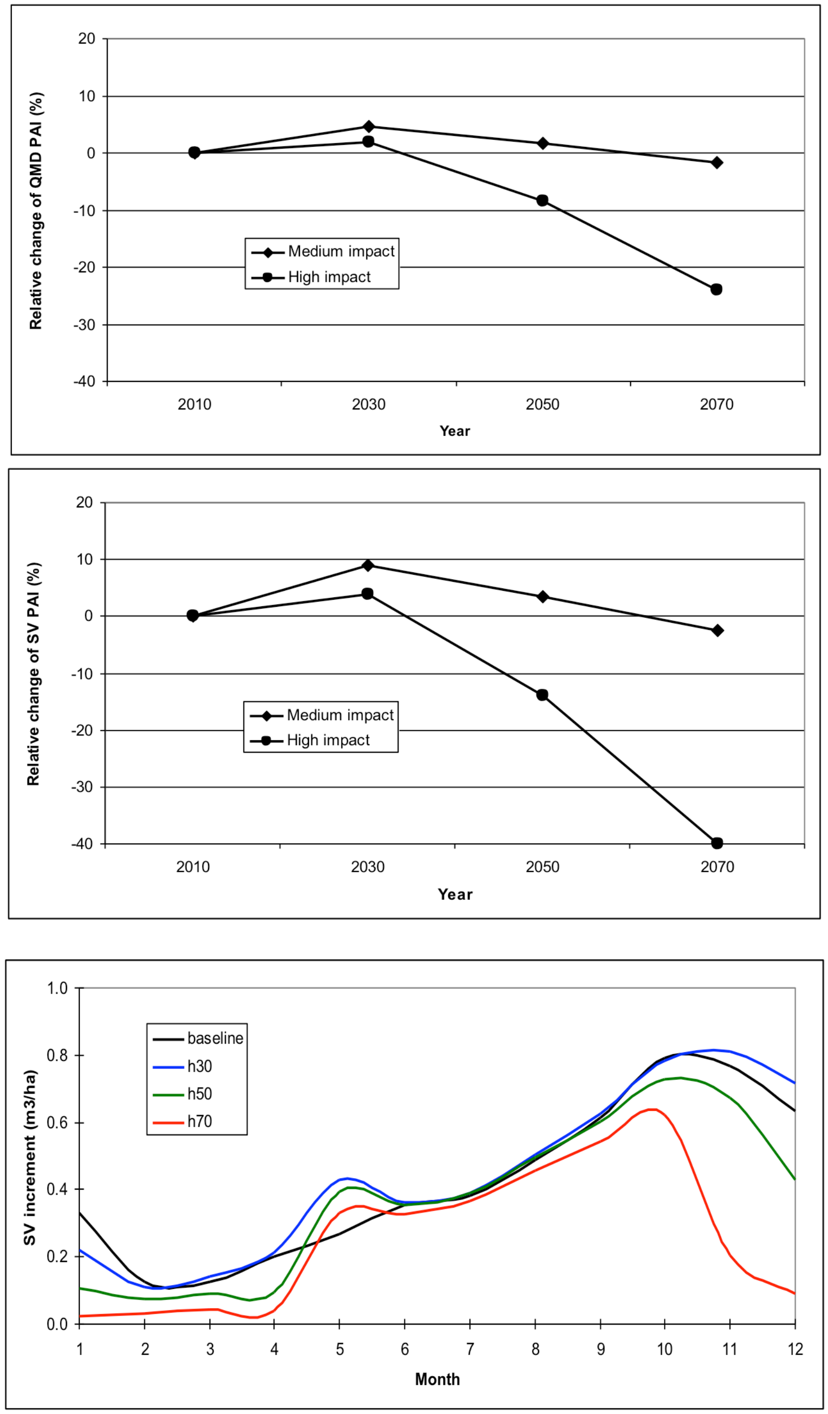

FIGURE 5.2: Relative changes for karri forest in (a) mean diameter and (b) stand volume and (c) mean seasonal change in stand volume under medium and high climate change scenarios.

Medium term trends and variability

The region has experienced a decline in rainfall and an increase in average temperature since the mid 1970's (Hope *et al*., 2006; Suppiah *et al*., 2007; Bates *et al*., 2008). Compared to averages for 1969 to 1999, the region's May to July rainfall decline has intensified and expanded in geographic extent (Indian Ocean Climate Initiative 2012). The decline in May to October rainfall is partly due to reduction in the number and intensity of extreme weather events (Indian Ocean Climate Initiative 2012). Decreases in precipitation have corresponded with significant declines in streamflow and groundwater levels in forested catchments (Croton and Reed 2007; Petrone *et al*., 2010; Kinal and Stoneman 2011, 2012). Kinal and Stoneman (2012) examined records of annual streamflow, stream salinity and groundwater for a small jarrah forest catchment for the period 1976 to 2011 in order to better understand why there has been a disproportionately larger decline in average annual streamflow than in average annual rainfall. They concluded that disconnection between the ground water and stream beds occurred around 2001 and was signalled by a change in the annual stream salinity signature from moderately high and variable, to low and constant, and by the transition in piezometric levels at the catchment outlet from mostly above ground, to mostly below ground. They also concluded that groundwater played a key role in streamflow generation in the jarrah forest.

Research undertaken by CSIRO has established that the overstorey of the jarrah forest dominated by tall, large diameter trees uses less water than regrowth stands in the high rainfall zone (>1100 mm year^{-1}) of the northern jarrah forest. Macfarlane *et al*., (2010) measured leaf area, cover, sapwood area and sapwood density at three paired old growth and regrowth stands. They also measured sapflow velocity at one paired stand (Dwellingup) from June 2007 to October 2008 and their results were summarized thus.

> Old stands had more basal area but less foliage cover, less leaf area and slightly thinner sapwood. The ratio of sapwood area to basal area decreased markedly as tree size increased. Sapwood area of the regrowth forest stands (6.6±0.30 m^2 ha^{-1}) was nearly double that of the old stands (3.4±0.17 m^2 ha^{-1}), despite larger basal area at the old stands. Leaf area index of the regrowth stands (2.1±0.26) was only one-third larger than that at the old stands (1.5±0.15); hence, the ratio of leaf area to sapwood area was larger in old stands than in regrowth stands (0.45±0.022 m^2 cm^{-2} versus 0.32±0.045 m^2 cm^{-2}). Neither sapwood density (540–650 kg m^{-3}) nor sap velocity differed greatly between regrowth and old stands. At the old forest site, daily transpiration rose from 0.5 mm day^{-1} in winter to 0.9 mm day^{-1} in spring–summer, compared to 0.9 mm day^{-1} and 1.8 mm day^{-1} at the regrowth site. Annual water use by the overstorey trees was estimated to be 230 mm year^{-1} for the old stand and 500 mm year^{-1} at the regrowth stand, or 20% and 44% of annual rainfall.

The Panel noted that the sites used in this study were not necessarily representative of old-growth and regrowth forest. The extent to which transpiration of different understorey types in the jarrah forests contribute to the water balance of the forest has yet to be fully quantified.

In forests dominated by regrowth, thinning to reduce canopy interception and transpiration should result in higher recharge of soil water (Burrows *et al*., 2011). So far, the thinning trials established in cut-over jarrah forest in the Wungong catchment have yet to provide an insight into these relationships, no doubt due to the post-thinning drought. However, despite the drought, surface soil was moister and juvenile jarrah plants were less water stressed in thinned than in unthinned plots (Qiu *et al*., 2012). Various reports and discussion documents on the Wungong catchment trials are available on the Water Corporation website (see for example Batini 2012a, 2012b).

Some workers consider that thinning may exacerbate the spread of *Phytophthora* dieback if soils become temporarily waterlogged. Brief evidence to the contrary is provided in a report (Batini 2012c) on a thinning trial established in the Cobiac research catchment in 2008. Batini assessed crown health in 2012, following a severe drought in 2010. Comparisons made between an un-thinned stand (104 tree crowns) and thinned stands that were classified as either dieback-free (104 crowns) or as dieback-affected (162 crowns), revealed that thinning substantially increased the crown health on the retained trees, irrespective of the dieback status of the site. In contrast, within the un-thinned control there were several recently dead trees and many others had poor crowns.

Drought events have triggered canopy collapse in pockets of the northern jarrah forest over recent decades. However, droughts did occur prior to 1975 but were balanced by above-average inflows about once in three years (Batini 2007, 2011) so canopy collapse was less evident than in recent decades. Recent attention has been given to impacts of drought both within DEC and outside (Matusick *et al*., 2013; Brouwers *et al*., 2013). In the northern jarrah forest, an aerial survey with ground truthing revealed that recent forest canopy collapse was concentrated in well-defined patches, across a wide geographical distribution. Of the 8.2% of the Northern jarrah forest surveyed, approximately 1,350 ha (1.5%) had collapsed (Matusick *et al*., 2013). Jarrah suffered higher rates of crown dieback (80%) than the co-dominant marri (51%) where they co-occurred. An aerial survey undertaken by DEC in 2011 revealed that there was no significant drought damage to the overstorey in the drier eastern part of the forest. In their analysis, Brouwers *et al*., (2013) concluded that at a landscape level of assessment, the impact of drought was particularly evident in the overstorey on shallow soils associated with rocks. More recent observations reveal that about two thirds of drought affected trees are recovering from the production of epicormic shoots (G. Hardy pers. comm., Murdoch University).

As part of one approach to monitoring forest condition, DEC has mapped vegetation trend classes, using Landsat imagery, for the South-west forests within the RFA boundary. The Woody Vegetation Index (band3 + band5)/2 developed in the Land Monitor Project (Furby *et al.* 2008; Lehmann *et al.* 2012) was applied to the imagery from 1990 – 2004 and 2004 – 2011. Vegetation cover decline (overstorey and understorey) was evident in parts of the forest. The maps provided to the Panel had not been corrected for silvicultural and harvesting operations, nor for canopy loss from wild fire. A large proportion of the temporary decrease in vegetation cover in the karri forest is due to timber harvesting and regeneration during these periods. The understorey vegetation no doubt contributes to the decrease in vegetation cover but this needs quantifying. Table 5.1 shows that severe vegetation cover loss was quite similar or lower in the 2004 – 2011 period compared to the earlier assessment.

TABLE 5.1: Vegetation change by ecosystem, excluding mine rehabilitation.

Forest ecosystem	Total area (ha)	Decline in vegetation cover	
		1990-2003 (ha)	2004-2011 (ha)
Jarrah – Blackwood Plateau	267,213	3,918	275
Jarrah – North-east	259,783	407	808
Jarrah – North-west	436,413	2,061	2,000
Jarrah - South	420,280	2,980	556
Karri – Main Belt	151,432	7,073	1,438
Wandoo Forest	99,171	107	174
Wandoo Open Woodland	44,754	225	412

DEC also used Landsat imagery in an attempt to analyze the degree of recovery in areas affected by the 2011 drought in the Northern Jarrah forest. "Recovery" was measured in terms of the increase in NDVI between March 2011 and March 2012. These data have not been validated in the field so the relative contribution of the forest strata to the change in NVDI is unknown. Table 5.2 shows that the North West Jarrah Forest was most affected by the drought and that the extent of the high impact affected area was ca. 500 ha.

Following the summer 2010/2011 drought, DEC appraised the extent of woody vegetation canopy change for Landsat images taken between January 2011 and March 2011. The area statistics in Table 5.2 were generated by intersection of the DEC estate available for timber production against a theme labeled 'drought'. The 'drought' theme is based on classification of the change in NDVI for Landsat images taken between January 2011 and March 2011. Areas of recorded harvesting, burning, mining and clearing were removed, and terrain corrections were applied to remove the effect of incidence angle on the image reflectance. A classification of NDVI was then devised using aerial imagery of confirmed drought affected areas e.g. Areas with a decrease in NDVI of greater than 0.1 were classified as 'High impact' (significant loss), while areas with a decrease in NDVI of less than 0.06 were classified as unchanged (to reflect normal leaf shed patterns over summer). The 'drought' recorded is therefore a derived attribute describing vegetation change, and the relative categories are indicative only. The NDVI is generally regarded as representative of woody vegetation, and can includes both overstorey and understorey components. Table 5.2 shows that the North West Jarrah Forest was most affected by the drought and that the extent of the high impact affected area was ca. 500 ha

TABLE 5.2: Area of summer 2010/2011 drought impact in DEC estate available for timber production, excluding mine rehabilitation

Forest ecosystem	Drought impact (net available area for timber production ha)			
	High	Moderate	Low	Total
Jarrah - Blackwood Plateau	-	0	4	4
Jarrah - North East	14	30	80	124
Jarrah - North West	494	736	1,594	2,824
Jarrah - Sandy Basins	11	13	25	49
Wandoo forest	5	13	27	45
Wandoo open woodland	6	8	20	34
Whicher Scarp	1	-	2	3
Total	531	800	1,752	3,083

DEC also used Landsat imagery in an attempt to analyze the degree of recovery in areas affected by the 2010/2011 drought in the Northern Jarrah forest. "Recovery" was measured in terms of the increase in NDVI between March 2011 and March 2012. For example, information provided to the Panel indicated that for areas that experienced a greater than 0.1 decline in NDVI between January 2011 and March 2011, 15% recorded an increase in NDVI of greater than 0.225. These data have not been validated in the field so the relative contribution of the forest strata to the change in NVDI is unknown. These data reveal the resilience of the Northern Jarrah Forest to short-term drought. Nevertheless, the cumulative impact of repeated drought cycles requires long-term investigative research.

The Panel concluded that although there was good evidence of drought events over the past decade in the jarrah forest, the impact on crown condition was restricted to limited parts of the forest where factors such as shallow soil depth predispose the forest to water deficit in years of well below average rainfall. Contrary to media reports, the level of tree mortality remains relatively low and there is no evidence that the forest overall is reaching a tipping point. Indeed, jarrah appears to be a very resilient species. Notably, jarrah in the lower rainfall zones has not experienced as much drought impact, relative to extant area, as jarrah in higher rainfall zones.

Seasonal characteristics

Figure 5.1c suggests that changes in the seasonal growth of jarrah associated with climate change could have further implications but these are beyond the level of resolution that could be credited to this analysis. The Panel believes that the impacts of such changes are better assessed by specifically monitoring the impact of climate change and seasonal shifts on vegetation cover and growth.

The Panel therefore believes that DEC should extend their remote sensing of vegetation change over the next FMP. In addition they should establish large permanent monitoring plots within which individual tree canopy responses can be monitored in the long term, based on the argument of Brouwers *et al*. (2013) concerning the establishment and continuation of large spatio-temporal scale monitoring and research programs in Mediterranean eco-regions. These data and plots would also be available to researchers inside and outside DEC facilitating greater integrated research. They would also be used by DEC to apply the 3-PG models to investigate tree water use and other attributes.

Recommendation 5.2, Remote sensing and permanent monitoring plots: DEC should extend their remote sensing of vegetation change over the next FMP and should establish large permanent monitoring plots within which individual tree canopy responses can be monitored in the long term. These plots should also be available to researchers outside DEC facilitating greater integrated research, as well as being used by DEC to investigate tree water use and other attributes using the 3-PG model.

The Panel is well aware of concerns expressed regarding the effects of drought and its possible association with climate change. It is also aware that the evidence available from long-term tree-ring studies (Cullen and Grierson 2009; Prior *et al*., 2012) indicates that cyclical changes of this type have long been part of the natural climate variation and hence strong conclusions should not be drawn from short-term data. Indeed, the jarrah forest experienced an eleven-month drought in 1972/73 prior to the decline in long-term average rainfall post 1975. The Panel therefore endorses the DEC precautionary approach of examining the possible impact of climate change on growth and hence on future volumes of sawlogs that might be available.

The findings suggest that there is little impact on sustained yield over the next 50 years, so there is time to refine knowledge and adapt to those changes without incurring undue stress on timber production and associated biodiversity and water values. There are, however, specific issues mooted in Recommendation 7.5, dealing with the thinning of re-afforested minesites, that need decisions to be taken in the near future by mining companies and/or Government if they are to produce timber in the longer term as well as aiding water availability now and in the future.

6. PESTS, DISEASES AND FIRE

6.1 Pests and diseases

Phytophthora dieback

Phytophthora cinnamomi is a major threatening process in the South-west Botanical Province of WA. The extent of the geographical distribution of disease, known as Phytophthora dieback, is captured in the Phytophthora Dieback Atlas of 2006. The rate of spread and projected impact of *Phytophthora* dieback are factors likely to affect the sustained yield for jarrah. In 2011/2012 DEC remeasured disease boundaries for the 55 sites previously reported (Ferguson *et al.,* 2003) plus a further 38 sites. Variations in the rate of spread between broad forest zones and in the direction of spread were apparent (Table 6.1) as previously recorded (Strelein *et al.,* 2006). It is notable that the overall rate of spread has diminished. In particular, the annual autonomous rate of spread upslope has declined by 0.9, 0.4, 1.4 and 0.7 $m.y^{-1}$ for the Darling Plateau (West), Darling Plateau (East), Blackwood Plateau and Southern Crystalline Plateau, respectively, since the earlier assessment. Unpublished data from the Centre for Phytophthora Science and Management for 10 jarrah forest plots shows that the mean dieback front movement between December 2002 and October 2012 was ca. 8 cm y^{-1} (Giles Hardy, pers comm.). This slow rate of spread is most likely due the pathogen spreading via root to root contact.

TABLE 6.1: Autonomous spread of *Phytophthora* dieback -2001/2 to 2011/2012

	Average Annual Spread, (Std Dev) $m.y^{-1}$		
	Direction of Spread		
Zone	Downslope	Flank	Upslope
Darling Plateau (West)	0.36 (0.47)	0.22 (0.28)	0.38 (0.60)
Darling Plateau (East)	0.0	0.0	0.0
Blackwood Plateau	0.10 (0.14)	0.57 (0.57)	0.77 (0.66)
Southern Crystalline Plateau	1.20	1.29 (1.82)	0.54 (0.37)

In the FMP04, the projected future extent of *Phytophthora* dieback occurrence in the forest available for timber production increased over time from 14% in 2002 to 35% by 2060. Due to the much-reduced spread rates observed in the recent data, the modeling process was not sufficiently sensitive (due to pixel size) and the consequent spread over the 2014-2023 period was too small to affect disease area by strata. Consequently the disease spread variability was examined in a sensitivity analysis to assess the possible impact on future woodflows arising from the altered rates of spread within the strata (forest type, silvicultural status and disease status).

To examine impact on growth, 38 plots exhibiting different disease impact categories were selected with similar starting basal area, site attributes, cutting history and reliable disease date stamps. These permanent sample plots span up to 40 years of *Phytophthora* dieback impact; an important advantage over the 20-year period spanned by remeasurement of the jarrah inventory plots. As basal area increments did not differ between geographic zones, plot data were summarized by impact category only. The basal area increments on those plots with high impact showed a 3% reduction compared to the non-infested plots, while on low or moderate impact sites there was a 5% reduction. Due to this small difference DEC proposed using a single value of 4% across all vegetation complexes (Table 6.2).

TABLE 6.2: Comparison of change in basal area for infested and uninfested plots

	Initial BA m^2ha^{-1}	SD BA	Min BA m^2ha^{-1}	Max BA m^2ha^{-1}	10 yr Incremen t m^2ha^{-1}	Std Dev Increment m^2ha^{-1}	Number of plots	Relative change in BA
Healthy	17.1	5.1	11.0	30.6	1.56	1.62	18	
Dieback	19.9	6.2	9.6	31.9	0.92	2.17	20	96%

Notwithstanding the considerable duration of the plots available for measurement, the Panel is concerned that the data set used in Table 6.2 to examine the impact on growth is unbalanced since it contains only 5 high impact plots out of a total of 20 plots. DEC provided a further analysis based on re-measurement of 151 jarrah inventory plots for the period 1990 to 2010, in which 103 plots were dieback free and 38 plots were dieback infested (Figure 6.1). Impact categories were not separately identified. The large error bars for the larger two diameter class cohorts where dieback was present highlight the variability in tree growth with diameter class. Larger tree cohorts are therefore desirable in paired plots in the future in order to obtain definitive quantitative trends of the impact of *Phytophthora* dieback on yield.

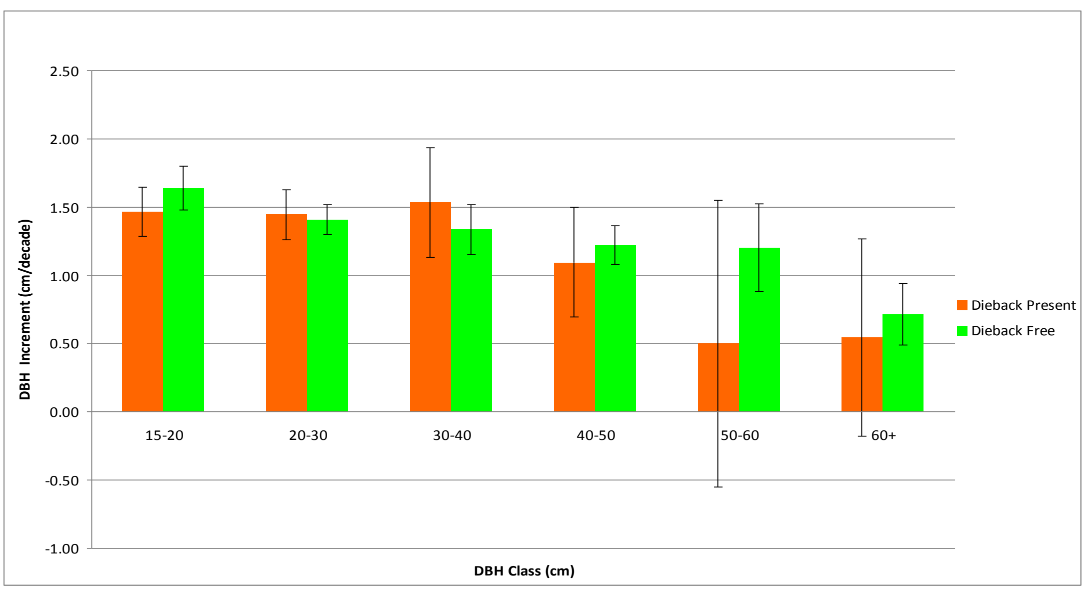

FIGURE 6.1: Jarrah diameter growth by diameter class.

Ferguson *et al*., (2003) recommended developing a capacity to model the introduction of new infection sites rather than simply the extension of existing occurrences. This was to be based on analysis of areas that have been remapped for disease some years apart and correlated with likely contributing vector factors. DEC informed the Panel that this work has not proceeded due to available resources being fully utilized on monitoring and reporting of other dieback KPIs and the current cycle of lower rainfall. DEC is however exploring developing a Phytophthora and Climate Change Model using the CSIRO and BoM (2007) Climate Change dataset to create projections for spread and impact of *Phytophthora* dieback.

Regrettably, the Panel believes that the DEC conclusion misses the point of long term monitoring, which is not about the short term fluctuations of climate that occur. Once established, with a commitment to continuation, the costs reduce but the information increases progressively. The commitment of on-going resources to long-term monitoring is critical. New technologies may complement the process but the basic fact remains that a relatively slow moving and diverse but site-selective infestation (relative to sub-surface water movement) can only be assessed from continuing long term monitoring and associated research. It is a completely false economy to engage in start-stop research on such issues.

The Panel believes that the impact of *Phytopthora* on growth is still very uncertain. It accepts that Table 6.2 represents the best current data available but does not believe them to provide the best estimate of impacts. The adjustments used in DFMP should therefore continue to be used but the Panel strongly urges that more research be carried out over the forthcoming Plan period. The Panel notes that many of its concerns are consistent with the DEC (2013) report on the effect of climate change and the impact of *Phytopthora*.

Recommendation 6.1, Best estimates for *Phytophthora*-infested jarrah sites: Notwithstanding the recent changes in short-term climate, the Panel recommends jarrah growth on *Phytophthora*-infested high impact sites be reduced by 20%, and by 5% on moderate impact sites, as used in DFMP.

Recommendation 6.2, Further dieback and disease research: The Panel strongly urges that further work be undertaken to develop a Phytophthora and Climate Change model that has the capacity to model a wide range of scenarios including disease outbreaks of *Phytophthora cinnamomi* (and other *Phytophthora* species if they are shown to be having an impact on the forests) and new infection sites following extreme weather events such as unseasonal storms.

Armillaria

Specific adjustments have been made to silvicultural treatment and defect allowances for the projected impact of *Armillaria*. The proposed karri silvicultural guidelines provide for thinning in *Armillaria* stands, and within the karri yield tables the future degrade of sawlog was based on the destructive sampling of regrowth trees in areas with high incidence of *Armillaria*.

The Panel supports the approach adopted. However, the next and later rotations on *Armillaria* sites should logically repeat the degrade impact of sawlog used in the first. This will have a negligible effect on sustained yield.

Recommendation 6.3, *Armillaria* degrade sites: Although having a negligible effect on sustained yield, the next and later rotations on *Armillaria* sites should repeat the degrade adjustment of sawlog used in the current rotation in the calculation of sustained yield.

Pests

A severe outbreak of gumleaf skeletoniser (GLS, *Uraba lugens*) occurred in the southern jarrah forest in 1982-1988, leading to defoliation of over 300,000 ha of jarrah forest by 1986 (Farr, 2002; 2009). Outbreak of GLS was initiated on marginal jarrah forest on poorly drained sites prone to inundation in winter and drought in summer (Farr *et al.* 2004). Smaller outbreaks continue to occur from time to time (Farr and Wills 2012). Although altered frequency and severity of outbreaks may occur under higher severity climate scenarios, there is a strong likelihood that under drying conditions there may be a lessening of the outbreak events in the wetter areas of the forest.

Since the 1960s when foliar damage from the jarrah leafminer (*Perthida glyphopa*) was severe in the Manjimup region, the pest has been moving north in the jarrah forest (Burbidge and Wills 2005). DEC Science Division has an active project to monitor the northern extent of jarrah leafminer outbreak. Monitoring undertaken by DEC in 2004, and reported in Wills (2009), shows that the leafminer is making inroads in forests near Dwellingup.

Impacts of GLS and jarrah leafminer on growth to date are incorporated into the measured increments used in the yield predictions for jarrah regrowth and two-tiered forest. Nevertheless, they merit some weight in determining the safety margins to be applied to calculate the final sustained yield for jarrah.

Phoracantha borer affects regrowth karri stands in a defined geographical area (Farr, 2010). Yield adjustments, through higher rates of log product degrade, have been made for areas with high incidence of borer recorded in 2010. No increase in extent is assumed for the proposed FMP14.

Recommendation 6.4, Other pests and diseases: The Panel supports the approach adopted by DEC in making adjustments to reflect karri and jarrah pests and diseases other than *Phytophthora*. It notes that future seemingly unpredictable episodes of infestation are best taken account through the safety margin to be applied to the final calculated sustained yield, although it believes that this source would be quite a very small contributor, given their nature and likely extent.

6.2 Fire

DEC has reviewed factors of the environment and current forest management that influence potential loss of timber resource due to bushfire in the jarrah and karri forests. These include the following:

- changes in climate and weather settings affecting bushfire risk over the period of the FMP04;
- the current age class distribution of fuels in areas of the jarrah and karri forests where stands available for ongoing wood production are concentrated;
- expansion of thinning in post-1967 karri regrowth stands during the last decade; and
- lessons learned from bushfires during the period of FMP04.

Comparison of trends in fuel dryness and fire danger (McCaw, 2013), calculated from daily records of the jarrah surface moisture content (an indicator of fine fuel dryness) and jarrah forest fire danger index, clearly indicate drier fuel conditions on average and an increase in the average daily fire danger in the past decade (Table 6.3). The decade since 2003 has experienced a series of dry years with rainfall very much below average in 2006, 2010 and 2012. This has resulted in declining streamflow and groundwater, and reduced moisture recharge of coarse woody debris in the forest.

TABLE 6.3: Changes in 95th percentile values of jarrah surface moisture content and forest fire danger index over time

Location	Period	No. of observations	Surface moisture content (%)	Fire danger index
Pemberton	1980-1993	1226	7	74
	2000-2012	1348	6	100
Manjimup (Donnelly)	1983-1993	553	9	71
	1996-2002 2007-2012	1690	5	95

Analysis of fuel age distributions (McCaw, 2013) for three Landscape Management Units in the Warren Region, revealed that regrowth karri stands are concentrated in landscapes dominated by fuels older than 15 years. Similar analysis for five Landscape Management Units that represent a large proportion of the area of jarrah forest available for timber harvesting revealed an increase in the area carrying fuels older than 7 years since last fire.

Commercial thinning of post-1967 karri regrowth stands has expanded during the period of FMP 2004, with the program approaching 1000 ha thinned per annum from 2004 onwards. Most regrowth stands have not been burnt in the period between regeneration and first thinning that typically takes place at an age of about 30 years. Prescribed burning of stands after thinning has proved difficult because of the large quantities of fuel in thinned stands, and the relatively narrow range of weather and fuel moisture conditions under which a low intensity fire can be achieved. Retained stems are vulnerable to serious damage if burnt under dry conditions when the large woody components of the thinning debris (>25 mm diameter) are consumed. Analysis of the February 2012 Babbington fire illustrated the vulnerability of thinned stands over unthinned karri stands to fire damage. DEC has used similar conditions to those of the Babbington fire to simulate fire behavior and potential loss of regrowth karri (McCaw, 2013) and these usefully inform later determination of the safety margin to be applied to the final sustained yield.

DEC suggests that as bushfires are likely to be more difficult to suppress, and to burn larger areas of forest before they are contained, the potential for loss of sawlog yield during the period of the DFMP is therefore greater than it has been during the current FMP04.

However, based on the recommendations of the previous review (Ferguson *et al.*, 2003), DEC proposed that karri and jarrah regrowth stands be transitioned to new regeneration at a rate of 3% of the area in the fire sensitive age range of 1-30 years at that stage in the scheduling for sustained yield calculations in the DFMP. Similarly, 0.1% of mature forest is set to non-forest at any harvest point in the scheduling, assuming that the level of damage results in there being no recoverable products in the remaining trees.

The DEC methods of adjusting for fire through area adjustments are unsatisfactory in the light of the changes that the current Panel propose in dealing with risk and uncertainty. The inventory data already reflect the impact of past fires. Fire is episodic and seemingly unpredictable in a deterministic model, such as DEC has developed. Area adjustments of this kind exacerbate splintering, imprecision and may introduce biases that cannot be gauged or adjusted.

The one-shot area corrections applied to karri regrowth in the 1 to 30 year age class when scheduled contribute to imprecision and unnecessary complication. Essentially this correction implies the loss of 3% of the average yield per hectare that would have accumulated over an average of first 15 years of a karri regrowth stand. Multiplying this loss by the area of karri regrowth provides an estimate of the aggregate loss in standing volume due to fire. An appropriate adjustment for sustained yield can then be calculated by applying von Mantel's formula (Davis and Johnston, 1987). The Panel has already recommended that deliberate conservatism should be avoided in the calculation of sustained yield and now recommends that this particular correction be dropped.

The setting of 0.1% of mature forest to non-forest at any harvest is another example of a deliberately conservative assumption because it takes no account of the capacity to salvage most of the mature tree volume lost in a fire. Furthermore, the current inventory at 2014 already reflects past losses due to fire. Suitable data appear to be available, an adjustment to annual growth functions could be derived and the adjustment transferred through to the yield estimates for strata. If not, it could be the subject of a similar adjustment to that of karri regrowth using von Mantel's formula.

Recommendation 6.5, Fire adjustments: The Panel recommends that DEC drop the previous area adjustments, for fire, thereby avoiding deliberate conservatism. DEC should develop adjustments to aggregate standing volumes of sawlogs based on available data. This would enable the approximate adjustments to sustained yield to be calculated and so inform later determination of the safety margin to be applied to the calculation of sustained yield.

7. WOODFLOW SCHEDULING

Woodstock software is used to select a set of woodflows for the various Forest Types that will aggregate to best meet the constraints whilst, as far as is possible, providing the most volume possible for utilization over the planning horizon. Technically, it is a constrained optimization program using a linear programming algorithm that computes the best aggregate schedule of woodflows, while meeting the considerable array of market, legal and operational constraints.

7.1 Process

Earlier sections of the report have reviewed how harvest volume outcomes are predicted in the future for various silvicultural and management strategies numbering about 756 in total. Some of these strategies are mutually exclusive and need to be examined as alternative scenarios. The best set from these has to be selected for each scenario, while recognizing many hundreds of constraints. Some of the constraints are area constraints that simply reflect the fact that one cannot harvest more than the area of the Forest Type concerned. Others relate to FPC contractual constraints on wood flows to particular sawmills. Others reflect operational constraints in terms of the minimum volume per hectare that constitutes an economically viable harvest operation. Still others reflect the operational desire to spread harvesting geographically or to limit the maximum size of the harvest coupe. The number of constraints is limiting in terms of an acceptable computing time and that is why, in some cases, simplification of the number of Themes may be necessary. Even if the scenario can be solved in an acceptable time, there may be no feasible solution because one or more constraints cannot be satisfied - a piece of information that is itself valuable. In that event, consideration must be given to changing or weakening the constraint. For a scenario for which the best aggregate schedule of woodflows can be solved, software (MOSEK) associated with Woodstock also provides values that show the sensitivity of the aggregate wood volume over 100 years to a change n the value of the constraint – the so-called dual prices.

A systematic approach in documenting and running the scenarios is important, as is the checking of the specification of the scenario and the sensibility of the outcomes. Outcomes are checked by running the simulation models used in scheduling the current FMP, as well as checking the sensibility of outcomes by other experts. Some further simulation of detailed outcomes is possible using Woodstock. DEC also arranged to have the lead scientist of Remsoft the supplier of Woodstock, to review and comment on a scenario. His report stated:

> In summary, the overall structure and form of the models is good and consistent and best practices are mostly employed throughout, though some effort should be used to further reduce the number of variables contained in the resulting matrices.

This is a view the Panel endorses.

7.2 Outcomes

The Panel's charter is not to canvass the setting of the sustained yield but to report on the process used in the calculation of sustained yield. As part of that process, the panel has examined the dual prices associated with many of the major constraints to see it these foreshadow an undue sensitivity to the values used for the constraints. Such an outcome would indicate that revision of the value of the constraint or reformulation of the function used to estimate it was warranted. A dual price simply expresses how much the objective function (in this case, aggregate amount of wood to be harvested per year) would change for each unit change in the value of the constraint.

The Panel has had the opportunity to inspect one scenario with respect to the dual prices that apply to the constraints. The results signal an issue that needs to be resolved because the dual prices on the contractual commitment to one processor are very high. Because this is based on the results of only one preliminary scenario and calculation, the Panel does not propose to make this data public, but the result is stark. Clearly, the costs of maintaining this contract appear disproportionate to the financial outcomes for the State and for other processors seeking more sawlogs.

Surprisingly, this is one of the very few constraints that impose substantial penalties on the sustained yield. With two exceptions, other constraints were either slack or involved small penalties.. The two exceptions in the trial scenario that the Panel inspected were the even-flow jarrah sawlog constraint and the even-flow karri sawlog constraint. These are constraints to ensure that the wood flow is even between 2014 and 2110 but has scope to fluctuate by plus or minus 5% variation around that value in any individual planning period. They often shape the woodflows in ways that make it difficult to gauge the tradeoffs, their dual prices in the final period being difficult to interpret because of the sequential character of the constraint. No problems emerged in meeting the contractual and security agreement commitments and, indeed, there may be scope for some increases in sawlog volumes. These represent preliminary results for one scenario and much further work needs to be done before the final sustained yields are available. Neverthless, the suggested imposition of constraints on annual areas to be cutover need to be investigated carefully, as constraints of this kind typically involve a very high dual price, signaling that this is a very inefficient way of setting the sustained yield.

7.3 Improvements to scheduling

Partly as a result of the interactions involved in this review, some significant progress has been made over the period of this review with respect to:

- the efficiency of processing to shorten solution times;
- refreshing some of the spatial themes to incorporate updated tenure, dieback and availability data;
- refining some of the yield tables for regrowth karri to account for a revision of utilization expectations for sawlogs from second and subsequent thinnings; and
- exploring the Panel's suggestion of aggregating the jarrah strata, or alternatively, aggregating within FMIS to a minimum base raster cell size for Woodstock that is around a minimum of 10 ha to reduce the subsequent splintering, but trading off detail.

The last of these is not yet resolved and the Panel recognizes that the recommendation on pooling of jarrah strata that follows is subject to further investigation.

The Panel has made a number of recommendations concerning strategic planning, specification of constraints, simplification of the model, and changes to the scenarios to be examined.

Strategic planning

Changes in the mix of sawlog grades and sizes are inevitable as a consequence of the history of past cutting. These and the capacity to sell non-sawlog volume can have major impacts on the economic viability of sawmilling and other timber utilization and therefore need to be explored. As far as possible, these impacts need to be taken into the process of simulating the allocation of allowable harvest levels to individual sawmills or processors in terms of location and scale, rather than assuming that a particular level of sustained yield is immutable and an automatic solution for all times.

For example, the preliminary woodflow analyses use an even flow constraint for the aggregate wood flows of sawlogs. In the case of karri this results in a continuing mixture of smaller logs from harvesting even-aged regrowth, together with a mix of larger sizes from the harvesting of remaining two-tiered karri stands.

From an industry perspective, a more economically viable solution may be to constrain the solutions so as to bring forward the completion of harvest of the two-tiered karri and to defer the commencement of harvest of even-aged regrowth in order to see a step change to a smaller average log size but one exhibiting lesser variability in size. This would enable the successful purchaser to better adapt to the log mix with appropriate technology and scale. That step change will probably involve a later start and a probable increase in karri woodflow from the even-aged plantations compared to the present DFMP simulation and scheduling. It would need the support of a longer term contract of sale, say 20 years, in order to attract the additional investment in the new technology needed.

The karri example is only one example of strategic issues. There are others associated with the future utilization of the Northern jarrah sawlogs. Most of the larger sawmills are not well located to utilize this supply, nor is it well placed for additional supply from southern areas, should that be available in the final outcome. A modest additional supply may be available for a more northerly located sawmill and that possibility should be explored, along with the potential for rationalization of all sawmill locations at appropriate future times in the final analyses for the calculation of sustained yield. Such an exercise would, of course, work within the existing contractual and legal arrangements and involve active liaison between DEC and the FPC in terms of long term planning to best meet the economic needs of industry and the associated social needs of dependent communities.

Recommendation 7.1, Strategic planning and step changes in scheduling: Analyses of sustained yield should be based on strategic planning by DEC and FPC to assist the future development of economically viable timber processors and dependent communities. This may necessitate step changes in scale and timber grade and size, in contrast to a long-term static sustained yield.

Specifying constraints

Various options are provided in the Woodstock model to facilitate the setting up of constraints – for example, the non-declining yield and sequential flow (e.g. plus or minus 5% options. The Panel believes that while these options can be useful, they should be used sparingly. Any sequential time dependent constraint can create problems even though being easier to set up. A non-declining yield, by definition, will take on the highest value possible value in the first period of its specification, given that it can at least be continued (or increased) for all subsequent periods. Non-declining yield constraints also generally result in a buildup in the standing volume at the end of the periods to which it was applied (Hof, 1993, Bettinger *et al*., 2012). While an increase may well be desired, the non-declining yield provides no mechanism for setting what that goal might be, so it becomes a 'black box' outcome rather than a planned outcome. A sequential flow constraint (with a plus or minus 5% option) may appear appealing because it allows fluctuations to occur but these also are sequential flow constraints that are planned to happen, not real-world variations, and they can amplify real-world variation to unacceptable levels.

In a later section, the Panel recommends (see Recommendation 9.2) that a shorter planning horizon be used in scheduling, subject to later simpler analyses to test the sustainability goal of nearing a 'normal' steady state. This shorter horizon should ease some of the problems experienced with computing times in the early runs of the model. It also makes the task of setting constraints period by period easier. This is important as there are some fixed constraints in relation to existing contracts and security agreements to be incorporated and there are some step change constraints that the Panel has already mooted, together with strategic rethinking by DEC and FPC about the best locations and associated scales of processing plants when those contracts and agreements cease.

Simplifications

As noted earlier, consideration is being given to a systematic review of the Themes to eliminate redundancy or aggregate categories to reduce the complexity of the model and so reduce the number of small slivers and patches. Other algorithms that may handle this level of detail better are becoming available and should be examined in the preparation of the next FMP.

One particular simplification concerns the pooling and/or simplification of the jarrah Silvicultural Status, to which reference was made in Section 2.

While the stratification of uneven-aged jarrah forest into these categories is very useful in aiding the application of silvicultural guidelines in the field, the Panel does not believe that the differences in mean volumes per hectare or their variances are sufficiently different to merit separation in the scheduling. SILVIA is a reasonably flexible individual tree simulation model. It could still be applied with equal validity to the inventory plots in the new pooled stratum, using the prescription appropriate to the Silvicultural Status and thus enabling a single yield table to be estimated for the new stratum. The new stratum would reflect the proportions of gap, shelterwood and selective prescriptions in the field inventory plots. This pooling may also greatly improve the precision of the estimates of standing sawlog volume for the new stratum and facilitate comparison of changes in mean volume per hectare and other statistics over the period of the plan. It might then be labelled 'uneven-aged' jarrah, as we have done through much of this report.

As later discussion under re-afforested minesites will show, the Panel is skeptical of the frequency/intensity of the thinning schedule for re-afforested minesites that is applied more generally to even-aged jarrah regrowth. As yet, there is no economic justification for the relatively frequent light thinning for this slow-growing species. Even allowing for the still hypothetical economic net benefits that water as well as timber production might confer, the repeated thinnings in the initial 60 years after the first thinning seem too frequent and therefore too light to be practicable. However, this is not to argue against an initial thinning as early as is practicable. This is probably the single most important contributor to the economics because it is the difference between no timber or water production and some of both.

The Panel recognizes that these suggestions raise a host of issues concerning implementation in the scheduling. Where current analysis yields clear directions and can be implemented in a timely fashion for the proposed FMP14, that change should obviously be done. However, where that is not possible, the implications are not inimical to the current calculation of sustained yield – it simply means that the precision may not be as good as might be attained with further work in the period of next plan.

Recommendation 7.2, Pooling and/or simplification of jarrah strata for scheduling: The Panel recommends that, where practicable in the time available, the pooling and/or simplification of the jarrah Silvicultural Status used in scheduling be pursued for the proposed FMP14. Further research on this should be pursued in the next plan.

As noted earlier, Woodstock is not suited to analysis of the impact of fire or drought because they are episodic events, whose future occurrence cannot be predicted with any precision. Other forms of analysis can be used to gauge the sensitivity of the sustained yield to such events. For example, it might better be examined by applying an average volume loss based on recent fires or droughts to the total volume of growing stock for the Forest Type concerned and then applying von Mantels' formula to gauge the approximate change in sustained yield. Nevertheless, the historic average losses from fire and drought need to be the safety margin to be applied to the final calculated sustained yield, as noted in Section 8.1.

Recommendation 7.3, Adjusting for fire and drought: The potential impact of fire and drought on sustained yield should be analyzed by means other than Woodstock and adjustment for them incorporated in the safety margin to be applied to the final sustained yield calculated from Woodstock.

The harvest of wandoo is another area where the annual harvest is currently so small and the resource so dispersed that the sustained yield is better calculated by other means, such as that referred to above for fire and like events, rather than overcomplicate Woodstock and incur the additional computing time involved. In practice, the harvest volume will largely come in the course of harvesting mixed jarrah-wandoo stands as a supplementary volume arising.

One further but long-standing simplification is the omission of marri sawlogs from the formal woodflow scheduling. Despite many attempts to overcome them, the difficulties in determining log quality in standing trees remain (Ferguson *et al*., 2003; URS, 2012) and hence marri sawlogs are also a supplementary volume arising.

Recommendation 7.4, Wandoo and marri: The sustained yields for wandoo and marri should be calculated by means other than Woodstock.

Scenarios

At present, the principal variants being used to explore future industry structure and utilization options utilize the same area, climate, and other settings endorsed to date by the Conservation Commission and are based on:

1. Continuing utilization of sawlogs but with non-sawlog utilization limited to current markets (e.g karri and young marri woodchips charlogs for SIMCOA, firewood)
2. Continuing utilization of sawlogs and full non-sawlog utilization from 2014
3. As in #1 to 2023, then a transition to full non-sawlog utilization.

All incorporate the DFMP options approved to date by the Conservation Commission and include adjustments for climate change, dieback, other diseases and fire. Some of the latter will need revision in the light of earlier Panel recommendations, especially given the desirable liaison between DEC and FPC to refine the strategic development of the existing sawmilling industry and that of non-sawlog utilization. Whilst some of these changes can be incorporated as step changes, others relating to non-sawlog utilization (URS, 2012) will remain uncertain until the commitment to invest. This is a further reason that greater flexibility is needed in the proposed FMP14 both in planning such change, and once the commitment is made, in order to provide the security that large investment needs. It is significant that all the possible opportunities mooted by URS (2012) involve annual volume in excess of 100,000 m^3ha^{-1} and some more than 200,000 m^3ha^{-1}. Those changes cannot be cast in stone and provision needs to be made for a transparent update in the proposed FMP14 to accommodate major opportunities or shocks.

The Conservation Commission is yet to determine its recommendation on two options in the DFMP. These can be examined using separate scenarios for each alternative in each option. Specifically, these are:

- The exclusion of high impact dieback infested sites carrying less than 18 m2/ha of basal area.
- The limited redesign of Fauna Habitat Zones

Each additional scenario represents a substantial demand in terms of staff and computing time, so the sooner some of these questions can be resolved, the better. One other concern affecting scenarios has been raised in submissions.

Re-afforested minesites

A further area of uncertainty regarding all scenarios concerns the possibility of thinning of mine sites re-afforested with jarrah. Being mainly in high rainfall areas, thinning would probably provide a significant marginal net social benefit in terms of water production. Research on the responses to thinning on re-afforested minesites and on native jarrah regrowth forest (Croton and Reed, 2007, Batini, 2012a, 2012b, Reed *et al*., 2012) provides sufficient data to gauge initial responses in terms of additional water production and timber production. However, as several submissions pointed out, there are also gains to ecosystem health.

The Panel notes some uncertainty exists as to the capacity of about half the re-afforested minesites to produce timber in the future because of inadequate stocking. The following comments therefore refer to that portion that is adequately stocked.

For adequately stocked areas, an initial thinning and treatment of stumps, as early as is practicable, represents a make or break decision for future timber production as well as the immediate impact on water production and therefore represents ‘best practice’ in terms of restoring productive capacity. Re-afforested minesites that are left unthinned and untreated will produce negligible volumes of sawlogs over a proposed rotation of 200 years.

Notwithstanding past research on thinning, further research is needed to establish the timing and intensity of initial and later thinnings and to enable an economic analysis to be undertaken that includes the net benefit from water production. The net benefits from water production are more difficult to gauge because the price of water to the consumer is not the relevant measure of the benefit. The so-called ‘backstop’ price of water to consumer (Ferguson, 1995) via desalination has to be converted to a residual price at the catchment head by deducting the long run marginal cost of reticulation.

However, the preceding review tends to assume that thinning is solely a matter of whether or not it represents an economic investment. This may not be the case. There are other factors to be considered relating to the legal agreements between the mining companies and the Government and whether these refer to and require companies to implement ‘best practice’. The chances of any significant volume of large sawlogs from these re-afforested minesites without thinning is negligible, given the propensity of jarrah to lock rather than self-thin, so the issue is highly relevant to the calculation of sustained yield.

Recommendation 7.5, Re-afforested minesites: The Conservation Commission and/or DEC should ascertain the intentions of the mining companies and Government in relation to thinning of re-afforested minesites and draw their attention to best practice. If this issue cannot be resolved in time for the calculations in the proposed FMP14, this resource will have to be treated as an unresolved option, involving two alternative scenarios (one thinned and the other omitting the resource) for sustained yield. In any event, further research is needed on the frequency and intensity of thinning and the associated economics.

8. SPECIFYING SAFETY MARGINS

8.1 Introduction

In developing the various stages involved in the calculation of sustained yield, any biases in the estimating and predictive functions involved have been removed, as far as is practicable, given the data available. The Panel is satisfied, with the exception of minor changes or adjustments already noted, that this has been achieved.

However, any prediction of this kind embodies some inherent variability (imprecision) due to the sampling base and statistical procedures involved. Thus the remaining question to be addressed is what safety margin is needed in the sustained yield, if any, to protect DEC and/or FPC against the possibility that the calculated value is an overestimate that would place any dependent contractual arrangement at risk from the inability to supply the committed amount.

To answer this, we need first to examine what is or should be the attitude of DEC and FPC to risk. The Auditor-General of Tasmania (2011) has indicated that a risk-free rate of discount should be used in valuation of the Forestry Tasmania estate. This follows a well-established economic principle that if the Forestry Tasmania contribution to State investment is small and its returns statistically independent of those for the State economy as a whole, it should be risk-neutral in discounting (Arrow and Lind, 1970). On this basis, risk-neutrality would be appropriate in gauging the safety margin applying to the discount rate for any similar commercial State-owned entity, making the safety margin effectively zero. However, the Forest Products Commission and senior executives might have a very different view, because of the risks involved to their reputations, and might therefore apply a safety margin on that account.

These are matters for DEC and the FPC to resolve. Nevertheless, for a large commercial State-owned entity, there is a valid argument for a risk-neutral or, at least, only a very small amount of risk aversion in setting a safety margin. Failing a stochastic analysis that enables the odds of breaching the contract to be evaluated, the application of a safety margin is a pragmatic choice that often aims to minimize the maximum risk, especially of breach of contract or insolvency.

8.2 Adjustments for risk and uncertainty

DEC has undertaken a review of risk and uncertainty involved in the calculation of sustained yield using the traditional ISO–31000 approach. At least one member of the Panel has severe reservations about both the terminology and the approach, because they blur the distinctions between probabilities, episodic event outcomes and the expected value or cost of that type of event. Nevertheless, the systematic identification of uncertainties in each step of the calculation process is a useful basis on which to reflect.

Net Area

The uncertainties here appear to be of low probability of occurrence and no adjustment would be warranted.

Inventory

The only uncertainty identified relates to difference between actual silvicultural outcomes from the intended condition of the treatment. However no evidence is given so the Panel infers that the probabilities of differences are spread symmetrically and therefore no or very little adjustment is required, especially if an earlier recommendation (#7.2) to pool some of the jarrah Silvicultural Status types is pursued.

Growth and Yield

Of the five uncertainties listed, only that relating to the absence of markets for thinning jarrah/marri stands appears to be a risk of high probability. A specific provision in Woodstock scheduling enables the sensitivity of any scenario to this event to be tested and thus no further adjustment is needed.

Those relating to the cumulative impacts of fungi, insects and fire are of moderate probability and are at risk of beieng under-estimated because they are modelled in isolation. This statement about isolation seems somewhat at odds with the multiplicative corrections carried out in the yield tables and it therefore seems that no further adjustment is needed. However, monitoring of the situation is needed.

The impact of increasing difficulty in the utilization of smaller jarrah logs can be monitored from the Woodstock output and therefore no further adjustment is needed.

The impact of the loss of volume from bushfires in karri can be analyzed in other ways than Woodstock, as suggested in an earlier Panel Recommendation 7.3.

The impact of the simplifications in landscape scale and patch scale silvicultural settings can be evaluated from successive inventories and no further adjustment is needed.

Scheduling

The uncertainty that the overall complexity of the strategic settings cannot be represented in the model is of high probability but arguably very low impact because the Panel would argue for further simplification and reliance instead on the monitoring of outcomes through successive inventories.

The representation of patch and landscape constraints appears to be a repetition of the uncertainty under growth and yield.

Thinning for water production is a scenario choice to be resolved and not an uncertainty in this context.

The final two areas of uncertainty relate to strategy industry policy matters and are the subjects for scenario evaluation, not adjustments for uncertainty that relate to the steps involved in developing the Woodstock model.

8.3 Conclusions

In the light of the preceding analysis, the Panel returns to pragmatic estimates of adjustments for risk that are intended to provide protection against seemingly unpredictable risks such as fire, cyclones, drought, and pests and diseases. The latter have already been noted to be of minor magnitude, given the provisions already made in calculating the sustained yield.

As past events show, jarrah is remarkably resilient to the impact of fire and cyclones. The inventory and yield processes, salvage logging, and adjustments already incorporated generally seem sufficient but a 10 per cent overall adjustment would nevertheless be prudent.

While inventory and yield processes, salvage logging and existing adjustments also seem largely sufficient for karri, the concentration of the areas and volumes and lesser recovery from fires make a higher adjustment of 15 per cent seem prudent.

Recommendation 8.1, Safety margins: The Panel recommends that safety margins of 10% and 15% be applied to the calculated sustained yields of jarrah and karri respectively to allow for the impacts of seemingly unpredictable events such as fire, cyclones, drought, pests and diseases.

The choice of 10 and 15% for these safety margins may seem too low to some but it is important to recognise that they actually imply larger progressive changes in the standing volumes and hence growing stock of the forests concerned.

Each year in which the allowable cut is less than the calculated sustained yield, that amount of volume accumulates and together with growth on that portion, carries forward. For a ‘normal ‘ forest’, a 10% or 15% reduction in the sustained yield over the entire nominal rotations involved would imply a 20% or 30% increase in the standing volumes of growing stock, according to von Mantels formula. The changes will be proportionately less over the period of the plan but they nevertheless represent a planned (by way of safety margin) of building up the growing stock and productive capacity.

9. IMPLEMENTING SUSTAINED YIELD

9.1 Introduction

The sustained yield, after adjustment for a safety margin, becomes the ceiling for the allowable cut, which is then allocated in contracts or licenses to individual processors, generally through transparent and competitive processes.

The legislation dealing with sustained yield reflects a mode of thinking that warrants reconsideration in relation to future industry development and environmental management. Being trade exposed, the timber industry, in common with most others, has to ride the cyclical waves of the global economy. To do that successfully, it needs some flexibility in its production levels to take advantage of the upside of the cycle by selling more and by reducing the cut in the downside. Rolling averages and 'take or pay' clauses in contracts and licenses can be used to give effect to this flexibility, while protecting the seller. If used, that flexibility also needs to be reflected in the way the sustained yield is monitored and regulated- not as a fixed and immutable target but in terms of the future capacity to sustain, not limited to whether last year's cut exceeded the 'sustained yield' by 2% - hence the strong preference for the use of the term 'sustainable yield' (Ferguson, 2009, 2013).

Allied to this issue is the choice of the period that the FMP is to cover, presently 10 years. The Panel believes that this period is too long and that a five-year period would be more appropriate to enable the plan to adapt to shocks, such as major fires, cyclones or pest or disease outbreaks and global trade and economic change. To some degree this thinking has already been embodied in mid-term audits and reviews, so the proposed change is hardly radical.

Technology can assist this process. If Silvicultural Guidelines and like information, 3-year and other harvest plans, and the strategic 5-year FMP are available on the web (supplemented by access through local library services), the costly production process involved in a 10-year plan can be eased considerably.

Some of this greater flexibility also needs to be reflected in the translation of the present 'sustained yield' into operations on the ground.

9.2 Operational feasibility

The proposed FMP14 is the first to utilize a scheduling process (Woodstock) based on constrained optimization – a development recommended in FMP04- to select the array of strategies that meet the constraints while providing as much sawlog on a sustainable basis as is possible. However, the process also included a number of important changes from FMP04 in order to reflect better the forest condition and aid later harvest planning. These included:

(1) Exclusion from harvesting

- Steep slopes. These areas are excluded (based on a GIS analysis of slopes greater than 14 degrees) from the net area of the forest type themes.

- Unviable areas of two-tiered jarrah or karri forest. These areas have been excluded or deferred based on the SILREC records of areas cutover during the last two decades, or for larger areas, identified through a coupe-scale review process that derived the Availability theme in Woodstock.

- Future unmapped old-growth forest. Based on the extent of unmapped old-growth forest identified during the detailed coupe level planning over the period of the current FMP, a reduction to the available area of relevant forest type and silviculture status was made to provide for future areas of old-growth forest that may arise in the future.

- Future log landings, water points and other cleared areas in regrowth karri forest.

- Historically high impact areas of forest pests and disease.

(2) Deferral from harvesting for specified periods

- Areas in which the timing of availability is constrained through the silvicultural guidelines. Examples include the areas in two-tiered jarrah forest that have been previously cutover to a shelterwood status.

- Areas temporarily deferred to provide for visual amenity purposes. These areas have been incorporated into the Availability theme, or as part of the 'Tenure' theme.
- Small isolated (fragmented) patches of two-tiered karri forest. Areas less than 2 hectares were either excluded or deferred from future harvesting. For example, areas deferred are typically surrounded by young regrowth forest for which the preferred timing of thinning would align with the harvest of remaining two-tiered patches.

(3) A separate but complementary process to check the feasibility of supply for the period of the Proposed FMP (2014-2023).

This process has examined the array of potential coupes that could be accessed during the period to 2024 to check that the total sawlog volumes scheduled by Woodstock for this period are operationally feasible to obtain, given the finer-scale constraints at the coupe level that are not directly incorporated in the strategic Woodstock model. This work is informed by the routine planning processes undertaken in the preparation of three-year harvest plans and includes the interaction with strategic prescribed fire and mining plans. Direct alignment of the indicative ten-year harvest plans with the operational harvest plans ensures that no further adjustment is needed, as distinct from Forestry Tasmania coupe planning. This work is substantially complete, but cannot be finalized until the final sustained yields are calculated for each species.

The Panel notes that some testing has been carried out of the Remsoft's tactical planning software (called Stanley) to complement the strategic scheduling and planning by

Woodstock. The Panel recommends that harvest planning be migrated to this platform following completion of the proposed FMP14. For reasons discussed in Section 7.2, it also recommends that calculation of dual prices be carried out as a matter of course for any penultimate run of the Woodstock scheduling software. Dual prices enable the magnitude of the impact of binding constraints on the objective function to be assessed and thus provide guidance on the tradeoffs involved. In some cases, anomalous values of a dual price can also signal errors in the specification of the scenario.

Recommendation 9.1, Use of Stanley and dual prices: The Panel recommends that harvest planning be migrated to the Stanley platform following completion of the proposed FMP14. For reasons discussed in Section 7.2, it also recommends that calculation of dual prices be carried out as a matter of course for any penultimate run of the Woodstock scheduling software.

9.3 Future scheduling and planning processes

The proposed FMP14 will represent a considerable step forward from its predecessor. That said, some characteristics of it merit further consideration in addition to the earlier plea for greater flexibility. These relate to the choice of the planning horizon for scheduling, the setting of more explicit sustainability goals, and the application of new technologies.

Planning horizon for scheduling

The present scheduling of the sustained yield in the proposed FMP14 extends annually to 100 years. Such detail beyond about 50 years lacks credulity because of our limited capacity to predict that detail precisely and without bias so far in the future. Few if any businesses would attempt to engage in such detailed scheduling into the future. Beyond about 50 years, planning should reduce to applying broad trends in growth and harvest levels that enable the sustainability goal of a steady state to be assessed at, say 100 years.

About 400 years ago, John Evelyn (1670) introduced into the English language the already established German notion of the 'normal forest' where an estate is divided into a number of coupes with equal potential, with one part harvested each year, so that the forest and yields were in steady-state. Once a forest has achieved this steady state, a yield simulation is unnecessary, because – except for force majeure – the yield will remain constant. Whilst the notion of a normal forest is a theoretical one that is rarely attainable in practice, it helps to make the point that sustainable yields can be estimated from a relatively short simulation if the end point is near to steady state. The time taken to reach steady state depends on the initial condition of the forest, and on the growth rate of the forest, but in most cases 100 years is an ample simulation.

This raises the question of how the framework of a 'normal' forest relates to the management of a commercial forestry operation. Strangely, perhaps, the framework holds. Whatever rotation length one chooses on commercial grounds will still yield a 'near-normal' forest, when implemented in the manner Evelyn described, albeit at some expense to the average timber production over the long run.

It also raises the question of how yields should be scheduled as an estate approaches a steady state. The American notion of "non-declining even flow" (Bettinger *et al*., 2009) doesn't make much sense if a forest is far from steady-state, whether overstocked because of past underuse, or understocked because of wildfire or an afforestation program. If the forest is far from a steady state, there should be a logical and deliberate decision to manage the estate towards the steady-state condition – recognising that this could involve a 'step-up' pathway to accommodate new industry.

Sustainability goals

One sustainability goal for timber production is, as flagged above, the attainment of a steady state 'near-normal condition. As indicated earlier, normality has rather precise definition but the von Mantel's formula derived from that definition is robust and can provide a good indication of whether the sustained yield is declining or increasing in a major way from that scheduled over the planning horizon. One reason for the resilience of forests is that sustainable forestry involves holding a large bank of growing stock as capital and generally only involves harvesting a volume roughly equivalent to the growth. Shocks to the system can generally be absorbed with comparatively little adjustment to harvest levels.

Recommendation 9.2, Planning horizon and sustainability goals: The Panel recommends that future planning beyond the proposed FMP14 should focus on a planning horizon for scheduling of about 50 years. Beyond about 50 years, planning should reduce to applying broad trends in growth and harvest levels that enable the sustainability goal of a steady state to be assessed at, say 100 years.

A number of submissions have pointed to the benefits that Western Australian native forests may supply in the form of carbon sequestration and net gains relative to emissions. However, at present, carbon sequestration and emissions relating to the publicly-owned productive forest estate, and indeed to the entire publicly-owned forest estate, receive no formal acknowledgement in Commonwealth or State policies, other than the broad brush recognition in the national carbon accounting framework. Should that position change such that net carbon sequestration in native forests received some form of incentive, DEC would be in a good position to provide the relevant data since its inventory system is well suited to such a task.

In the FMP that follows the proposed FMP14, however, greater attention needs to be given to monitoring and reporting of the status of broader environmental goals on biodiversity, fragmentation, connectedness, water production and salinity predicted at the end of the 50-year scheduling period. This is a relatively new approach to monitor and report on whether those environmental values are generally being maintained or improved and will involve the definition of suitable metrics to monitor and predict change. Given the close interweaving of the forest available for timber harvesting with those in the conservation reserves, the extent of the latter, the use of structural goals, and the detail of the Silvicultural and Harvesting Guidelines, and the FORESTCHECK program, the Panel is confident that these goals are generally being met, based on present data and research. However, improvements in local area planning are always possible given the greater detail available from present and proposed technologies. This does not imply a uni-directional change – while some additional local informal reserves may well be required, some existing ones may be deemed unnecessary when the opportunity costs in relation to timber production are weighed against their contribution to environmental values.

It is not proposed that this work should involve large additional expenditure but rather it should seek to identify simple broad metrics that can be assessed from existing data from DEC and other departments, research data, planning processes, FORESTCHECK and the GIS database.

Recommendation 9.3, **Environmental goals in next plan**; The Panel recommends that greater attention be given to monitoring and reporting of the broader environmental goals on biodiversity, fragmentation, connectedness, water production and salinity at the end of the 50-year scheduling period of the next Plan, using metrics that can be informed by existing data and processes.

New technologies

New technologies are continually being developed that can improve forest inventory and planning and DEC needs to maintain its monitoring and testing of these. Two stand out as being technologies that are now well-developed and whose costs are declining rapidly as additional contractors enter the market with new or improved equipment. As indicated in Section 6, LiDAR and multispectral mapping offer particular advantages because they would complement the existing inventory used by DEC. Trials conducted by DEC in 2008 indicated that LiDAR would enable more precise heighting and crown cover estimates of both the inventory plots and the entire forest, probably providing a very substantial gain in precision and freedom from bias. Multispectral sensing will probably provide much more precise identification of those areas whose crowns show the affects of disease, fire or drought. These are technologies that also have major advantages for monitoring conservation reserves and water production issues and hence merit early consideration for purchase by DEC for the entire forest estate.

Scheduling software is also being continually refined and new technologies developed. While the new technologies may require some further time to warrant field testing, the use of evolutional algorithms (instead of linear programming) for scheduling is advancing rapidly (Chikumbo and Nicholas, 2009; Chikumbo, 2011) and needs to be monitored by DEC.

Operational harvest planning is now being aided elsewhere by the use of large-scale aerial remote sensing by drones. These are surprisingly inexpensive. Again, they warrant monitoring and possible field-testing by DEC.

Recommendation 9.4, LiDAR and multispectral imagery: The Panel recommends that DEC continue to monitor and test the use of new technologies and, in particular, develop a department-wide plan for the purchase of LiDAR and multispectral imagery for the South-west forest region.

In the next FMP, the Panel believes that consideration should be given to developing the scheduling based on an objective of maximizing the discounted net revenue to FPC. This would have two advantages. (1) It would enable the economic issues of location to be better reflected in the analyses and enable the associated Stanley software to be better used and integrated with the scheduling. (2) It would be consistent with the planning needed to underpin valuation of the production forest estate for accounting and certification purposes (Ferguson, 2013). This would also facilitate closer liaison between DEC and FPC on planning matters.

Recommendation 9.5, Change to economic objective: The Panel recommends that consideration should be given in the next FMP to developing the scheduling based on an objective of maximizing the discounted net revenue to FPC, to enable better integration of economic factors into the planning and to provide a basis on which estate valuation for accounting purposes could be based.

As noted earlier, the more that routine forest monitoring and rapid feedback can be introduced, the less the environmental impacts, disruptive industry changes, major new research initiatives and associated political opprobrium.

9.4 Resilience

In closing, the resilience of the jarrah forest, in particular, is worth noting given the public concerns about drought and climate change. There will, of course, always be particular locations on shallow or freely drained soils where small patch mortality may occur under drought conditions.

However, the data from re-measurements of involving 5284 trees on 105 permanent plots, some over 50 years, point to a very low tree mortality in the larger trees sizes above 45 cm DBHOB. The annual average mortality is about 0.2 trees.ha^{-1}.year^{-1} on high site quality sites and 0.1 on moderate site quality sites. And these results in part reflect the impact of two major fires and a cyclone during the re-measurement period.

The aim of calculating the sustained yields and regulating the allowable cuts accordingly is to ensure that the jarrah and karri forests remain in at least as good if not a better condition at the end of the FMP and remain in a sustainable and productive condition for future generations.

10. CONCLUSIONS

The Terms of Reference have been addressed in the preceding sections but for the sake of completeness we wish to attest that:

The Panel believes that, subject to the implementation of earlier recommendations regarding improvements or changes to the processes involved in calculating the sustained yield, that the

1. structure, operation and outputs from the woodflow models are robust and flexible enough for computing the sustained yields and other wood availability figures included in the proposed FMP;
2. uncertainty associated with a drying climate has been adequately factored into the sustained yield calculations;
3. level of provision for other risks and uncertainty associated with the volume estimates are appropriate; and
4. calculations incorporate suitable adjustments for the operational feasibility of obtaining the strategic woodflows.

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GLOSSARY

Allowable cut	The maximum volume of a particular native forest log type that can be harvested during the period of the next FMP.
Basal area	The sum of the cross-sectional areas of trees in a given stand measured at 1.3 metres above the ground. It is usually expressed as square metres per hectare.
Biological diversity (Biodiversity)	The variability among living biological entities and the ecosystems and ecological complexes of which those entities are a part and includes: (a) diversity within native species and between native species; (b) diversity of ecosystems; and (c) diversity of other biodiversity components.
Bole	The tree trunk from the ground to the crown break. The bole does not include the major branches supporting the crown.
Buffer strip	A strip of vegetation retained on the edge of a feature such as a stream or rock outcrop. Buffer strips can serve a variety of purposes in the landscape including protection of the feature from a disturbing activity, and provide flora and fauna habitat and aesthetic values.
CALM	Conservation and Land Management
Catchment	The land area drained by a single stream, river, or drainage network.
Clearfell	A silvicultural method in which all, or nearly all, trees in a defined area are removed at one time to allow regeneration to establish and develop as an even-aged stand.
Coupe	An area of forest that is planned for timber harvesting as a single unit. It may contain more than one silvicultural objective, such as a number of discrete gaps and areas of thinning.
Criterion	A category, condition or processes by which sustainable forest management may be assessed.
FMP04, FMP14	The *Forest Management Plan 2004–2013* currently in force and the management plan now in preparation..
DEC	The Western Australian Department of Environment and Conservation.
Dieback **(*Phytophthora* dieback)**	In the south-west of Western Australia a disease of plants caused by infection by the soil-borne organisms of the genus *Phytophthora*, of which *P. cinnamomi* is the most widespread.
DFMP	The *Draft Forest Management Plan 2014-2023*as released by the Conservation Commission for public consultation.
Ecologically sustainable forest	Forest management and use consistent with the principles

management ESFM	described in section 19(2) of the CALM Act.
Ecosystem	A community or an assemblage of communities of organisms, interacting with one another and the environment in which they live.
EPA	Environmental Protection Authority
Even-aged forest	A forest dominated by trees of a similar age. In native forests, this includes stands where the non-dominant age classes comprise less than 15 per cent crown cover.
Fauna	The animals inhabiting an area; including mammals, birds, reptiles, amphibians and invertebrates. Usually restricted to animals occurring naturally and excluding feral or introduced animals.
First and second grade sawlog jarrah	A log cut from the bole of a jarrah tree that is a minimum of 2.4 metres in length, has a minimum under bark diameter of 200 millimetres and has a minimum of 30 per cent millable timber on the worst end face.
First and second grade sawlog karri	A log cut from the bole of a karri tree that is a minimum of 2.4 metres in length, has a minimum under bark diameter of 200 millimetres and has a minimum of 30 per cent millable timber on the worst end face.
Flora	The plants growing in an area; including flowering and non-flowering plants, ferns, mosses, lichens, algae and fungi. Usually restricted to species occurring naturally and excluding weeds.
FMIS	**F**orest **M**anagement **I**nformation **S**ystem. The Department of Environment and Conservation's raster-based geographic information system used to manage and analyse spatial forest data.
Forest	An area, incorporating all living and non-living components, that is dominated by trees having usually a single stem and a mature or potentially mature stand height exceeding two metres and with existing or potential crown cover of overstorey strata about equal to or greater than 20 per cent.
FORESTCHECK	An integrated monitoring project, designed to provide information about changes and trends in biodiversity.
Forest ecosystem	An indigenous ecosystem with an overstorey of trees of more than 20 per cent crown cover. These ecosystems should normally be discriminated at a resolution requiring a map-standard scale of 1:100,000. Preferably these units should be defined in terms of floristic composition in combination with substrate and position within the landscape.
Forest operations	Work activities undertaken in the forest to achieve the management objectives for that forest.
Forest products industry	For the purposes of this plan, the wood products industry and upstream in-forest operations, including timber harvesting and log

haulage.

Forest regeneration The renewal of a forest arising from planting or from seed or the young plants on a site. The process by which a forest is renewed.

FORSCHED **FOR**est **SCHED**uler. A computer system for scheduling and simulating yield from forest harvesting operations for one or more rotations, applied in the calculation of sustained yield for the current FMP.

FPC Forest Products Commission of Western Australia

Gap A discrete opening in the overstorey canopy that reduces competition and allows seedlings to become established and/or develop.

Group selection The removal or retention of trees in relatively small groups with the object of creating a gap or retaining a group of younger trees to grow on. While there is no specific size of the group, it is generally considered to be of a size below which the edge effects dominate.

Guideline A document type that guides and directs actions for achieving consistency and required standards. Guidelines permit some flexibility in their application.

Habitat A component of an ecosystem providing food and shelter to a particular organism.

High impact A term applied to certain forest sites where *Phytophthora cinnamomi* has caused or is expected to cause extensive mortality of jarrah trees.

Informal reserve See 'Reserve – Informal'.

IRIS **I**ntegrated **R**esources **I**nformation **S**ystem. A computer system for storage, processing and retrieval of information for forest inventory with GIS linkages.

JARSIM **JAR**rah **SIM**ulator. A computer system that estimates future growth of jarrah stands.

KARSIM **KAR**ri **SIM**ulator. A computer system that estimates future growth of karri stands.

KPI Key performance indicator

Landscape The visual elements of both the natural and the built environment and including landforms, vegetation, waterform, land-use and architecture.

Landscape Management Unit An agglomeration of vegetation complexes and ecological vegetation systems, as defined and mapped by Mattiske and Havel (2002), to form more compact management units that recognise the underlying ecological characteristics.

Landscape scale A mosaic where the mix of local ecosystems and landforms is repeated in a similar form over a kilometres-wide area. Several

	attributes including geology, soil types, vegetation types, local flora and fauna, climate and natural disturbance regimes tend to be similar and repeated across the whole area. It could be a (sub) catchment or, for convenience, an administrative management unit such as a forest block or an aggregation of forest blocks. Landscape scale is usually tens of thousands to a few thousand hectares.
Leaf area index	Index of the one-sided green leaf area per unit ground surface area in broadleaf canopies.
Lignotuber	A woody swelling formed at the base of some eucalypts that has the ability to produce new shoots when the existing ones are destroyed.
Local scale	A discrete area of land to which one or more operations have been or are planned to be applied.
Mature stand	The stand development stage beginning with the formation of large persistent branches forming the outline of the crown as the crown reaches its maximum size, and finishing with the commencement of a senescent stand.
Monitoring	A process of repeated measurement or observation, for specified purposes of one or more elements, usually according to prearranged schedules in space and time, using comparable data collection methods. Often used to assess a management program, condition of the environment and/or resources being managed, to help determine if desired activities, processes, outputs and outcomes are being achieved.
Montréal Process	An agreed on framework of criteria and indicators that provide member countries with a common definition of what characterises sustainable management of temperate and boreal forests.
Non-bole log	Wood from the branches of a tree above the crown break. The non-bole material in mature trees is not included in inventory and is additional to the sustained yield.
NDVI	Normalized Difference Vegetation Index – an indicator used to analyze remote sensing data
Old-growth forest	Ecologically mature forest where the effects of unnatural disturbance are now negligible. The definition focuses on forest in which the upper stratum or overstorey is in a late mature to senescent growth stage.
Other bole volume	Bole log products not meeting first or second grade sawlog standards.
PAI	Mean annual increment over a defined period of years.
Patch	A group of trees resulting from a natural regeneration event or a past management activity such as gap creation and regeneration. May also refer to a particular, relatively small area of forest and/or other vegetation type(s).

Pest	Troublesome or destructive animals including insects, either introduced or native.
Phytophthora cinnamomi	Water mould. The pathogen that causes most *Phytophthora* dieback disease.
Policy	A document containing principles and rules that outline an organisation's position and which guides decisions and actions taken in the conduct of its activities.
Prescribed burning	The controlled application of fire under specified environmental conditions to a predetermined area and at the time, intensity and rate of spread required to attain planned resource management objectives.
Prescription	A detailed specification of the objectives, area, procedures and standards for a task to be undertaken.
RFA	Regional Forest Agreement
Regrowth forest	Native forest which is dominated by similar aged stems that have not reached the mature growth stage, originating from previous harvest events, such as gap creation, or other disturbances, such as bushfire.
Reserve – conservation	An area set aside primarily for the conservation of natural ecosystems but which may allow a level of recreation consistent with the proper maintenance and restoration of the natural environment.
Reserve – formal	One of the land category categories of national park, nature reserve, conservation park, or CALM Act sections 5(1)(g) or 5(1)(h) reserves for the purpose of conservation.
Reserve – informal	An area set aside for conservation under an approved management plan; has had opportunity for the public to comment on changes to reserve boundaries; able to be accurately defined on a map; and is of an area and design sufficient to sustain the values it seeks to protect. See Appendix 11.
Resilience	The capacity of an ecosystem to withstand external pressures and, over time, return to its prior condition, including its ability to maintain its essential characteristics such as taxonomic composition, structural forms, ecosystem functions and processes
Riparian	Pertaining to the banks of streams, rivers or lakes.
Rotation	The period between regeneration establishment and the final harvest.
Shelterwood	A jarrah silvicultural treatment that involves a partial reduction in the density of overstorey trees and action to establish regeneration under the remaining mature trees.
Silviculture	The theory and practice (silvicultural practices) of managing the establishment, composition, health, quality and growth of forests and woodlands to achieve specified management objectives.

SILREC	**SIL**vicultural **REC**ord System. A Department of Environment and Conservation spatial database for managing and recording harvesting extent and silvicultural practices.
SILVIA	**SILV**icultural **I**mpact **A**nalysis. A computer system for simulating silvicultural treatment and describes potential yield, silvicultural options and residual stand outcomes under user specified silvicultural strategies.
Single tree selection	A silvicultural method where trees from a range of size classes are removed throughout the stand to promote growth of remaining trees.
Stand	A group of trees or patch of forest that can be distinguished from other groups on the basis of size, age, species composition, structural condition or other attribute.
Stand volume	The standing volume per hectare
Stanley	Tactical planning software complementary to Woodstock
Structure	When applied to a forest, is the horizontal and vertical distribution of the alive and dead vegetation.
Sustained yield	For the purpose of this plan, the first and second grade sawlog yield that a forest can produce for an extended period (to at least the year 2070) at a given intensity of management.
Thinning	A felling made to reduce the density of trees within a stand. Usually undertaken to improve the growth of trees that remain by reducing competition, without either permanently breaking the canopy or encouraging regeneration. May also be undertaken to enhance forest health, water production or achieve another objective.
Timber harvesting	The cutting, felling, and gathering of forest products undertaken as part of a planned sequence of silvicultural activities including the regeneration of the forest.
Two-tiered forest	Native forest stands of mixed age and structure, comprising mature trees intermixed with younger regrowth trees arising from regeneration following the death or removal of mature trees by previous harvests or other disturbances. Also referred to as 'mixed age forest' or 'uneven-aged forest'.
Uneven-aged forest	A forest composed of three or more age classes, either intimately mixed or in small groups.
Whole of forest scale	All land categories that are subject to the plan.
Woodflows	Projected supply of wood products arising from scheduling the area of forest available and the sequence of harvesting operations over an extended period of time.
Woodstock™	Proprietary forest management planning software developed by the Remsoft Corporation.

Yield	The amount of product produced from the forest by a particular management strategy.
Yield regulation	The process by which the yield of any product is controlled to achieve the stipulated levels in a management plan.