Department of
Environment and Conservation

Our environment, our future

Sustained yield information sheet series

Sustained yield from native forests

This series of documents are provided to aid understanding of why and how the levels of sustained yields of timber are calculated for the public native forests of south-west Western Australia. The documents are aggregated in three parts, as follows:

Part 1: Background to sustained yield

1.1 What is sustained yield?

1.2 Why have sustained yield?

1.3 Responsibilities for determining and managing to sustained yield levels

1.4 How sustained yield is calculated

1.5 Glossary

Part 2: Sustained yield - current *Forest Management Plan 2004-2013*

The process for calculating the sustained yield of jarrah and karri sawlogs, and the data used in the calculations, for the Forest Management Plan (2004-2013) ('current FMP') are set out under the headings below:

2.1 Management objectives

2.2 Area available for timber production

2.3 Inventory of the forest

2.4 Estimating growth and timber yield

2.5 Scheduling wood flow

2.6 Independent review

Part 3: Sustained yield - *Draft Forest Management Plan 2014-2023*

The process for calculating the sustained yields of jarrah and karri sawlogs for the *Draft Forest Management Plan 2014-2023* ('Draft FMP') is essentially the same as described in Part 2.

All things being equal, this would give the same sustained yields for the Draft FMP as set for the current FMP. However, since the sustained yield calculations were made for the current FMP, some of the inputs to the calculation have changed as a result of time (e.g. growth of trees), improvements to data accuracy (e.g. new field surveys). There are also some proposed changes to management settings outlined in the Draft FMP (e.g. proposed additions to conservation reserves).

Rather than re-state what is in Part 2, Part 3 documents describe the key changes proposed in the Draft FMP that affect the sustained yield levels calculated for the Draft FMP.

It should be noted that the purpose of the Draft FMP is to seek comment on proposed management activities. Because the sustained yield level will vary depending on which proposed activities are implemented or not, the sustained yield levels are by necessity presented as a range. The range has been generated by developing a scenario (Scenario 1) where the combination of proposed changes that overall would increase the sustained yield are assumed to be implemented, and a second scenario (Scenario 2), where conversely, the proposals that overall would decrease the sustained yield are assumed to be implemented.

Comments received on the Draft FMP will be considered and used to produce the *Proposed Forest Management Plan 2014-2023* ('Proposed FMP'), which will be submitted by the Conservation Commission of Western Australia (in 2013) to the Environmental Protection Authority (EPA) for assessment. The EPA will provide its report to the Minster for Environment.

The headings for Part 3 are as follows:

3.1 Management objectives

3.2 Area available for timber production

3.3 Inventory of the forest

3.4 Estimating growth and timber yield

3.5 Scheduling wood flow

3.6 Independent review

1.1 What is sustained yield?

There are many published definitions of sustained yield[1], however, they will usually be based around three elements:

- sustainability;
- products that will be sustained; and
- extended periods of time for supply.

Sustainability

Inherent in definitions of a sustained yield of timber products is the concept of sustainability. Sustainability means that to ensure timber products can be produced continuously for extended periods of time, the capacity of the forest to continue to grow the trees has to be maintained. A panel[2] appointed by the WA Minister for Environment in 1999 to advise on the management of the public karri and tingle forests of the South-west, defined sustainability as:

- the capacity for continued (forest) productivity where the primary requirement is for site and soil protection and for adequate regeneration and protection.

Therefore, although the concept of sustained yield is about a continuous supply of a product that industry can use, it cannot be viewed in isolation from how the forest is managed to obtain the desired products.

In this regard, management of publicly owned forests is about much more than timber, and so society, through Government policy, usually looks to forest managers to ensure biodiversity is conserved, water catchments are not polluted and recreation opportunities are available.

There can be conflict between the amount of timber produced and the ability of the forest to provide these other values and services. Therefore, the level at which sustained yield of timber can be set will be constrained by the need for timber to be produced by a management regime that seeks to also provide the nature conservation, catchment protection and recreation and other values at the levels desired by society.

The current expression of the management regime that balances the various requirements from the forest is termed ecologically sustainable forest management (ESFM). ESFM requires that a sustained yield for timber be calculated within settings that also provide for required levels of the:

- conservation of biological diversity;
- maintenance of ecosystem health and vitality;
- maintenance of soil and water;
- maintenance of carbon cycles;

[1] for example, see page 140 of the *Forest Management Plan (2004-2013)*

[2] Ferguson, I. F., Adams, M., Bradshaw, J., Davies, S., McCormack, R., Young, J. (2001) *Calculating Sustained Yield for the Forest Management Plan (2004-2013): A Preliminary Review.* Report to the Conservation Commission of WA by the Independent Panel. Conservation Commission of Western Australia, Perth.

- maintenance of productive capacity;
- maintenance of natural and cultural heritage; and
- maintenance of socio-economic benefits.

The concept of sustained yield, as applied in a western industrial society, was developed in the eighteenth century in Europe (see '*1.2 Why have sustained yield?'*), to manage timber resources where demand exceeded supply.

In the context of recent and future forest management plans, a more complete definition of sustained yield for the publicly owned south-west native forests would be:

> *The maximum nearly constant level of jarrah and karri sawlogs that can be supplied over an extended period of time within the ecologically sustainable forest management settings determined in the management plan approved by the Minister for Environment.*

What this definition makes clear is that there is no one level of sustained yield for the south-west forests. The level of sustained yield will vary according to inherent natural factors such as the nature of the standing timber resource and the time taken to grow a commercial sized sawlog. The level will also vary as a result of management objectives and strategies such as the specifications for the log products to be sustained (jarrah and karri sawlogs), the various ESFM settings to provide for other values, and commercial and social factors such as the efficiency of log utilisation by industry. Consequently, calculations of sustained yield are undertaken for each management plan and depending on the settings adopted, may vary between plans.

Products to sustain

The rationale for the development of a sustained yield of timber in the 17th century was economic and social (see '*1.2 Why have sustained yield?'*). At this time, timber in all forms was central to economic activity through its use for cooking, heating, building and as a fuel for other industries.

The early focus on sustainability was therefore not on sustaining the range of goods and services from forests, but on maintaining the ability of the forests to supply timber over the long-term. This was put into place by countering pressure to clear forests, improving management so that regeneration after cutting was effective, and looking after the forest between harvests. In its simplest form, early implementation of sustained yield meant dividing the forest into sections equal in number to the years it took for the trees to reach a size where they could be felled, and then felling and regenerating the oldest section each year.

Over time, forests became protected from clearing and improved management assured regeneration and ongoing growth. Managers then began to focus sustained yield on the products that best suited the prevailing industry and consequently best stabilised the economy that was dependent on the forest. With fossil fuels taking over the role of wood as a fuel, and available areas reduced following urban and agricultural clearing, production from forests focussed on those that yielded the highest financial return or the greatest social benefit.

In earlier times in WA, products such as mining timbers (for the coal mines in Collie or the gold mines in the Goldfields) and bark for the tanning industry were a priority. In more recent times, round timbers for transmission poles, bridge timbers and peeling logs for veneer was the primary product as they were in short supply, along with sawlogs. The focus has now shifted to sawlog supply for value added uses in furniture and flooring materials, with less used for housing construction.

Extended time periods

Trees are long-living organisms. Some species of south-west forest eucalypts can produce small sawlogs after 30 to 50 years of growth, but will mature between 100 and 150 years and may live and continue to grow for up to 300+ years. Consequently, sawlogs can start to be produced after 30 to 50 years by a partial cut that aims to promote growth on the retained trees, or a gap cut where regeneration is required to renew the forest.

The time period between harvests in a managed forest is termed the "cutting cycle" and a sustained yield calculation will incorporate different cutting cycles in the forest because of:

- the growth rates and characteristics of the trees;
- the need for longer cutting cycles to provide for the aesthetic and nature conservation values of large old trees;
- the need to vary the cycle of disturbance for different groups of flora and fauna;
- the need for harvesting at specific times to smooth out supply to industry; and
- the effect of time on the economics of growing trees, harvesting and milling them (younger logs typically have inherently more undesirable characteristics that preclude their processing or use for many end-products).

Therefore, the period over which sustained yield must be considered needs to be at least to the period of the longest cutting cycle, to ensure that the long-term structure of the forest resulting from harvesting is understood. This period may be 100+ years, however, the actual sustained yield of sawlogs can only be realistically calculated for a shorter term (perhaps 70 years), and then the period over which the supply to industry is guaranteed is only the next 10 years of the approved management plan.

Further reading

Ferguson, I., Gardner, J., Hopper, S., and Young, J., (1999) *Report to the Minister for the Environment: Ministerial Advisory Group on Karri and Tingle Management.* Department of Environment, Perth.

Ferguson, I., Adams, M., Bradshaw, J., Davies, S., McCormack, R., Young, J. (2001) *Calculating Sustained Yield for the Forest Management Plan (2004-2013): A Preliminary Review.* Report to the Conservation Commission of Western Australia by the Independent Panel. Conservation Commission of Western Australia, Perth.

Ferguson, I., Adams M., Bradshaw, J., Davey, S., McCormack, R., Young, J. (2003). *Stage 3 Report. Calculating Sustained Yield for the Forest Management Plan (2004-2013).* Report for the Conservation Commission of Western Australia by the Independent Panel. Conservation Commission of Western Australia, Perth.

1.2 Why have sustained yield?

Sustaining yield from native forest, as it is practised in current public forest management, is the culmination of 300 years of evolution in both technique and social attitudes to the forest. In its present form, the calculation of a sustained yield for timber is a sophisticated exercise in planning for the long-term supply of the full range of products and services that forests provide. That is, the supply of timber for industry is integrated with, and limited by, the required amount of recreation, nature conservation and water and other values and services that the forest must also provide.

However, this was not always the case.

Origins of the concept of sustained yield

Humans have always used their knowledge of the forest to obtain the goods and services that forests provide; hence forest management has a long history that predates the current industrial or capital-intensive management systems that are now available for the management of forests.

In some parts of the world, traditional, or as they are often termed, "indigenous" forest management systems, incorporated the concept of stewardship; that is the use of the forest needed to be sustainable so that subsequent generations could obtain the same goods and services. Consequently, sustainability was the norm rather than the exception in these cultures.

However, in Europe in particular, early human development saw forests largely as obstacles to agricultural development and it was only the limitations of technology that prevented greater clearing. As Europe became industrialised and nation states developed, traditional forest management declined and the concept of stewardship in forest management declined with it, leading to over-exploitation of forests.

It was inevitable that the over-exploitation and mismanagement of forests and woodlands brought on by industrialisation would reach a crisis point and result in a need to address looming shortages of timber. The coming crisis was appreciated and as a consequence the modern concept of sustained yield was developed during the seventeenth and eighteenth centuries, particularly in Germany and France, to ameliorate the threat to timber supply. Although this period is most clearly linked to the origins of sustained yield, it is probable that ever since ownership of woodlands and forests came about, some owners attempted to provide for continuous supply from their forests. Ancient Chinese literature mentions the need to conserve forests for future generations and in England, the Doomsday book of 1086 recorded woodlands as a land use, and later documents from the mid thirteenth century provide detailed records of individual woodlands, their boundaries and ownership, with an indication that they were managed for a continuous supply of timber.

In 1662, fearing a shortage of oak for ship building, the Commissioners of the British Navy requested the Royal Society investigate the problem and provide recommendations on addressing it.

The person in charge of the investigation was John Evelyn and following two years of study, he produced a 400 page book titled *Sylva or a Discourse on Forest Trees and the Propagation of Timber in his Majesties Dominions.*

In the book, Evelyn argues for the conservation and restoration of woodlands and cites examples of forests in France and Germany where landowners divided their lots into eighty portions, felling and planting one each year. Importantly, Evelyn also argued the philosophical underpinning of the concept of sustained yield - that each generation should be providing for the next, i.e. "men should be

perpetually planting that so posterity might have trees fit for their service".

At the same time, France was also facing a shortage of timber and King Louis XIV commissioned his Finance Minister, Jean Baptiste Colbert, to undertake an inquiry into the state of the forests and the quality of their management. Colbert identified gross mismanagement and over exploitation of the forests. To correct this situation, new rules for forest management were introduced in 1669 through the *Grande Ordannance forestiere.* Although the *Ordannance* was more about administrative control of the forests, it promoted the concept of current management taking into consideration the needs of future generations.

The term 'sustained yield' was first documented in Germany in the early part of the eighteenth century, in a handbook on forestry by Hans Carl von Carlowitz with the (abbreviated) title *Sylvicultura oeconomica*. Carlowitz drew on Colbert and Evelyn in producing his book, in which he details how to cultivate and manage forests such that there was a balance between renewal and cutting, so that timber could be used forever, continuously and perpetually. The impetus for Carlowitz to produce his book was the growing realisation of an impending shortage of timber that was vital to the mining economy of Saxony.

A feature of *Sylvcultura oeconomica* was its development of the concept that there were limits to the use of natural resources and humanity should not work against nature, but within its limits. Carlowitz also argued that sustained yield was important economically, as it provided stability and durability for the community dependant on the forest.

At the time these approaches to sustaining timber yields were developed, timber in all its forms was vital to industry as a building material and for fuel. Carlowitz for example, was a mining administrator in Saxony, where a major use of timber was as charcoal in smelting the mined ore. As a consequence, sustained yield focused mainly on sustaining the whole forest rather than any individual timber product. Sustainability was put in place by preserving the forests from clearing, ensuring adequate regeneration after cutting for timber and protecting the growing forest so that it reached maturity to enable a future harvest.

Following the publication of *Sylvicultura oeconomica*, sustained yield became the foundation of a new scientific approach to forest management. The approach spread throughout Europe with such effect that by the mid nineteenth century, following more than a hundred years of application, many woodlands had been converted into areas with a relatively even spread of age classes, which reduced their natural diversity.

The industrialisation of woodlands drew criticism from those who saw the new approach as a departure from the working with nature philosophy espoused in *Sylvicultura oeconomica.* The debate on the relative importance given to timber, nature conservation, recreation and other forest values and services in forest management has continued to this day.

The concept of sustained yield, although carried into the new world forests of Australia and the USA by European trained foresters, did not at first easily transfer into practice. This was because the forests they found were largely in the old age classes with little regrowth, and the early political imperatives for use of the forests, that appeared limitless, were clearing for agriculture and townships, and a source of resource for development of the fledgling economies.

For the forests that came under management, the challenge in achieving sustained yield was then to cut the mature forest and regenerate it over an extended transition period, which would eventually lead to a yield that could be sustained by the total growth increment on the regenerating forest.

Legislative requirement for sustained yield

Although having a sustained yield of timber was a basic tenet of forest management for several hundred years, in the latter half of the twentieth century legislators all over the world sought to enshrine the requirement for sustained yield in legislation. Their reasons were the same as those that drove the development of sustained yield in Europe, but with the added desire to deal with the balance between the output of timber, conservation and other values, products and services forests provide.

The USA *Multiple Use and Sustained Yield Act 1960* was an early example of legislation on sustained yield. This Act also included the need to sustain production of forest values other than timber.

In Western Australia, legislation to require sustained yield came in 1991 with an amendment to the *Conservation and Land Management Act 1984* (CALM Act).

Section 54(1) of the CALM Act makes it the responsibility of the Conservation Commission of Western Australia to prepare proposed management plans through the agency of the Department of Environment and Conservation, and section 55 (1a) describes the uses that may be provided for in a management plan dealing with State forest. Where timber production is one of the uses for indigenous State forest, the requirement was amended to read "timber production on a sustained yield basis".

The CALM Act also sets out functions of the Conservation Commission of Western Australia. These include:

- s. 19(i) - to advise the Minister for Environment on the production and harvesting on a sustained yield basis, of forest produce throughout the State; and
- s. 19(h) (i) & (ii) - to advise the Minister on the application of the principles of ecologically sustainable forest management in the management of State forest and forest produce.

Conclusion

Setting a sustained yield for timber was introduced to forest management in Europe around 300 years ago, to:

- better manage forests in the face of over-exploitation;
- match timber harvest with the long-term productivity of the forest; and
- create economic stability and durability for communities dependent on the forest.

These reasons are still valid and current legislation in Western Australia requires sustained yield for timber production from public native forests. Legislation also requires ecologically sustainable forest management be implemented, which means the management regime must cater for, among other things, the conservation of biodiversity, soil and water protection and recreation.

Further reading

More detail on the history of the development of sustained yield of timber can be found in:

Ulrich Grober (2007). *Deep Roots – A conceptual history of sustainable development* (Nachhaltigkeit). Berlin

Cassells, D. S., Bonell M., Gilmour D. A., Valentine P. S. (1988). *Conservation and Management of Australia's tropical rainforest: local realities and global responsibilities.* Journal of the Ecological Society of Australia Vol 15, pgs 313-326.

1.3 Responsibilities for determining and managing to sustained yield levels

A long-term sustained yield for native forest timber is calculated in the development of each ten-year forest management plan, to determine the 'allowable cut' over the period of the plan.

There are six entities in Western Australia with an involvement in the process of calculating, approving and regulating sustained yield. These are:

- Department of Environment and Conservation
- Forest Products Commission
- Conservation Commission of Western Australia
- Minister for Forestry
- Minister for Environment
- Environmental Protection Authority

The roles and responsibilities of each are summarised below and described further in the *Conservation and Land Management Act 1984* (CALM Act), *Forest Products Act 2000*, and the *Environmental Protection Act 1986*.

Department of Environment and Conservation (DEC)

- is the agent for the Conservation Commission for preparation of forest management plans. This includes the calculation of sustained yield. DEC is required by the CALM Act to consult the Forest Products Commission (FPC) on the development of a forest management plan, including the calculation of sustained yield.
- maintains forest datasets and information to calculate sustained yield.
- regulates the FPC to ensure harvest levels conform to the allowable cut in the approved plan and that silviculture is consistent with the ecologically sustainable forest management (ESFM) settings adopted in the approved plan.

Forest Products Commission (FPC)

- informs DEC on industry objectives, log product requirements and economic and operational constraints relevant to the calculation of sustained yield.
- issues timber harvesting contracts to the level of the allowable cut. Supervises timber harvesting contracts.
- provides harvesting and silviculture records back to DEC to maintain the datasets required for the calculation of sustained yield.

Conservation Commission of Western Australia (Conservation Commission)

- responsible for preparing the forest management plan through the agency of DEC. Consequently, the Conservation Commission is responsible for the contents of the plan, including ensuring the proposed allowable cut is consistent with ESFM principles and settings.
- submits the proposed plan to the Environmental Protection Authority (EPA) for their review and independent advice to the Minister for Environment.
- submits the proposed plan to the Minister for Environment for consideration and approval.
- monitors the performance of DEC and the FPC in carrying out and complying with the approved management plan.

Minister for Environment

- considers the proposed plan and the advice of the EPA and, as appropriate, approves (and may condition) the proposed plan submitted by the Conservation Commission, including an allowable cut for the ten year period of the plan.

Minister for Forest Products (currently Minister for Forestry)

- consulted on development of a forest management plan before the plan is approved the Minister for Environment.

Environmental Protection Authority (EPA)

- may assess the proposed forest management plan and provides advice to the Minister for Environment as to whether the plan should be implemented and if it should be implemented, the conditions that might be imposed on implementation.
- monitors the implementation of any conditions the Minister for Environment places on the approved plan.

1.4 How sustained yield is calculated

There are five basic steps to the calculation of a sustained yield from native forests. They are:

1. specify management objectives.
2. determine the area of forest available for timber production.
3. prepare an inventory of the forest.
4. predict growth and forecast the future condition of the forest.
5. simulate the harvesting schedule over time and predict the volume of timber derived.

These five steps are described in more detail below.

Specify the management objectives

Public forests provide many goods and services for society, however to a greater or less extent, as the production of one rises the production of the others must decrease. Therefore, the starting point for the calculation of sustained yield will always be setting the objectives for management of native forests.

Objectives for and decisions on the following need to be made before a calculation of sustained yield can be made:

- What level of output of each of the goods and services is required?
- What ecologically sustainable forest management (ESFM) settings does that imply?
  - area available
  - management restrictions on harvesting to provide for other values, goods and services
  - silvicultural treatments (how each forest type will be treated to ensure regeneration and growth)
  - biodiversity conservation and socio-economic outcomes
- Which species and what log products from those species are to be sustained?
- What is the period over which yield is to be sustained?

Determine the area of forest available for timber harvesting

The area of forest available for timber harvesting is clearly critical to the calculation of sustained yield. The area of forest available for timber harvesting in the public forests of the south-west is determined by:

- Parliament – in the south-west, formal reserves such as national parks, conservation parks and nature reserves are excluded from timber harvesting to maximise their conservation and recreation values.
- Government policy – governments sometimes commit (eg, through the forest management plan) to reserving areas of State forest as formal reserves but have not yet passed the necessary legislation. These areas are excluded from calculations.
- Management planning – ESFM settings in the forest management plan exclude areas that are potentially available for timber harvesting to protect local or specific nature conservation, soil,

water, heritage or other values. These areas are often termed informal reserves and are set according to the management objectives for the forest.

- Forest structure – areas that are non-forest such as roads, rock outcrops or heathland are identified and excluded.

Prepare an inventory of the forest resource

An inventory of the forest available for harvesting is undertaken by measuring the trees in a sub-set of the forest called a sample, and extrapolating the results across the whole forest. Sampling can be undertaken:

- systematically across the whole forest; or
- in like areas called strata. Strata are based on factors such as dominant species, site productivity, forest structure and previous treatment.

There have been various timber inventories of the south-west forests over time. The most recent inventory of the jarrah forest was undertaken using a systematic sample, while the inventory of the karri forest was based on a stratification of the forest.

The inventory provides information for each species on the number, size and distribution of trees throughout the forest. From this an estimate of the volume of log products standing in the forest can be made. It is important to know the standing volume in the forest because the rate at which these products can be harvested needs to be balanced against the growth of trees into size classes that will produce various log products.

A whole-of-forest inventory is a large, complex operation and may not be required for every management plan. Therefore, the inventory data is maintained current by amending it to take into account changes resulting from historic events such as timber removal, disease spread, bushfires and storms, as well as growth.

Predict growth and future condition of the forest

How fast the forest is growing is an important factor in the determination of sustained yield, because if the harvest from the available forest is to be relatively constant over an extended period of time, the volume removed must eventually align with the total growth. In a forest dominated by mature trees, growth is low and the annual volume removed in the short to medium term will be greater than the annual total growth. This situation will persist until there are enough vigorously growing young trees to balance harvest with growth.

Growth rate is influenced by site productivity, forest structure, climate, disease, natural mortality and stand density level. Estimates of the rate of growth of the forest are usually made from remeasured plots and growth models for the species of trees of interest. Growth models are often developed from periodic measurements of tree growth in ‘permanent’ plots. Growth models will normally be designed to project the growth of a stand (group) of trees, rather than individual trees.

In predicting growth over an extended time period, account must be taken of various factors that can impact the forecast growth being able to be realised as sawlog that meets the required standard. Factors that will decrease growth or result in the tree not producing a sawlog that meets the required specifications include natural mortality, death of trees and degrade of the sawlog from fire, insects, fungi, storms and climate change. Provision for these factors is included in calculations.

Simulate harvesting and predict the timber yield

A yield can be calculated when good information is available on the area available, the distribution of species and structure of the forest, how fast it is growing and the various factors that can impact the realisation of predicted sawlog yield.

The first step in determining timber yield over time is to determine the quantity of sawlog and other log products that will be produced when a particular silviculture method is applied to a forest stand with a specific structure. The end result of this step is a series of projections or data, called yield tables, which cover the various combinations of the silviculture methods and stand structure.

The harvesting simulation applies the silviculture method to the stands and uses the yield tables to predict the volume of sawlogs (and other log products) that will be derived. The simulation adds up the volumes produced each year from the entire forest to determine the flow of sawlogs (and other log products) through time.

Silvicultural treatments in the form of guidelines[3] exist for different forest types and they determine, among other things:

- the size or quality of trees that are to be harvested;
- how many and of what specifications the trees are that have to be left for future growth and habitat reasons; and
- how 'spread out' in space and time harvest events and areas have to be.

The ESFM settings that have been set through management objectives reflected in silviculture guidelines have a major influence on sustained yield, which then affects the quantity of timber the yield tables predict will become available.

The simulated harvesting is undertaken for the extended period required (100 years+) and the yields from each stand added for each year to give the annual yield over the longer-term. This process is repeated a number of times using different settings and cutting cycles in order to ensure the conservation, timber and other values are balanced, and to 'smooth' out the yield over time.

[3] *Silvicultural Practice in the Jarrah Forest*

Silvicultural Practice in Wandoo Forest and woodland

Silvicultural Practice in the Karri Forest

1.5 Glossary

Allowable cut	The maximum volume of a particular native forest log type that can be harvested during the period of the Forest Management Plan. The Minister for Environment determines the allowable cut for the ten-year period of the Forest Management Plan.
Basal area	The sum of the cross-sectional areas of trees in a given stand measured at 1.3 metres above the ground. Basal area is usually expressed as square metres per hectare.
Bole	The tree trunk from the ground to crown break. The bole does not include the major branches of the crown.
Cutting cycle	The time period between one harvest operation and the next in a stand. Note this is not necessarily the same as the rotation length.
ESFM (Ecologically sustainable forest management)	Forest management and use in accordance with the principles described in section 19(2) of the CALM Act.
FORSCHED	Forest Scheduler. A computer system developed to simulate the woodflows arising from scheduling harvesting operations for one or more cutting cycles.
GIS (Geographic Information System)	A computer system for mapping and analysing geographic phenomenon that exist and events that have occurred, on the surface of the earth.
Growth model	A descriptive model that uses mathematical equations to grow a stand of trees forward in time.
Growth rate	The increment put on by an individual tree or stand of trees over a given period, usually a year. Volume increment is usually measured as cubic metres per hectare.
Guideline	A document type that guides and directs actions for achieving consistency and required standards. Guidelines permit some flexibility in their application.
IOPS	Integrated Operations Planning System. A GIS/database system for simulating short to medium term plans and operations and their outcomes over time.

IRIS	Integrated Resources Information System. A computer system (with GIS linkages) developed for storage, processing and retrieval of forest inventory data.
LOIS	Logging Operations Information System. A computer system (operated by the Forests Products Commission) used to manage log production and sales records.
JARSIM	Jarrah Simulator. A computer based growth model that estimates future growth of regrowth jarrah stands. The system provides inputs to the forest yield scheduler FORSCHED.
KARSIM	Karri Simulator. A computer based growth model that estimates future growth of regrowth karri stands. The system provides inputs to the forest yield scheduler FORSCHED.
Montreal Process	An agreed framework of criteria and indicators that provide member countries with a common definition of what characterises sustainable management of temperate and boreal forests.
Montreal Criteria	Seven criteria identified by the Montréal Process (12 countries including Australia covering 90 per cent of the world's temperate and boreal forests) to define what is important about forests and to characterize sustainable management. The criteria describe vital functions and attributes of biodiversity, productivity, forest health, the carbon cycle, and soil and water protection, socio-economic benefits (timber, recreation and cultural values), and the laws and regulations that constitute the forest policy framework. For further information, go to: http://www.rinya.maff.go.jp/mpci/
Overcutting	A general term for when the volume removed over a set period of time exceeds the allowable cut for the same period of time.
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 designated in a management plan as set aside to conserve forest values from disturbance caused by timber harvesting or associated activities.

Rotation length	The period between regeneration establishment and final cutting. Rotation length may be based on many factors such as attainment of a particular size, attainment of a particular economic value or biological condition. During one rotation length there may be several cutting cycles.
Sawlog	A log that meets the minimum standards of size and quality to be sawn for timber.
SILREC	Silviculture Recording System. A spatial database for managing and recording harvesting extent and silviculture practices.
SILVIA	Silvicultural Impact Analysis. A computer system for simulating silvicultural treatments. The system generates potential yield, silvicultural operations and residual stand outcomes under user specified silvicultural strategies.
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.
Site quality	The productive capacity of a site.
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.
Stratification / strata	Stratification involves the subdividing of forest areas into uniform or homogenous strata, usually on the basis of forest type, forest structure and other characteristics such as site quality which correlate with the standing timber volumes or future yield.
Structure	The horizontal and vertical distribution of the trees in the forest. The forest structure is often described by the age and size of different stages of tree and stand development.
Sustainability	The capacity of forests to maintain their health, productivity, diversity, and overall integrity, in the long run, in the context of human activity and use.

Sustained yield	The yield that a forest can produce continuously at a given intensity of management. For the purpose of the current *Forest Management Plan 2004-2013* and the *Draft Forest Management plan 2014-2023*, it is the non-declining yield of first and second grade sawlogs that a forest can produce for an extended period (to at least the year 2070) at the intensity of management set out in the respective plans.
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	A general term used to describe native forest stands of mixed age and structure. These generally comprise mature trees intermixed with younger regrowth trees that have arisen from regeneration following the death or removal of mature trees by previous harvests or other disturbances. These forests are sometimes also referred to as 'mixed age forest' or 'uneven-aged forest'.
WOODSTOCK™	A computer modelling system for the spatial optimisation and scheduling of the harvesting of native forests and plantations.
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 levels stipulated in a management plan.

2.1 Management objectives

Setting objectives for management of the forest is the starting point for the calculation of a sustained yield of timber (see '*1.4 How sustained yield is calculated'*). In the case of the current FMP, the management objectives and actions set in that plan provide the management context within which the calculations of sustained yield were made.

Ecologically sustainable forest management (ESFM) settings

The Montreal Criteria[4] have been used to describe the key aspects of sustainable forest management. The current FMP used the Montreal Criteria as a framework for its objectives and actions to ensure it encompassed all that was necessary to implement ecologically sustainable forest management.

The table below sets out the Montreal Criteria and the number of objectives and actions the current FMP has for each criterion. Under each criterion is listed in dot point format, the major factors within the objectives and actions that had affected the calculation of sustained yield.

ESFM (Montreal) Criteria	**# of Objectives in FMP**	**# of Actions in FMP**
Conservation of biological diversity • setting the formal and informal reserve systems and Fauna Habitat Zones determines the area remaining available for timber production • increases to the retention of habitat elements in harvesting were prescribed, which reduces the potential timber yields	10	20
Maintenance of productive capacity • requires regrowth stands be managed to optimise their productive capacity • ensures regeneration of cleared areas • minimises reductions to the net area available for timber production	7	26
Maintenance of ecosystem health and vitality • specific silviculture treatments for jarrah dieback affected forest reduces the potential timber yields • application of appropriate fire management to minimise losses to major bushfires • management of pests, weeds and diseases to reduce tree mortality and degrade	4	12

[4] see Montreal Criteria in the Glossary for further information

ESFM (Montreal) Criteria	**# of Objectives in FMP**	**# of Actions in FMP**
Maintenance of soil and water • specific silviculture treatments for salt sensitive catchments reduces potential yields	3	10
Maintenance of carbon cycles • requirement to incorporate climate change consideration into land management planning requires allowances in sustained yield calculation	2	3
Maintenance of natural and cultural heritage	3	4
Maintenance of socio-economic benefits • industry requirement for species and quality of sawlog • objectives for value adding the highest quality logs	7	10

Within this suite of management objectives, the tree species and products for which the yield is to be sustained also need to be specified.

Timber products to be sustained

Historically the sawn timber industry has been dominated by the utilisation of jarrah and karri, but marri, wandoo, blackbutt, sheoak and a range of lesser species have played important roles.

A sustained yield could be calculated for each species or all species combined, however, it is only sensible to address the species of dominant interest to the market, as it is those that will need to be regulated to ensure a long-term continuous supply.

Jarrah and karri are the most dominant species used commercially to produce sawn timber. In past years, marri was harvested on a large scale to be chipped and exported for paper making. However, that market no longer exists and marri is less favoured as a sawlog because of its inherent defect. Therefore, it is logical that jarrah and karri be the species for which a sustained yield is calculated. The production of other species then becomes a consequence of regulating the yield for jarrah and karri sawlogs.

The jarrah and karri inventories measured the whole tree bole and the level of defect visible on the surface and estimated internal defect. Consequently, the volume of a specific dimension and quality can be assigned to various log products within the tree bole.

While the calculation of sustained yield could be done on a whole bole basis, it has not made sense to do so in the context of the current industry, which is dependent on a known minimum standard sawlog.

Consequently, sustained yield has been calculated for the product on which most of the native forest hardwood industry is based. **This is first and second grade sawlogs of jarrah and karri**.

The specifications of first and second grade sawlogs used in the calculation of sustained yields are:

Sawlog grade	Log specifications		
	Minimum length (m)	Minimum top end diameter under bark (mm)	Acceptable defect
First and second grade jarrah	2.1	200	Minimum millable wood 30% at worst end
First and second grade karri	2.4	200	Minimum millable wood 30% at worst end

Further reading

Conservation Commission of Western Australia (2004). *Forest Management Plan 2004-2013*. Perth, Western Australia.

2.2 Area available for timber production

In 2003 when the current FMP was prepared, the total area of land vested in the Conservation Commission of Western Australia within the FMP boundaries was 2,237,820 ha[5].

However, the actual area that can be harvested for timber and consequently used in the calculation of sustained yield is much smaller. This is because some areas of forest are managed exclusively for nature conservation and other values which exclude disturbance.

As a consequence, some categories of land are **excluded** from commercial timber harvesting and thus, the calculation of sustained yield. These are:

Existing and proposed reserves described in the CALM Act

- Nature reserves, national parks, conservation parks, 5(1)(g) and 5(1)(h) reserves. These are areas permanently reserved, or that it is proposed through the current FMP to permanently reserve, for nature conservation, recreation and heritage protection.
- Proposed forest conservation areas (FCA). These are areas proposed to be classified as a Forest Conservation Area under section 62(1) of the CALM Act.

Areas set aside through objectives and actions in the current FMP

- Informal reserves. These are areas of State forest and timber reserve described in Appendix 3 of the FMP and set aside to protect local or specific nature conservation, soil, water, heritage or other specified values. Old-growth forest on State forest and timber reserve was a new category of informal reserve in the current FMP.
- Fauna habitat zones (FHZ). Approximately 52,000 hectares of State forest and timber reserve were set aside to be allocated in patches of forest of a minimum area of 200 hectares, and set out in a systematic manner through the jarrah, karri and wandoo forest.

Figure 1 illustrates the relative scale of these various categories of land excluded from timber harvesting in a sample portion of the jarrah forest. The areas labelled 'State forest available for timber harvesting' are part of the area upon which the calculation of sustained yield is based.

[5] current Forest Management Plan (2004-2013) Appendix 8

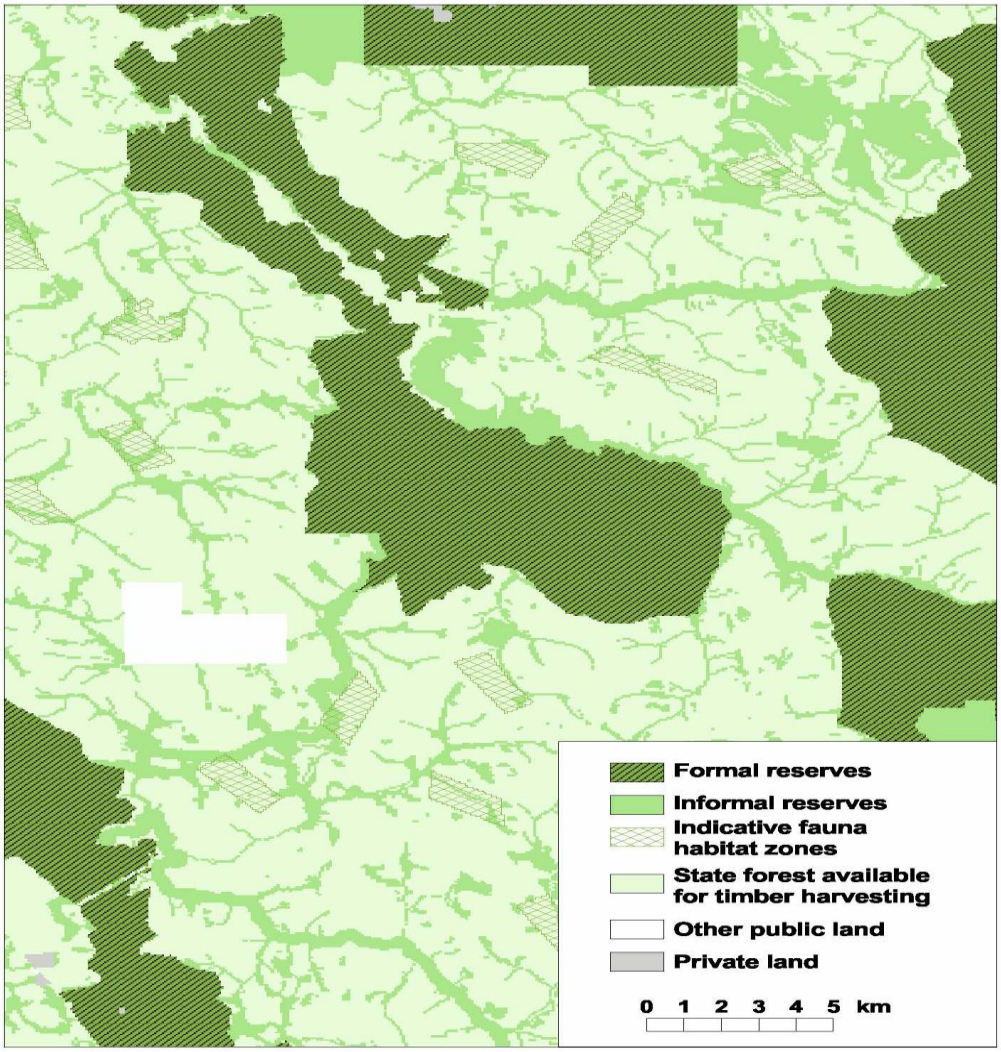

Figure 1: Map depicting the spatial mosaic, relative scale and connectivity associated with formal reserves, informal reserves and fauna habitat zones in a portion of the jarrah forest.

Area of forest types used in sustained yield calculations

The total area available for timber harvesting within the current FMP boundary and used in the calculation of sustained yield can be further subdivided by the dominant forest type:

	Forest type				
	Jarrah (ha)	Karri (ha)	Wandoo (ha)	Non forest/ other (ha)	TOTAL (ha)
Total area of land vested in the Conservation Commission in FMP boundary	**1,569,250**	**175,250**	**145,710**	**347,610**	**2,237,820**
Area excluded from timber production					
Existing/proposed formal reserves & FCA	635,840	92,440	98,360		
Informal reserves	132,050	21,720	9,360		
Fauna Habitat Zones	49,450	1,090	1,520		
Sub-total	817,340	115,250	109,240		
Area available for timber production	**751,910**	**60,000**	**36,470**		**848,380***
Percentage of total area of each forest type available for timber production	**48**	**34**	**24**		

*This area comprises 38 per cent of the total land area, or 45 percent of the total forest area, on land vested in the Conservation Commission in the FMP boundary.

When calculating sustained yields, there are further reductions 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.

2.3 Inventory of the forest

Broadly speaking, the forests of the south-west available for timber production have two distinct structures: two-tiered and even-aged regrowth.

The two-tiered structure, which is often termed "mixed or uneven-aged", consists of mature trees intermixed with young regrowth that has arisen from regeneration, following the death or removal of small patches of mature trees by natural events or timber harvesting (Figure 1). This applies to both jarrah and karri forest.

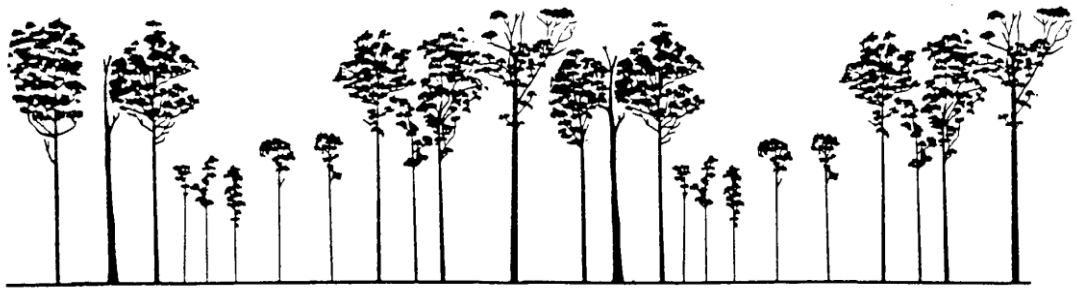

Figure 1: An illustration of a mixed or two tiered stand depicting groups of mature and regrowth trees.

Even-aged regrowth occurs when the mature forest has been removed and the site regenerated over a broad area by a natural event, such as fire, or more usually by timber harvesting (Figure 2).

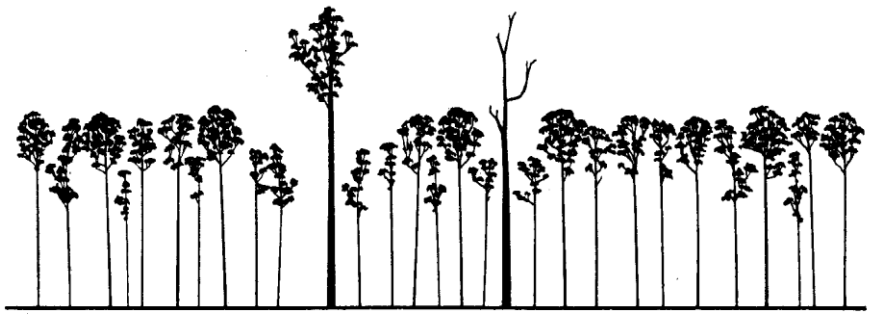

Figure 2: An illustration of a regrowth stand depicting regenerated regrowth stems with mature habitat trees.

Different inventory techniques were used to estimate the timber volume within these two forest structures for the purpose of sustained yield calculations. These are described below.

Two-tiered or mixed structure forest

Jarrah

The inventory of the two-tiered jarrah forest that provided the estimates of standing volume was designed and carried out by the Department of Environment and Conservation (DEC) from 1988 to 1993.

The inventory involved a two-stage sampling method. The first stage involved establishing and photographing sample plots set out on a systematic grid throughout the forest, at an intensity of approximately one plot per 50 hectares. This resulted in approximately 29,000 plots being identified

and photographed. Plots were photographed from twin cameras mounted on a helicopter (Figure 3) to provide a stereoscopic image (3 dimensional). The attributes of the trees on each plot were measured from the photographs to provide an estimate of the gross bole volume.

Figure 3: A Bell 206B Jetranger helicopter with boom mounted camera pods used in the jarrah inventory.

In the second stage, one in ten of the photo plots (over 2,900) were remeasured by ground survey (Figure 4). This was to calibrate the photographic measurements and to devise relationships to differentiate the bole volume into different log products.

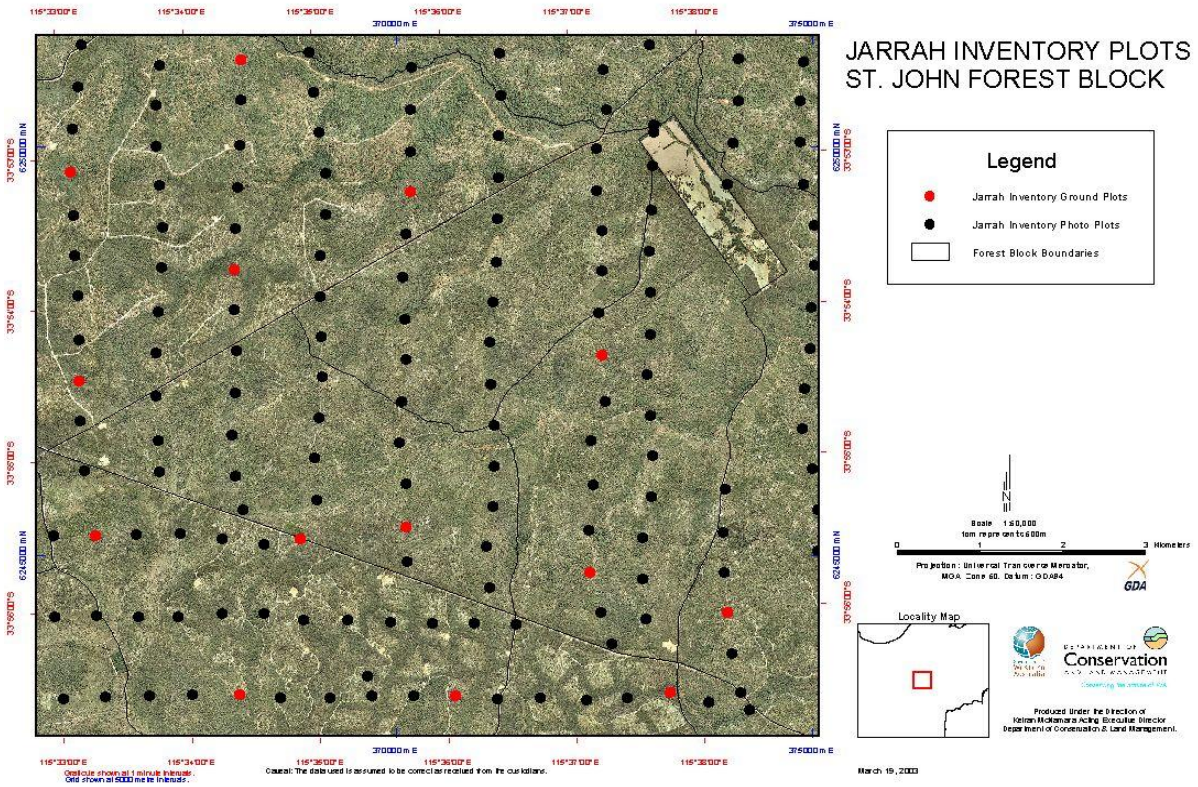

Figure 4: Example of first stage (photo) and second stage (ground) plots used in the jarrah inventory.

Data from the inventory is stored in the Integrated Resource Information System (IRIS), which also processes these tree records to produce the estimates of standing volume for the different log products. Almost 63,000 trees were measured in the ground plots, and the processing predicted over 105,000 log products.

A feature of the inventory was that it did not estimate the volume of sawlogs in trees to the existing specification, but measured and described the whole tree bole. The features and defects described for each tree correspond with those that determine the timber suitability for broad product types (each product has a specific list of acceptable and unacceptable features that define suitable log specifications). The size, shape and level of the observed defects in the tree bole have been correlated with the end products recovered from logs in sawmilling trials. In this way the quantity of any specified log product (i.e. combinations of size and quality) can be estimated from all the trees which are sampled within a designated geographic boundary.

This inventory approach enables the relevance of the tree measurements to be maintained over time, should changes arise in the type or dimension of logs required by industry. Updating estimates for a log product change or a new log product involves reprocessing the data rather than collecting new measurements in the field.

Karri

In preparation for the current FMP, a new strategic inventory of the two-tiered karri forest was undertaken. This was prompted in part by a change in the relative composition of the karri forest available for timber harvesting, following the reservation of all old-growth forest.

Undertaken in 2002, the inventory involved new stratification using aerial photography of the almost 15,000 hectares of two-tiered karri forest, to provide site quality, species, structure and stocking information. Ground plots were then established systematically within the revised mapping strata. Over 50 new ground plots were established and measured, in addition to relevant plots from the earlier jarrah inventory that are located in the mixed jarrah/karri forest.

The karri inventory data is also stored in IRIS and processed to produce estimates of the standing volume of the different log product categories.

Even-aged regrowth

Systematic sampling is effective for mixed structure forest, because the forest is highly variable over short distances and a large systematic sample ensures the diversity is sampled. However, even-aged regrowth tends to be much more homogenous over broader areas, and it is more efficient to stratify the forest into uniform areas; then, a smaller random sample size can be employed within each strata because of its uniformity (Figure 5). This was the method used for jarrah and karri even-aged regrowth.

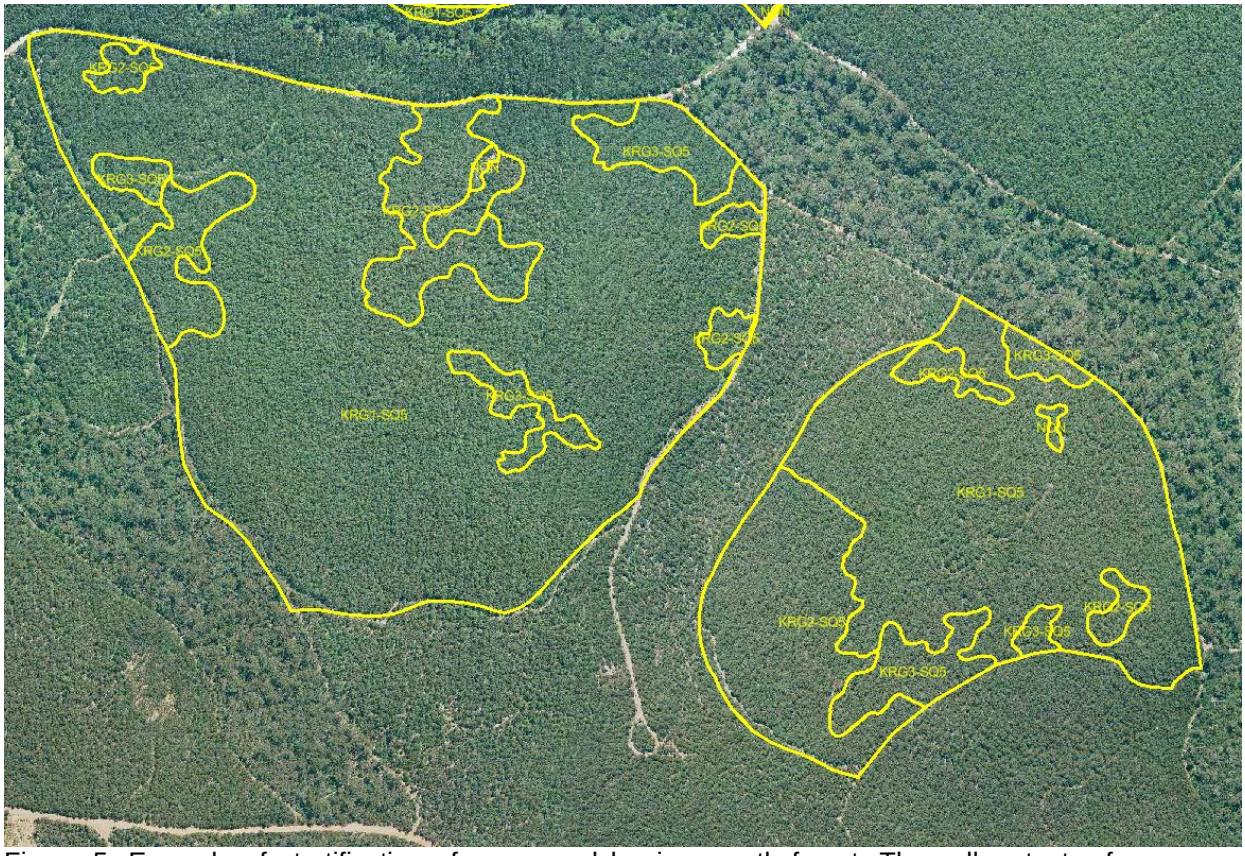

Figure 5: Example of stratification of even-aged karri regrowth forest. The yellow text references different site quality and stocking density classes for subsequent inventory.

Standing volumes

An estimate of the total standing inventory in the forest available for timber harvesting was obtained by combining the information generated from the various inventories (Table 1). The relative precision of the estimates varied between the species, due to the differences in the underlying sample sizes, type of inventory, and updates for changes to the year 2003 since the prior measurements.

Table 1: Standing volume of principal timber species in 2003

	Standing volume in 2003 (millions of cubic metres)		
Species	**Gross bole volume**	**Sawlog volume grade 1 and 2**	**Other bole volume**
Jarrah	66.1	17.1	49.0
Karri	10.0	3.0	7.0
Marri	25.7	Not estimated	25.7
Wandoo	1.2	0.3	0.9
Blackbutt	1.4	0.3	1.1
Sheoak	1.9	Not estimated	1.9

Further reading

Biggs, P. (1990). *Inventory of the jarrah forest of Western Australia using large-scale photography and ground sampling.* In: LaBau, V.J. and Cunia, T. (Eds) State-of-the-art methodology of forest inventory: a symposium proceedings. Meeting held 30 July – 5 August, 1989 Syracuse, New York. USDA Forest Service General Technical Report PNW-GTR 263, p 298-302

Biggs, P. (1991) *Aerial tree volume functions for eucalypts in Western Australia*. Canadian Journal of Forest Research 21(12), pp. 1823-1828.

Biggs, P. (1991) *Estimation of timber volumes in jarrah forest using large scale aerial photographs and ground samples.* PhD thesis, University of Melbourne.

Spencer, R.D. (Ed) 1992 *Application of Modern Inventory Techniques in the Forests of Western Australia*. CALM Occasional Paper 1/92, 88 pp.

2.4 Estimating growth and timber yield

In order to calculate a sustained yield, it is necessary to be able to predict well into the future two important variables:

- *growth*, which is the increment in volume of wood in the forest in each year. Growth is usually measured in cubic metres per hectare per year; and
- *yield*, which is the volume of wood that will be produced after a certain period of time, when a particular forest structure is harvested using the appropriate silviculture treatment. Yield is usually measured in cubic metres per hectare.

The inventory section in this Part of the series (see '*2.3 Inventory of the forest'*) noted that broadly speaking, the forests of the south-west have two distinct structures, that which is a mixture of mature and regrowth (often referred to as two-tiered) and that which is (relatively) even-aged regrowth. The growth of, and yield from, these two different forest structures is estimated differently.

Two-tiered or mixed forest

In a forest dominated by mature and senescent trees, the net growth is low, because the trees have passed their physiological peak and volume increment is offset by tree death and degrade of the bole from fire, fungi and insects. The regrowth trees within these mixed forests may be growing actively, although their growth is reduced by competition for light, water and nutrients from their larger neighbours.

Growth rates for the two-tiered forest can be estimated using repeated measurements of permanent sample plots. The historical trends from such plots generally indicated that an average total volume growth of around 1.3 cubic metres per hectare per annum had occurred in the jarrah forest, although the rate of growth in the sawlog component of this total volume increment varied considerably. However, for the purposes of calculating the sawlog sustained yield for the current FMP, it was assumed that no net growth would be applied to the mature component of the two-tiered forests. This conservative assumption reflected in part the uncertainty at that time of projecting growth trends over the long term under a drying climate.

The estimate of timber yield that results from application of a particular silviculture guideline to a specific stand is termed a 'yield table'. For the current FMP, yield tables were derived using a computer system named SILVIA (SILviculture Impact Analysis).

SILVIA takes as its input, plot data in which each individual tree is described by those attributes used when selecting trees to fell or retain – tree species, size class, form, dominance and bole condition. According to the combination of attributes, each tree in the sample is 'flagged' by the computer as capable of meeting either the requirements to retain as a crop, habitat or seed tree or be removed through felling or culling.

Each silvicultural treatment has been translated into a series of rules for deciding which of the flagged trees in SILVIA will be felled and which will be retained. Because of the nature of the silvicultural treatments, rules vary depending on environmental factors such as the stand structure, presence of regeneration, rainfall zone, dieback disease status and site quality, but also due to other management factors, such as the visual landscape management zone.

SILVIA applies the appropriate silviculture guideline to individual plots or groups of plots, which represent forest strata, and provides as outputs the volume of logs that are removed and the structure

of the stand remaining. The volume of logs made available from the harvesting of the stand to a particular silviculture guideline constitutes the yield table for that operation.

For the calculation of sustained yield for the current FMP, there were 336 separate combinations of silviculture and stand type with their associated yield tables.

Even-aged regrowth forest

The growth of even-aged regrowth forest and the yield from them is predicted using specific growth models.

A model, as used in this sense, is an abstraction or a simplified representation of some aspect of reality – in this case the growth of trees. Models may be physical, like a model of a building, or descriptive. Growth models are descriptive in that they use mathematical equations to describe the growth processes and the yield that results from that growth.

A forest growth model, therefore, is one which projects the growth of trees over time and, for the purposes of the calculation of sustained yield, the volume of timber that will be available from those trees at some future point in time.

How growth models work can be quite varied, however, at a broad level they can be divided into two types: empirical and process.

Empirical models use inventory data and statistical modelling to develop equations between attributes such as tree diameter and volume. The empirical models do not attempt to represent any ecological or physiological growth processes, as it is assumed the net result of these processes underlie the actual measurements used to develop the models.

Where there is sufficient data, empirical models can be simpler, more efficient and may provide better estimates of growth than other model types. However, they have substantial site and species-specific data requirements that have to be repeated over time.

In contrast, process-based (or 'physiological') models predict the growth of individual trees or stands of trees by simulating the processes of growth, i.e. water uptake, photosynthesis, and transpiration.

Process-based models are usually very complex and require knowledge of a large number of stand and site parameters to be effective. Because of their complexity, they are used more as a research tool to examine the interaction of the growth processes rather than as a predictive tool for operational use.

The growth models used for jarrah and karri even-aged regrowth stands are the empirical type, and have been developed and refined over time by DEC.

Karri growth model

The karri growth model is named KARSIM (KARri SIMulator). Developed using tree measurement data from even-aged permanent sample plots, thinning and spacing trials, and other research data, KARSIM predicts the future condition of a stand based on growth rates that vary depending on site quality, tree stocking density, tree size and stand age.

KARSIM operates on an annual time step and simulates the growth, mortality and response to thinning and silvicultural treatments of trees within a stand. Yield tables can then be generated for input to woodflow scheduling systems (Figure 1).

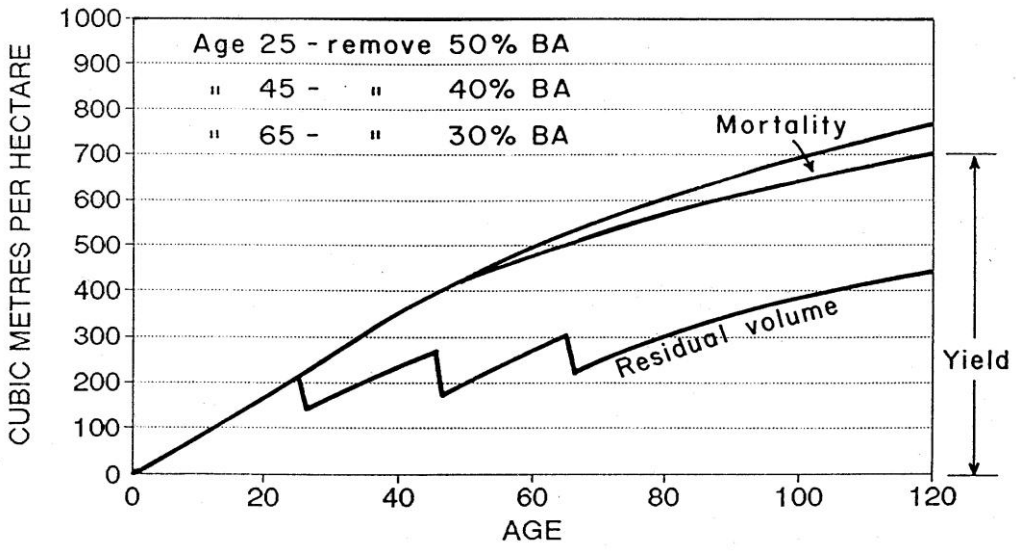

Figure 1: The volume yield projected over time by KARSIM for an even-aged karri regrowth stand growing on an average quality site and subjected to a series of thinnings at ages 25, 45 and 65.

The rate of volume growth in the even-aged karri stands varies with age, increasing rapidly in the first 20 years and then declining slowly over time. Across the regrowth karri age classes, the range in gross bole volume increment projected in KARSIM was from 9.1 to 1.3 cubic metres per hectare per year, with an average of 4.6 cubic metres per hectare per year.

Jarrah growth model

The model used to project growth and yield in the even-aged regrowth jarrah forest for the calculation of sustained yield is an empirical model called JARSIM (JARrah SIMulator).

Within JARSIM, tree growth rates are related to a range of factors that include site quality, age of the stand, stocking density of the trees, mix of species, and timing and intensity of periodic timber harvesting operations. The forest stand is represented as a list of trees described in terms of their species, diameter, condition and height of the bole. The individual trees are 'grown on' in annual time steps using the relationships relevant to the particular stand and its subsequent timber harvesting treatment. For each annual step, JARSIM estimates the stand condition (e.g. basal area, average diameter, which trees have died) and the available volume by tree size class.

The annual volume increment within each jarrah forest type varies depending on site and stand conditions, and this does not readily equate to age classes for most stand types. The range in increment of gross bole volume used was 0.2 to 3.5 cubic metres per hectare per year, with an average of 1.3 cubic metres per hectare per year.

Because the growth model takes account of which trees in the stand were felled in timber harvesting and which were left, it can be used to simulate the effect on timber yield caused by changes in ecologically sustainable forest management settings (such as how many, what species and what size of habitat trees are retained).

Quality assurance

As part of the quality assurance process for the calculation of sustained yield for the current FMP, an Independent Panel was formed to review DEC's calculations (see '*2.6 Independent Review*').

The Independent Panel did a gross check on the level of confidence that could be given to the JARSIM growth estimates by comparing the volume forecast from the growth on 68 growth plots over the sustained yield calculation time period with that forecast by JARSIM. They found that JARSIM was between 58 per cent and 85 per cent (depending on site quality) of the growth plot data, which they considered an appropriate level of conservatism.

The Independent Panel also reviewed the karri growth predictions and concluded that:

> *The Panel is of the view that growth and future stand condition has been estimated at a precision appropriate for the sustained yield calculation.*

Adjusting forecast yield to reflect the yield realised in operations

There are a number of reasons why the volumes forecast by models to be available in a harvesting operation may not be realised in the field. These include:

- the tree forecast to be removed may not be felled;
- a tree assessed as containing a sawlog may not have one when it is felled;
- the silviculture treatment may not be applied as prescribed or modelled;
- utilisation of sawlogs may not occur to the standard assumed by SILVIA; and
- the allowance for losses due to log breakage or shatter may be greater or less than predicted.

Monitoring utilisation in the field is therefore a necessary step to adjust the strategic inventory estimates in order to get better long and short-term yield predictions. Historically, monitoring utilisation has been undertaken by comparing the log sales with forecast yield. However, silviculture has become more complex and where a partial removal of the available trees in a stand is prescribed, a more detailed monitoring system has been required.

The utilisation is monitored through the measurement of those jarrah inventory ground plots that are located in areas harvested (Figure 2). The plots are remeasured before and after harvesting operations to determine the fate of each tree and the log products.

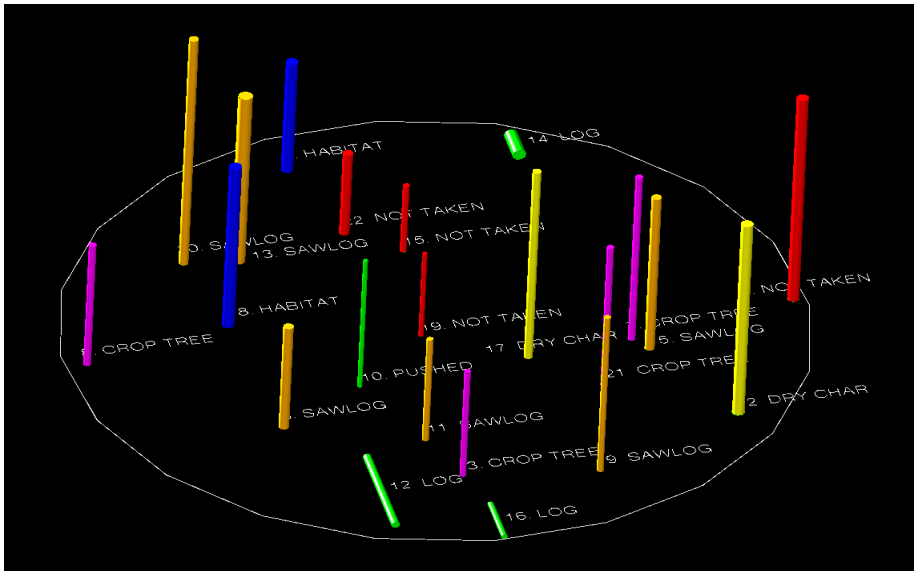

Figure 2: Example of the recorded status of trees within an inventory monitoring plot following harvesting in a patch of jarrah forest in Godfrey Forest Block.

After the accumulation of a large enough sample size, the results were analysed and the sawlog yield estimates provided by SILVIA adjusted to reflect field practice. The revised yield tables were used to generate the yields for the sustained yield calculations in the current FMP.

Accounting for factors that will vary future yield

The application of SILVIA and growth models to the different stand types provides an estimate of which trees will be retained, which trees will be felled and what the volume of timber will be that is derived from the felled trees. However, there are factors that can affect the predicted yield, particularly given the long periods of time over which the yields need to be estimated.

The factors that needed to be accounted for included:

- loss of growth due to fungal and insect pathogens;
- loss of growth due to a drying climate;
- death and damage to trees from fire;
- potential errors in the data used to determine area available; and
- loss of available area.

Loss of growth due to fungal and insect pathogens

The two main plant diseases that affect tree growth enough to warrant consideration in sustained yield calculations are jarrah dieback (caused by *Phytophthora cinnamomi*), which impacts on jarrah survival and growth, and *Armillaria*, which causes death and loss of growth, particularly in regrowth karri.

Jarrah dieback

Jarrah dieback will impact future yield in jarrah forest, and consequently must be factored in to the

sustained yield calculations. Its effect has been accounted for in two ways.

A silviculture guideline was written specifically for dieback affected forest and the yield tables for the application of this guideline reflect the impact of the disease on yield for known affected areas.

However, the biggest impact arises from spread of the pathogen into the future and the impact of resultant disease on yield over the extended time period over which sustained yield is calculated. This was accounted for by modelling the spread of the pathogen from current infestation boundaries and the consequent impact on the growth rate of jarrah from the time it was predicted to arrive (Figure 3).

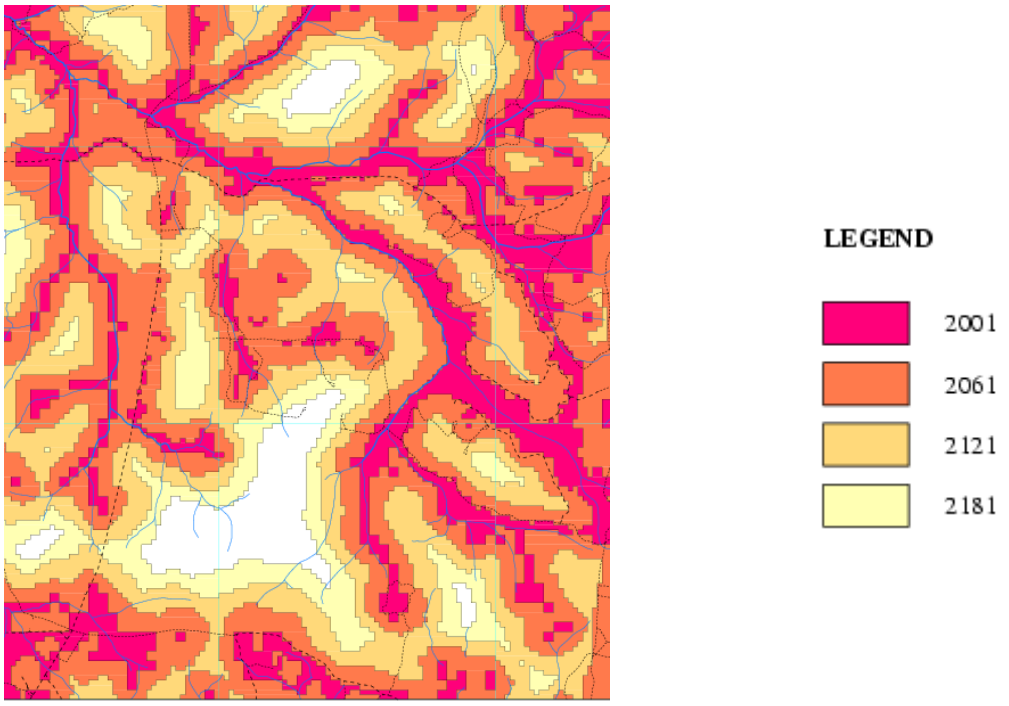

Figure 3: Modelled spread of dieback from 2001 to 2181 within a portion of Telerah Forest Block. The colours depict dieback spread within each period, with the white area projected to remain dieback free at 2181.

The modelling illustrated the long-term significance of jarrah dieback for biodiversity conservation, the health of forest ecosystems and timber yields: the modelled area of forest infested increased from around 14 per cent in 2001, to a predicted 34 per cent by 2061 and 46 per cent by 2121.

The impact of dieback infestation on vegetation structure and yield was categorised as high, medium or low impact based on the mapped vegetation complexes. The appropriate silviculture guideline and consequent yield tables were then applied to derive the yield for the sustained yield calculations. In addition, future yield on high impact sites was assumed, conservatively, to be zero and for moderate impact sites was discounted by up to 60 per cent.

Armillaria

Armillaria luteobubalina is a fungal pathogen that causes degrade and potential death of karri trees, particularly in high site quality regrowth stands.

The background level of mortality resulting from *Armillaria* has been incorporated into the karri growth model, through its presence in the growth plots that provided the data used to develop the relationships used in the model.

The impact of *Armillaria* was allowed for in two further ways. Firstly, product allocations in yield regimes have been discounted by 30 per cent from the projected estimates to account for timber degrade (Figure 4). Secondly, in some circumstances thinning may exacerbate the impact of *Armillaria*, so thinning in the sites regarded to be at highest risk from *Armillaria* was deferred for a period in the woodflow scheduling to allow research and monitoring to better inform management.

Figure 4: A typical scar on the bole of a regrowth karri stem, caused by Armillaria. Potential sawlogs from the lower bole will be downgraded due to the associated degrade.

Insects

Jarrah leafminer, Gumleaf skeletoniser and Bullseye borer are all insects that from time to time have outbreaks that may affect significant areas of forest.

For the sustained yield calculations, it was assumed that the effect of these insects on the standing yield was accounted for through the inventory measurements, and the incorporation in growth plots used to develop the relationships for the JARSIM and KARSIM growth models. As a consequence, no additional allowance was made.

Loss of growth due to a drying climate

The climate of the south-west of Western Australia is experiencing a drying trend that is forecast to continue due to the enhanced greenhouse effect. A reduction in rainfall leads to less water available to plants, which can result in lower growth rates and greater mortality.

To some extent, the effect of the drying climate to the time of inventory and growth model development is already incorporated into the growth plot measurements used to develop the growth models for jarrah and karri. Periodic re-measurement of inventory plots also provides a basis to incorporate the effect of any subsequent drying trends.

Making a realistic allowance for a future loss of growth from a drying climate is problematic given the long time period over which growth is estimated, and the high degree of uncertainty as to how dry it will get and over what time period.

However, a number of measures were taken in the current FMP to ameliorate the risk of over-estimating future growth and yield.

- No net volume growth was incorporated into the future yields from the mature trees in the two-tiered jarrah and karri forests. In other words, future growth in these stands was assumed, as a conservative setting, to be balanced by future mortality. This assumption applied to over 490,000 hectares of jarrah forest and 15,000 hectares of karri forest.
- Conservative growth rates were applied to the jarrah regrowth forest.
- An increased proportion of log degrade arising from insects and disease was assumed for karri regrowth.
- Somewhat lower regeneration numbers, a longer period for establishment and a higher mortality rate was factored in for the drier eastern jarrah forest.

Using these assumptions, the sensitivity of a drying climate on the sustained yield levels was tested in a number of scenarios and found to be low. This is because the decrease in growth was progressive over a long period of time, and its effect on yield was estimated to impact most in the next century.

Death and damage to trees from bushfires

Bushfire has the potential to kill trees and downgrade the quality of logs. However, it is regrowth stands where the greatest potential impact to the sustained yield calculation occurs, because larger mature trees in two-tiered forest are less vulnerable to damage from fire and the standing timber can often be salvaged if the trees are killed or damaged.

Jarrah regeneration is less vulnerable than karri regeneration because it is more resistant to fire and has a lower risk of being affected by a significant bushfire event, because it is more spatially dispersed. The effect of bushfire on jarrah growth and mortality was assumed to be adequately allowed for through incorporation in the inventory and the growth plot data that was used to develop the growth model JARSIM.

The sustained yield calculations for karri face the highest potential impact from bushfire because a significant loss is more likely in younger regrowth stands (Figure 5). This is because the regrowth occurs in larger patches, comprises a higher proportion of the total karri forest available for timber harvesting, and if an intense bushfire occurs up to around 30 years of age, it is likely to cause a complete loss of yield (because trees are too small to produce sawlogs or other logs to salvage).

Figure 5: Trees killed by wildfire in a stand of young karri regrowth in Sutton Forest Block.

The karri sustained yield calculation made a specific allowance for the impact of bushfire by using historical records to determine the likely bushfire frequency, and then modelled bushfire size under different weather conditions. From this analysis the sustained yield calculations assumed that there would be a loss of up to 3.4 per cent of the karri regeneration estate between the ages of 10 and 30 each year. Sustained yield calculations assumed the lost area would be replanted in the following year.

Refinement of the data used to determine the area available

Many mapped attributes are used individually or combined with others to generate the statistics required to calculate sustained yield. There are differences between the mapped or derived attributes and the field situation, sometimes due to errors in classifying the attributes, changes between sampling and analysis and spatial mapping accuracy.

The errors of most significance to sustained yield calculations will be those that affect the area available for timber harvesting. Formal reserves are accurately mapped when they are created, however, informal reserves are derived from rules applied to the various datasets and are generally not precisely mapped until they need to be demarcated in advance of a disturbance operation.

As a consequence, it is sometimes found that the actual boundaries of informal reserves differ from the assumed boundaries, and so the area available for harvesting differs. Well-developed procedures exist for amending the databases with the actual position of informal reserves as determined during demarcation for timber harvesting. This provides a basis to determine an area-adjustment factor, which makes provision for future variations that might arise over an extended period of time.

To account for the potential to over-estimate or under-estimate the area available in the sustained yield calculation, all coupes harvested in the years 2001, 2002 and 2003 were systematically examined to quantify the actual net variation to available area caused by changes to informal reserve boundaries or other reasons.

The survey found that jarrah coupes had suffered a decrease in available area of 0.28 per cent and karri coupes had resulted in a decrease of 1.11 per cent. To allow for this in the sustained yield calculation, the jarrah area was reduced by 0.28 per cent and the karri area by 1.11 per cent.

Loss of available area

Each year, a portion of the total area available for timber harvesting is permanently converted to roads, utilities infrastructure and other uses that render the area unsuitable for future timber harvest. The loss of area results in a loss of potential yield and needs to be accounted for.

The historical pattern of loss was analysed and as a guide to the future, the available area was reduced by the same amount.

Mining, particularly bauxite mining, constitutes a major conversion of two-tiered forest to regrowth forest each year. The rehabilitation process does cause a delay in growth and hence yield. However, long-term mine planning allows the annual area to be accurately forecast and subsequent rehabilitation scheduled into the yield.

Further reading

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Robinson, R.M. (2005) *Volume loss in thinned karri regrowth infected by Armillaria luteobubalina in Western Australia.* In: Manka, M. and Lakony, P. (eds) *Proceedings of the 11th IUFRO International Conference on Root and Butt Rots of Forest Trees*. Poznan and Bialowieza, Poland, 16-22 August 2004. The August Cieszkowski Agricultural University, Poznan, Poland, pp. 296-303.

Strelein, G.J., Sage, L.W. and Blankendaal, P.A. (2006) *Rates of disease extension of Phytophthora cinnamomi in the jarrah forest bioregion of southwestern Australia*. In: Brasier, C., Jung, T., and Osswald, W. (eds) *Progress in Research on Phytophthora Diseases of Forest Trees*. Proceedings of the 3rd International Working Party S07.02.09. Freising, Germany 11-18 September 2004. Forest Research, Surrey, UK, pp. 49-52.

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2.5 Scheduling wood flow

When calculating sustained yield, there are many options to choose from with regard to the area of two-tiered and regrowth forest that is harvested each year, where it is harvested from, the timing of the harvest and the time period before harvesting returns.

The decision making process that specifies how all the above options are implemented over the long time period of the sustained yield calculation, to achieve the defined management objectives, is termed 'scheduling'.

Scheduling of timber harvesting operations must be undertaken for the sustained yield calculation, to ensure that the various forest management objectives are adequately catered for, that the large variations in annual yield (which could arise if regrowth operations are undertaken to a set time schedule) are smoothed out and that harvesting is balanced across the different strata (to provide a manageable haul distance and a relatively even flow of size and quality of logs to industry).

Both the forest management objectives (see *'2.1 Management objectives'*) and silvicultural objectives have to be considered in the scheduling decisions. The silvicultural objectives are determined primarily by the current status of the stand (species, age classes, sizes, seed source or seedling occurrence, disease status). Each silvicultural objective generates a different set of future harvest options.

For the calculation of sustained yield for the current FMP, a computer system called FORSCHED (FORest SCHEDuler) was used.

FORSCHED simulated the yield of timber that would flow each year by applying specific silviculture treatments to specific forest types. For the calculation of sustained yield, there were 336 different combinations of forest and silviculture treatment, each with their own forecast timber yields, and 39 geographical supply zones to be scheduled.

Different forest strata within each supply zone could have different initial harvesting treatments required, which in turn meant different future return intervals and post-harvest treatments, all yielding different size and type of log products. The woodflow generated had to be balanced out over decades.

Scheduling was achieved by an iterative approach that varied the timing and area of the harvest operation applied to each stratum, until the annual yield had a low annual variation (smoothed) and was non-declining, indicating it was sustained.

FORSCHED provided tabular output of the total yield over time, as well as recorded the assumptions, treatments and yields for each operation.

Sustained yields

The scheduling in FORSCHED generated a non-declining yield of first and second grade jarrah sawlogs which averaged 131,000 cubic metres per annum over the long term. The karri sawlog woodflow averaged 54,000 cubic metres per annum for around 20 years, but then increased steadily in subsequent decades as sawlogs became available from thinning the large areas of older regrowth forests. The calculation of sustained yield for the current FMP therefore resulted in the following statistics:

Species	**Area available for harvesting (hectares)**	**Standing sawlog volume (million cubic metres)**	**Average annual allowable harvest (cubic metres of first and second grade sawlog)**	**Approximate percentage of standing volume cut each year**
Jarrah and wandoo	788,380	17.1	**131,000**	1.0%
Karri	60,000	3	**54,000**	2.0%

As a consequence of harvesting these 'allowable cut' levels of first and second grade sawlog, it was expected that the following additional 'other bole volume' would be made available:

Species	**Log grade**	**Average annual availability for 10 years (cubic metres)**
Jarrah	Bole logs other than first and second grade sawlogs	534,000
Karri*	Bole logs other than first and second grade sawlogs	117,000*
Marri	Bole logs other than first and second grade sawlogs	196,000

*The figure of 117,000 was subsequently amended to 160,000 in November 2011.

2.6 Independent review

The level of sustained yield has significant socio-economic implications, and there is a high degree of public interest in the relative weighting given to timber production and nature conservation values in forest management planning.

To provide assurances to stakeholders that the sustained yield data and calculations were adequate and reasonable, two independent reviews were undertaken and reports produced. There were three major reports from these reviews:

- *Maps and Data Assessment – Report on a consultancy for the Conservation Commission of Western Australia,* Perth (2002 I. F. Ferguson)
- *Calculating Sustained yield for the Forest Management Plan (2004-2013) A Preliminary Review.* Report to the Conservation Commission of Western Australia by the Independent Panel. (2001 I. Ferguson, M. Adams, J. Bradshaw, S. Davey, R. McCormack, J. Young)
- *Calculating Sustained yield for the Forest Management Plan (2004-2013) Stage 3 Report*. Report for the Conservation Commission of Western Australia by the Independent Panel. (2003 I. Ferguson, M. Adams, J. Bradshaw, S. Davey, R. McCormack, J. Young)

The full reports can be found on the Conservation Commission website. However, the Panel's conclusions for the main components in the calculation of sustained yields are summarised below.

Reliability of mapped attributes

The accuracy of mapped attributes is fundamental to sustained yield calculation because it sets the area available, area by forest type, area by forest structure, and other stand attributes.

Because some of the public had raised concerns about the reliability of mapped attributes related to the calculation of sustained yield, the 'Maps and Data Assessment' referred the issue to the sustained yield review. In the Stage 3 report the Independent Panel stated:

> *The stratification of the jarrah forest has been revised and most of the karri forest has a new stratification from large-scale aerial photos. The Geographic Information System is excellent. The Panel conducted spot checks of its capacity to accurately reflect the area of the various strata and is satisfied that it is very accurate. The Panel is satisfied that the stratification and mapping systems are sufficiently accurate and robust for the calculation of sustained yield. Well-developed protocols exist checking and correcting apparent errors in species and structural typing. Appropriate small allowances are made in calculating the sustained yield for the impact of these errors based on the historical experience of corrections. In summary, such errors have no significant effect on the overall capacity of the system to properly and accurately calculate the sustained yield.*

Inventory

Jarrah

> *The Panel considers that the design of the inventory system represents best practice, and that with the adjustments described above, provide inventory estimates at an appropriate level of precision and confidence for strategic yield scheduling.*

Karri

The Panel endorses the inventory system that is in place, and until more data is available, the Panel has no basis for suggesting variation to the current allowances while recognising that they are likely to be conservative.

Growth modelling

Jarrah

The Panel is therefore of the view that the growth estimates that have been used are appropriate for the estimation of sustained yield in this plan.

The Panel outlined a number of ways the growth model could be improved but because these required the acquisition of additional data they concluded:

Significant improvement in the available data cannot be achieved for at least a decade and there is little value in further development of the growth model until that is available.

Karri

The Panel is of the view that growth and future stand conditions has been estimated at a precision appropriate for sustained yield calculation with the expectation that the precision of the model will progressively improve as more data becomes available over time.

The predicted future stand condition and the expected condition following the simulated harvest are recorded for each simulation run providing satisfactory transparency of the assumptions made.

Yield forecasting and scheduling

The Panel believes that the systems employed to simulate long-term woodflows (FORSCHED and its supporting systems) are appropriate and robust for the purpose of long-term yield projection of jarrah and karri forests.

The Panel has investigated the operation of the systems and reviewed the derivation of the conversion factors. It is satisfied that the system produces adequate estimates of utilisable yield for the planning period.

The Panel is satisfied that the allowances made for minimum viable yield volume per hectare are appropriate and that the residual risk to sustained yield is small.

Accounting for factors that might vary the yield

The Panel has reviewed the methods used and the level of allowance made for the listed range of hazards. The Department of Conservation and Land Management (now the Department of Environment and Conservation) has evaluated prior experience in relation to losses associated with these risks and the allowances made and the methods used to make the adjustments reasonable.

For several of the factors identified, the Panel had specific recommendations to help in reducing future additional losses.

> *Area reduction: The Panel recommends that any proposal for significant changes in zoning or operational guidelines that affect harvestable areas must be accompanied by a re-estimation of sustained yield to allow evaluation of impacts on ESFM values.*
>
> *Phoracantha: During the period of the plan, on-going monitoring should be conducted across the thinnable karri regrowth estate to further assess the potential impact on yield and refine the allowance for yield reduction to be used in the future.*
>
> *Climate Change: Actual forest growth should continue to be monitored as the basis for forest yield simulation and possible adjustment for what is anticipated to be a slowly-changing phenomena. Data should be considered at the time of the next plan (2014). A watching brief should be maintained on relevant areas of climate change science.*

Sustained yield calculations

> *The Panel is well aware that various levels of allowable cut were proposed in the Draft Forest Management Plan and in recent Government statements. The role of the Panel is to confirm the levels of sustained yield appropriate to options that reflect different silvicultural and other settings and so enable trade-offs between feasible options to be better evaluated through due process.*
>
> *While we have not been able to supply a single tightly defined final option, the implications of our work are clear and we are confident that the table setting out the levels of sustained yield for various options is robust, the values are conservative, and that the methodology for analysing operational feasibility is robust.*

Further reading

As well as the Independent Panel reviews conducted for the current FMP, various aspects of the contributing inventory and forest stratification datasets and the computing systems were also reviewed and accredited during the Regional Forest Agreement process. The complete list is provided below.

Regional Forest Agreement and CRA processes

Ferguson, I.F., Adams, M., Brown, M.J., Cork, S.J., Egloff, B., Wilkinson, G. (1997). *Assessment of ecologically sustainable forest management in the south-west of Western Australia. Report of the Independent Expert Advisory Group*. Joint Commonwealth and WA Regional Forest Agreement Steering Committee.

Turner, B.J. (1998). *An Appraisal of Methods and Data Used by CALM to Estimate Wood Resource Yields for the South-west Forest Region of Western Australia.* Commonwealth and Western Australian Regional Forest Agreement Steering Committee, Canberra.

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Ferguson, I.F., Gardner, J., Hopper, S., Young, J. (1999). *Report to the Minister for Environment by the Ministerial Advisory Group on Karri and Tingle Management.* Ministerial Advisory Group on Karri and Tingle Management, Perth.

current Forest Management Plan (2004-2013)

Ferguson, I.F., Adams, M., Bradshaw, J., Davey, S., McCormack, R., Young, J. (2001a). *Calculating Sustained Yield for the Forest Management Plan (2004-2013): A Preliminary Review.* Report to the Conservation Commission of WA by the Independent Panel. Conservation Commission of Western Australia, Perth.

Ferguson, I.F., Adams, M., Bradshaw, J., Davey, S., McCormack, R., Young, J. (2001b). *Stage 2 Progress report. Calculating Sustained Yield for the Forest Management Plan (2004-2013).* Report to the Conservation Commission of WA by the Independent Panel. Conservation Commission of Western Australia, Perth.

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3.1 Management objectives

Setting objectives for management of the forest is the starting point for the calculation of a sustained yield of timber (see '*1.4 How sustained yield is calculated*'). In the case of the current FMP, the objectives and actions set in that plan provide the management context within which the calculations of sustained yield were made. Similarly, the Draft FMP has set out the context for the calculation of sustained yield through its '*Goals*' and '*Operations proposed to be undertaken (management activities)*'.

ESFM settings

The Montreal Criteria[6] have been defined by the countries involved in the Montreal Process to categorise sustainable forest management. Both the current and Draft FMPs use the Montreal Criteria as a framework.

The table below sets out the Draft FMP chapter headings (which equate to the Montreal Criteria) and identifies changes from the current FMP that have affected the calculation of sustained yields. The Draft FMP seeks comment on many of the proposed changes.

The changes proposed have the result of causing sustained yield levels to either increase or decrease. To simplify understanding of the scale of the impact of the proposals on sustained yields, the Draft FMP has calculated sustained yields using two scenarios. The first (Scenario 1) assumes that the proposed changes that overall would increase the sustained yield are implemented, and the other (Scenario 2) assumes proposed changes that overall would decrease the sustained yield are implemented.

Draft FMP chapter	Factors that may affect sustained yield
Biological diversity	• A proposed addition to the formal reserve system in Whicher Scarp ecosystem decreases the area available for timber harvesting. • Proposes changes to informal reserves which both add and subtract from the area available for timber harvesting. • Proposes an option to vary the size and location of some fauna habitat zones which increases the area available for timber harvesting (see '*3.2 Area available for timber production*') • Proposed changes to silviculture guidelines to enhance biodiversity outcomes.
Ecosystem health and vitality	• The *impact of Phytophthora* dieback and pests and other diseases on growth and yield are updated (see *'3.4 Estimating growth and timber yield*')
Soil and water	• Proposes 'silviculture for water production*' to increase water production*, which can affect future timber yield. • Proposes the removal of phased harvesting requirements in parts of the forest (see '*3.4 Estimating growth and timber yield*').

[6]see Montreal Criteria in the Glossary for further information

Draft FMP chapter	Factors that may affect sustained yield
Climate change and carbon cycles	• Incor*porates CSIRO predictions on climate c*hange to 2070, which imply lower future growth and consequently yield (see *'3.4 Estimating growth and timber yield'*)
Productive capacity	• Lower moisture availability for tree growth resulting from climate change may lower productivity and hence the level of sustained yield. • Silviculture changes are proposed to enhance productive capacity, but are expected to have a limited impact on sustained yield levels.
Heritage	Proposals do not affect the levels of sustained yield.
Socio-economic benefits	Proposals do not affect the levels of sustained yield.
Plan implementation and management	Proposals do not affect the levels of sustained yield.

The timber products to be sustained

The sustained yield calculated for the current FMP is for first and second grade sawlogs of jarrah and karri. The allowable level of supply of other log products is then a consequence of the production of jarrah and karri sawlogs using the appropriate silviculture.

There have been no substantive changes to the technical capability or structure of the wood processing industry that requires a different log type; consequently, the sustained yields for the Draft FMP are also derived for first and second grade sawlogs of jarrah and karri.

The specifications of first and second grade sawlogs used in the Draft FMP remain the same as the current FMP, as follows:

Sawlog grade	**Log specifications**		
	Minimum length (m)	**Minimum top end diameter under bark (mm)**	**Acceptable defect**
First and second grade jarrah	2.1	200	minimum millable wood 30% at worst end
First and second grade karri	2.4	200	minimum millable wood 30% at worst end

Further reading

Conservation Commission of Western Australia (2012). *Draft Forest Management Plan 2014-2023*. Perth, Western Australia.

3.2 Area available for timber production

In 2004, the total area of land vested in the Conservation Commission of Western Australia within the boundaries of the current FMP was 2,237,820 hectares[7].

However, the actual area that can be harvested for timber and consequently used in the calculation of sustained yield was much smaller, because some areas of forest are managed exclusively for nature conservation and other values which exclude disturbance.

The area available for timber production that was used to calculate the sustained yields of sawlogs for the current FMP was:

Jarrah/wandoo	788,380 hectares
Karri	60,000 hectares

The area available for timber production that can be used to calculate the sustained yield levels of jarrah and karri sawlogs for the Draft FMP is different from the above, due to refinements to data made over the life of the current FMP and different settings proposed in the Draft FMP.

The changes to the area available for the calculation of sustained yield for the Draft FMP are described below. The changes proposed have the result of either causing sustained yield levels to increase or decrease. To simplify understanding of the scale of the impact the proposals have on sustained yield levels, the Draft FMP has calculated sustained yields using two scenarios, one where the combination of proposed changes that overall would increase the sustained yield (Scenario 1) are assumed to be implemented, and the other (Scenario 2), where proposed changes that overall would decrease the sustained yield are assumed to be implemented.

Formal reserves

The design objectives for the formal reserve system include that it is comprehensive, adequate and representative. Botanical studies conducted in the Whicher Scarp during the life of the current FMP identified a new 'forest ecosystem', which is addressed in the Draft FMP through areas currently available for timber harvesting proposed to be added to the Whicher National Park to meet a target level of representation in the reserve system.

For the calculation of sustained yields for the Draft FMP, the area available was reduced by this amount for Scenario 2, but not for Scenario 1.

Informal reserves

Old-growth forest

At the commencement of the current FMP, there were areas of forest identified as old-growth forest that were subsequently assessed and found not to meet the criteria for old-growth forest. However, those areas remained as an informal reserve during the life of the current FMP. The area involved is 480 hectares. However, because some of these patches of forest were also another category of informal reserve (e.g. stream zone), the net area to be added to the calculation of sustained yield is 230 hectares. The Draft FMP proposes to remove the informal reserve status of these areas and include them as areas available for timber production

[7]current *Forest Management Plan 2004-2013* Appendix 8

in the calculation of sustained yield.

During the life of the current FMP, some areas that were not classified as old-growth forest were assessed and found to be old-growth forest. These were consequently added to the informal reserve system and withdrawn from the area available for calculating sustained yield for the Draft FMP. The area involved is 1,390 hectares.

Travel routes

A review of travel routes in the Department's Warren Region has identified 510 hectares of travel route zone that is no longer deemed necessary, because of changed traveller and land-use patterns. The area is made available for the calculation of sustained yields in Scenario 1, but not in Scenario 2.

A similar review of the Munda Biddi cycle trail, which had no travel route zones allocated to it in the current FMP, identified areas that would benefit from travel route zones. The area involved is 460 hectares and this has been deducted from the area available for the calculation of sustained yield for Scenario 2, but not from the area available for Scenario 1.

Fauna habitat zones

Fauna habitat zones (FHZ) are not a category of informal reserve, but were introduced in the current FMP, with 283 zones occupying an area of 52,042 hectares placed in indicative positions. To date, 102 of the FHZs have finalised boundaries (setting aside 21,534 hectares of forest that was formerly available for timber harvesting), leaving the remaining 181 still with indicative boundaries. The finalisation process to date has resulted in the nominal area of these FHZs becoming 52,673 hectares.

The Draft FMP proposes to keep finalised FHZs, but sets out two options for the 181 remaining indicative FHZs. Management option 1 is to keep to the current FMP proposal and progressively finalise their boundaries. Management option 2 is to retain those FHZs already finalised, but reduce the size of the remaining indicative zones, which makes some of the former FHZ areas available to other priority conservation needs and some for the timber production. Management option 2 would reduce the total area of FHZs to 44,244 hectares, which makes an additional 8,429 hectares available for timber production and hence available for the calculation of sustained yield in Scenario 1.

Area of forest used in the sustained yield calculations

In summary, the areas available for timber production used to calculate the sustained yields for the Scenario 1 and Scenario 2 in the Draft FMP are:

Scenario	Net area of jarrah/wandoo forest used to calculate sustained yield (hectares)	Net area of karri forest used to calculate sustained yield (hectares)
1	796,500	59,900
2	783,100	59,100

3.3 Inventory of the forest

The structure of the south-west native forests and how they were inventoried to provide the basic input to the calculation of sustained yield for jarrah and karri sawlogs, is described in the document '*2.3 Inventory of the forest*' of this series, which deals with calculation of sustained yield for the current FMP.

These descriptions remain relevant for the Draft FMP, so this document only describes the relevant changes or updates that were made to prepare the inventory data for the calculation of sustained yield for the Draft FMP.

The growth in the forest from the time when the jarrah and karri inventories were completed to 2010 has been accounted for in the calculation of sustained yield. However, re-measurement and reprocessing of inventory plots is ongoing and the inventory data used for the calculation of sustained yield for the Draft FMP will continue to be amended up to the time sustained yields are calculated for the 'Proposed FMP' (this will be submitted to the Environmental Protection Authority for assessment, following consideration of comments on the Draft FMP, in 2013).

The ongoing enhancement of the inventories to be used in the 'Proposed FMP' (compared to the versions used for the Draft FMP) is unlikely to substantially alter the range of sustained yields presented in the Draft FMP. The additions to the inventory will enhance the accuracy of the work underpinning the calculation of sustained yields for the 'Proposed FMP'.

Updating the inventory

Jarrah two-tiered forest

The current FMP used the jarrah inventory as it was measured in 1988-1993 for the calculation of the sustained yield for jarrah sawlogs. Although the sustained yield calculations for the current FMP were made for a period commencing at 2004, the inventory was not updated for growth that would have occurred from 1990 to 2003. This was because jarrah is a relatively slow growing species, and the increment of the jarrah forest over the period was considered to be insufficient to materially affect the level of sawlog sustained yields. In addition, not including the increment provided further mitigation of the possibility that sustained yields were over-estimated due to the effects of a drying climate.

However, given that a further ten years has elapsed, growth and change in the jarrah forest over the period since the 1988-1993 inventory measurement will be significant, and the projected loss of yield from a drying climate is explicitly incorporated into sustained yield calculations for the Draft FMP. An inventory re-measurement program has therefore been underway to update the jarrah inventory for changes since the original measurement (see '*2.3 Inventory of the forest*', in Part 2 of this series).

The update has been underway using a combination of ground plot re-measurement and modelling. To date, over 20 per cent of the inventory ground plots in areas available for timber production have been remeasured, and where applicable these have been used to update the inventory directly. The remaining plots have been updated by applying statistical relationships that were derived by comparing the 1990 plots that had been remeasured, with their 2010 re-measurement counterpart.

Karri two-tiered forest

The inventory of karri two-tiered forest was revised in 2002 for the current FMP. All the inventory plots in karri two-tiered forest have been remeasured and are currently being processed. The updated inventory will be available to feed into final calculations for the 'Proposed FMP'.

Jarrah and karri even-aged regrowth

Inventory plots within the jarrah and karri even-aged regrowth have been included in the program of measurement contributing to the calculation of sustained yield for the Draft FMP. Refinement of the update is however, ongoing and will be continued for use in the calculation of sustained yield for the 'Proposed FMP'.

Processing the inventory data

The inventory measurement data is stored and processed in the Department's Integrated Resource Information System (IRIS). The processing capability within IRIS has been enhanced to generate estimates of a broader range of log products. For the Draft FMP, the updated measurements for over 47,000 individual trees have been reprocessed through IRIS.

Stratification of the forest

Mapping the forest into strata that accurately reflect uniformity is important for inventory, and for the subsequent application of the appropriate silviculture treatment when modelling growth.

The quality of the stratification for the regrowth forests is in the process of being progressively enhanced. This refinement is being achieved with improved data obtained from new aerial photography (Figure 1) and ground assessments. This provides more accurate data on the mix of species, height of the trees and the number of trees per hectare of the sampled sites.

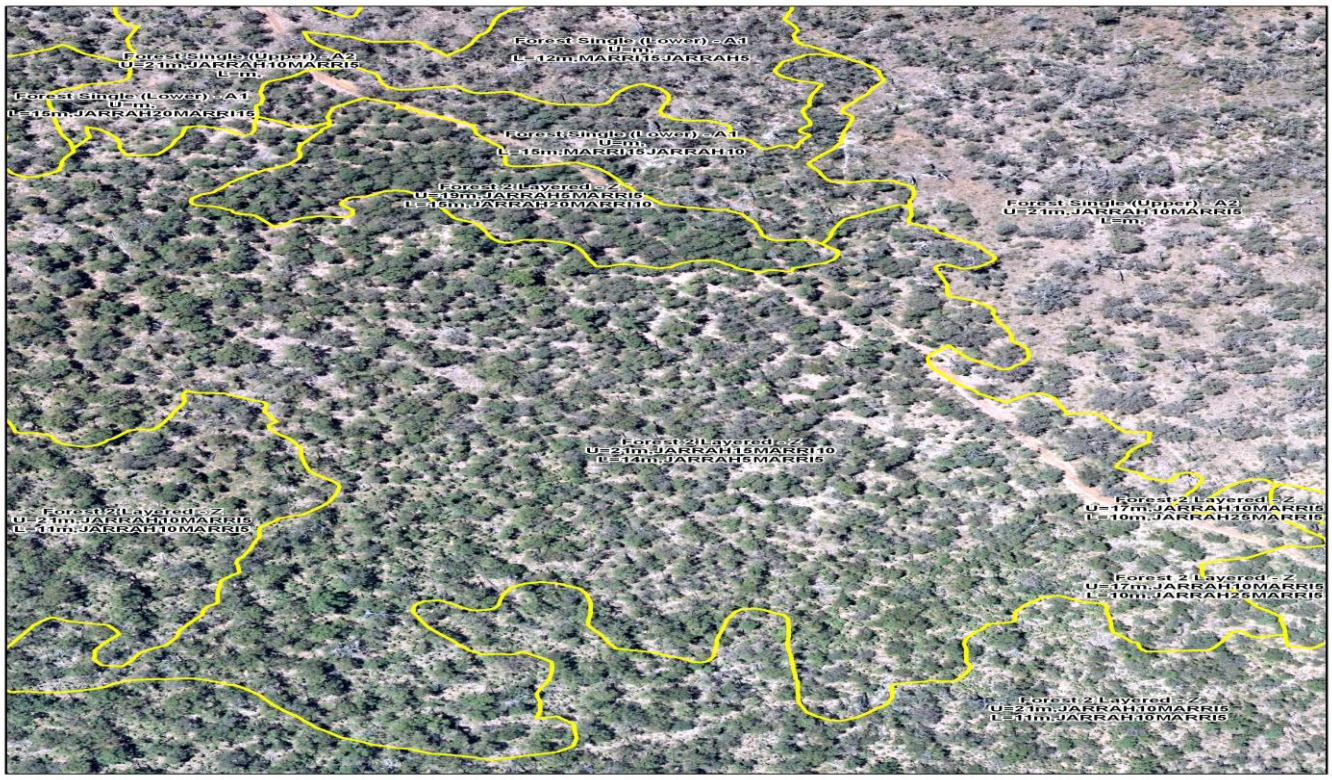

Figure 1: Example of the updated stratification for an area of jarrah forest, developed by interpreting high resolution digital photographs.

This work has been used to inform the calculations of sustained yields in the Draft FMP. However, the work is ongoing and like the inventory work, will provide enhanced data for sustained yield calculations for the 'Proposed FMP'.

3.4 Estimating growth and timber yield

The document titled '*2.4 Estimating growth and timber yield*' in Part 2 of this series describes how growth and yield were determined in the calculation of sustained yields for the current FMP.

The same principles and processes described in that document were also used in the calculation of sustained yields for the Draft FMP, so the similar details will not be repeated in this document. Instead, the following sections describe refinements that were either made to the processes to improve the accuracy of the calculations or are ongoing for inclusion in the 'Proposed FMP'. The 'Proposed FMP' is prepared following the public consultation period for the Draft FMP, and will be submitted to the Environmental Protection Authority for assessment in 2013.

Two-tiered forest

A selection of inventory plots within the two-tiered jarrah and karri forests have been remeasured to update the inventory to 2010 (see *'3.3 Inventory of the forest'*). For jarrah, the time between measurements is up to 20 years (e.g. 1990 to 2010), while for karri this period is around eight years (e.g. 2002 to 2010).

As well as providing an update on the standing volume in the forest, these plots can also be used to indicate the rate of growth during this period. Although stand growth can be highly variable and is dependent on the site, stand density and structure, at the whole of forest level the average diameter increment of the standing jarrah trees was 0.18 cm per year, and the volume growth averaged 1.08 cubic metres per hectare per year. These figures, from a sample of 157 plots distributed systematically throughout the jarrah forest, suggest that at the whole of forest scale the two-tiered forest has continued to grow at rates similar to those reported in earlier decades. However, with progressively drier conditions expected in future decades, the pattern of growth in the longer term is uncertain. For the purpose of the sustained yield calculations, the Draft plan assumed similar growth rates applied for the next decade (i.e. up to the end of the Draft FMP period in 2023), but thereafter assumed, as a precautionary setting, there was no net sawlog growth in the two-tiered component of the forest.

The document labelled '*2.4 Estimating growth and timber yield*' in Part 2 of this series, describes how the computer simulation program SILVIA is used to predict the yield from a stand when a particular silviculture is applied. SILVIA has been updated with the proposed changes to silvicultural treatments described in the Draft FMP, and new yield tables were derived for each stand type/silviculture combination. This involved SILVIA simulating 'tree marking' to the relevant silvicultural objective within the inventory plots, and estimating the log product mix that would be yielded from each tree. The total number of tree simulations performed during this process was over 1.517 million.

Even-aged regrowth forest

The jarrah (JARSIM) and karri (KARSIM) growth models are described in the document labelled '2.4 *Growth and yield*' in the Part 2 section of this series. These models were developed using growth data collected from plots which have experienced historical climate patterns, and because they are empirical models, the projected yields assume in part that future growth conditions will be similar to those historical patterns.

However, the south west forests have experienced a decline in rainfall over the last 40 years and climate modellers expect this to continue. As a consequence, growth rates could slow over the long term due to declining moisture availability. The relative impact of declining growth rates on the level of sawlog sustained yield is considered higher for the regrowth stands (which have a high proportion of smaller trees

yet to attain minimum sawlog size) than for the two-tiered stands (which have a higher proportion of standing trees already in sawlog size classes). Consequently, a method was sought to adjust the future yields projected by JARSIM and KARSIM to better reflect expected change in climate.

The use of a physiological growth model which uses rainfall and temperature as inputs, when combined with future climate projections of rainfall and temperature, is one approach to quantifying the possible decline in growth rate for the sustained yield calculations. The physiological growth model 3-PG[8] (an acronym for Physiological Processes Predicting Growth) has been widely used around the world to simulate the growth of even-aged forests, and DEC has calibrated the model for use in both jarrah and karri forests. Predictions of the growth in standing volume over time, made using the calibrated 3-PG model (using the historical rainfall and temperature recorded at nearby meteorological stations), have been consistent with the volumes measured in plots.

However, the 3-PG model output is restricted to stand-level values of tree mean diameter, basal area and total volume, which is insufficient information for detailed woodflow scheduling. Consequently, 3-PG has been used to develop 'scaling' factors to apply to the yield tables produced from the empirical models JARSIM and KARSIM. Using projections of future climate for the south west derived from the CSIRO (2007) datasets, the 3-PG growth model was used to simulate the growth of stands to 2030, 2050 and 2070, for each of high and moderate GHG emission projections. The future growth and yield from these stands was compared to that predicted by 3-PG using the average monthly rainfall and temperature values recorded for the 1990-2010 period. The 3-PG model predicted a progressive decline in tree mean diameter growth and stand volume growth relative to the growth that would have occurred if rainfall had remained at the 1990-2010 level. On average, the modelled future volume growth rate in jarrah declined by 7 per cent (medium climate change severity) to 23 per cent (high climate change severity) during the period to 2070. The modelled future volume growth rate in karri declined by an average of 17 per cent under the high severity climate change projection, and no significant change was predicted under the medium severity climate change projection.

These projections do not take account of measures that might be taken to ameliorate the effect of declining moisture on stand health, such as progressive adaptation of thinning guidelines to align vegetation density with the available water. However, for the purpose of calculating sustained yields for the Draft FMP, the regrowth yields were reduced by these predicted values to 2070, and the growth rates thereafter were maintained at the (reduced) 2070 level.

'Silviculture for water production'

The Draft FMP describes a proposal wherein the density of approximately 65,500 hectares of jarrah forest could be reduced to about 8 to 10 square metres of overstorey trees per hectare. The main purpose of the proposal is to decrease water use by vegetation and increase water run-off into streams.

The impact of implementing the 'silviculture for water production' proposal varies depending on the area treated, the location in the landscape and any follow-up treatments to maintain the overstorey basal area around 8 to 10 square metres per hectare.

The growth and yields arising from this type of stand management were projected using the same systems described for other two-tiered and regrowth jarrah forest (i.e. the inventory plots within the catchments were analysed in SILVIA to estimate the volumes potentially made available by thinning to this residual density, while the regrowth areas were informed by JARSIM simulations). However, the proposal aims to maintain the stands within a specific range of leaf area index, so the statistical relationship between leaf area index and basal area was incorporated into JARSIM to simulate the desired stand condition more accurately.

[8] The 3-PG model is a canopy carbon balance model which simulates tree and stand growth on a monthly time step. It comprises a number of sub-models for net primary production, biomass allocation, stem population dynamics, and soil water balance. It is described in Landsberg and Waring (1997) and Landsberg and Sands (2010).

Adjusting forecast yield to reflect the yield realised in operations

The calculation of sustained yield for the Draft FMP was informed by data from 164 utilisation plots that had been measured following harvest during the period of the current FMP. Further analysis is underway to refine the 'utilisation' factors to be applied for the 'Proposed FMP.

Accounting for factors that may vary future yield

Mitigating the risk of over-estimating yield

Inventory plots show that two-tiered forests are growing, however, for the calculation of sustained yield for the current FMP, the jarrah inventory was not updated from 1990 to 2003 and no growth was assumed in the two-tiered jarrah or karri stands. This conservative approach was done to mitigate the risk that sustained yield would be over-estimated, because the effects of climate change and other factors were not explicitly accounted for.

The Draft FMP explicitly accounts for the risk to regrowth yields from climate change, and the inventories of the two-tiered forests are being updated for growth to the present. Nevertheless, to mitigate the possibility that the impact of a drying climate will be worse than expected, a conservative approach has been continued by not assuming any growth in two-tiered stands from 2024 onwards.

Loss of growth due to fungal and insect pathogens

Accounting for the loss of growth and yield as a consequence of fungal and insect pathogens is described for the current FMP in the document '*2.4 Estimating growth and timber yield'*.

For the Draft FMP, the same process was followed and where it was available survey data to 2010 was used in place of the data used for the current FMP. Further data on the rate of spread of *Phytophthora* dieback and the effect of the disease on stand increment is being collected and will be applied in the modelling for the 'Proposed FMP'.

Figure 1: Adjustments for the impact on forest growth and yield of periodic defoliation such as this (due to skeletoniser in jarrah forest north of Manjimup) are represented in the broadscale inventory.

Slowing of growth due to a drying climate

Adjustments made to the growth and yields projected for two-tiered and regrowth forests to account for a drying climate have been described above. However, the Draft FMP proposes a number of modifications to the silvicultural guidelines and operations to either mitigate or adapt to climate change. These have been incorporated into the underlying 'rulesets' used to generate yield tables or applied in the timing of yield scheduling.

Death and damage to trees from bushfire

Accounting for the loss of growth and yield as a consequence of bushfires is described for the current FMP in the document '*2.4 Estimating growth and timber yield'*. Data gathered over the life of the current FMP indicate that the historical factors used in the current FMP to allow for loss of yield from bushfires were reasonable, and so the same allowance was made in the Draft FMP. However, further analysis is underway to refine this baseline adjustment for the 'Proposed FMP'.

It is possible that climate change will affect bush fire frequency and intensity and the losses associated with fires change from the historical pattern. However, no allowance was made for this because of the uncertainty related to firstly, the extent of climate change and then the impact of that change on bushfire frequency and intensity.

Errors in data used to determine area available

Databases with spatial and area information are updated annually with changes and mapping errors that were identified as a result of field operations. This is described in the document '*2.4 Estimating growth and timber yield*'. The respective spatial datasets were updated to prepare the Draft FMP.

Loss of available area

Accounting for loss of area was as described in the document '*2.4 Estimating growth and timber yield'*.

At the commencement of the current FMP, there was limited information on the likely loss of area resulting from the identification of unmapped old-growth forest. Over the life of the current FMP, data on the likelihood of the occurrence of unmapped old-growth forest was gathered and this has been used to revise the provision for this factor in the calculation of sustained yield.

Further reading

Conservation Commission of Western Australia (2008b). *Forest Management Plan 2004-2013 mid-term audit of performance report*. Perth, Western Australia.

Conservation Commission of Western Australia (2012). *Forest Management Plan 2004-2013 end-term audit of performance report.* Perth, Western Australia.

CSIRO (2007). *Climate Change in Australia – Technical Report 2007.* CSIRO Bureau of Meteorology, Melbourne, Victoria.

Landsberg, J., and Waring, R. (1997). *A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning.* Forest Ecology and Management, 95, pp 209–228.

Landsberg, J., and Sands, P. (2010). *Physiological Ecology of Forest Production: Principles, Processes and Models*. Academic Press, 352 pages.

Maher, D., Yates, C., McCaw, L., (2010). *'Vulnerability of Forests in South-West Western Australia to Timber Harvesting Under the Influence of Climate Change'*. Department of Environment and Conservation, Perth.

Robinson, R. (2008) *Forest health surveillance in Western Australia: a summary of major activities from 1997 to 2006.* Australian Forestry 71(3), pp. 202-211.

3.5 Scheduling wood flow

'Scheduling' is the process of planning a sequence of harvesting operations in time and space to meet multiple management objectives. An important management objective is the maintenance of a flow of wood over an extended period, which is the sustained yield level (see '*2.5 Scheduling wood flow*' in Part 2 of this series).

Scheduling tools

FORSCHED

For the calculation of sustained yield for the \current FMP, scheduling was achieved using a computer system called FORSCHED (see '*2.5 Scheduling wood flow*').

During the period of the current FMP, it was decided to replace FORSCHED with a proprietary forest planning tool called Woodstock™.

Woodstock™

Woodstock™ is a forest modelling system that has been under continuous improvement for nearly two decades, and is used by over 150 organisations around the world, including private companies, government agencies, consultancies and universities. In Australia, Woodstock™ is being used to manage public native forests in Tasmania, New South Wales and Victoria. One of the advantages provided by Woodstock™ over FORSCHED is that it can generate an optimised solution using linear programming techniques, rather than having to iteratively search for a 'best fit' solution for the specified settings.

Woodstock™ works by providing the tools for the forest planner to conceptualise the forest in a model of forest condition, dynamics, proposed goals and activities and any consequent changes to forest attributes. The forest model is then run with the goals, operations and other settings to generate a schedule of harvesting that meets the goals, constraints and settings. These outputs enable selection of the suite of settings and associated harvest schedule that best achieve the overall goals for the forest, and the yields calculated from the selected harvest schedule determines the sustained yield.

The model under development in Woodstock™ for the south-west forests has the following inputs:

- The forest condition has been described in terms of forest type, site quality, rainfall zone, silvicultural status, geographic zone, *Phytophthora* dieback status and predicted spread, tenure, and spatial constraints on the availability of areas for harvesting;
- Yield tables indicate stand density (e.g. stocking, basal area), standing timber resources, estimated carbon and other forest attributes. These include the best available representation of growth and current and expected impacts (e.g. such as dieback and climate change);
- Silvicultural and harvesting operation sequences are translated into mathematical 'relationships' ('actions' and 'transitions'), such that the various outcomes from harvesting an area are defined. In other words, the sequence of operations possible after an area is harvested is defined (e.g. regeneration release in two-tiered jarrah forest is followed in later years by thinning of the released regeneration). Other 'rulesets' are specified for karri and wandoo silviculture, infestation of stands as *Phytophthora* dieback spreads, and when stands are harvestable; and
- Specification of the outputs required (such as the areas harvested and volumes produced) and the constraints (such as maintaining an even or constant supply of log products).

Using Woodstock™ to calculate sustained yield

The forest model with the inputs described above can be run to calculate sustained yield (the 'goal') in a number of modelling scenarios, each with a particular mix of settings.

The modelling scenarios examine the consequences of management decisions and policies such as placing more or less forest in formal and/or informal reserves, implementing proposals (such as 'silviculture for water production'), and varying geographical priorities for harvest. Simulations can also be used to assess the sensitivity of the underlying model components to assumptions (such as the expected impact of climate change on yields).

The outputs are described in a series of reports, which provide the estimated sustained yields and include descriptions of the range of management settings and the factors that have greatest bearing on the outputs.

Use of Woodstock™ for the Draft FMP

A Woodstock™ model for the south-west forests has been under development for some time, but not all testing was completed to allow it to be used (solely) for the calculation of sustained yields for the Draft FMP. Consequently, the calculations for the Draft FMP have used a combination of Woodstock™ and FORSCHED applications. The spatial, inventory and yield data being prepared for Woodstock™ were used to calculate a sustained yield from woodflows averaged to the year 2070, with less detailed projections thereafter. The detailed climate change projections cover the period to 2070.

Ongoing data updates and finalisation of the programming for all of the goals, operations and constraints will enable Woodstock™ to be used for the calculation of sustained yields for the 'Proposed FMP'.

Sustained yield scenarios

The Draft FMP describes two scenarios used to calculate sustained yields: Scenario 1, which includes those combination of settings in the Draft plan that together, provide for higher sustained yields; and Scenario 2, where the combination of settings together provide for a lower sustained yield.

The process to calculate the level of sustained yield was the same for each scenario. The difference in the level of sustained yield between the two scenarios, therefore, is a consequence of whether the proposed activities outlined in the Draft FMP are included or not included. The range in each scenario results from the extent to which factors that have the potential to be varied, are varied.

Range in the level of sustained yield in the Draft FMP

The two scenarios give rise to the following ranges in the level of sustained yield for jarrah and karri first and second grade sawlogs:

Jarrah sustained yield levels for scenarios

Scenario	Net area of jarrah /wandoo forest available for harvesting (ha)	Range in average annual yield for 10 years (m^3)	Indicative level of average annual woodflow by geographic area (m^3)	
			North of Preston River	South of Preston River
1	796,500	101,000 – 137,000	56,000 – 75,000	45,000 – 62,000
2	783,100	95,000 – 125,000	56,000 – 72,000	39,000 – 53,000

Karri sustained yield levels for scenarios

Scenario	Net area of karri forest available for harvesting (ha)	Range in average annual yield for 10 years (m^3)
1	59,900	54,000 – 70,000
2	59,100	44,000 – 56,000

Sensitivity of the level of sustained yield to the proposed activities

The sensitivity of the level of sustained yields to each proposed activity was not separately quantified, as there are many possible permutations of how these could be combined within each scenario. However, the table below lists the proposed activities that give rise to differences in the two scenarios for sustained yield, identifies which scenario they were included in and provides an indication of the relative influence on sustained yield levels.

Proposed activity	Scale of impact on sustained yield level	
	Scenario 1	Scenario 2
'Silviculture for water production'	A program of 6,500 hectares per year lowers sustained yield and its implementation is associated with the lower end of the range in sustained yields. The upper end of the range is associated with a reduced program.	Not included.
Expanded thinning program in older jarrah stands in mining rehabilitation	Included. Assumes around 500 hectares per year are thinned. Significant to the level of sustained yield.	Not included.
Increase the rotation length for some 1930s regenerated karri stands	Not included.	Included. Significantly lowers karri sustained yield level due to loss of access to sawlog in short term.

Proposed activity	Scale of impact on sustained yield level	
	Scenario 1	**Scenario 2**
Establish additional reserves within the Whicher Scarp forest ecosystem	Not included.	Included. Approximately 3,000 hectares removed from the area contributing to sustained yields. Moderate impact because the jarrah forest involved is of relatively low productivity.
Remove from the informal reserve system areas incorrectly classified as old-growth forest	Included. Adjustments to the informal reserve system involve small areas and consequently have minor impact on sustained yield.	Not included.
Redistribute a selection of identified travel route zones (informal reserves) in the Warren Region	Included. Adjustments to the informal reserve system involve small areas and consequently have minor impact on sustained yield.	Not included.
Add to the informal reserve system travel routes on parts of the Munda Biddi Trail	Not included.	Included. Adjustments to the informal reserve system involve small areas and consequently have minor impact on sustained yield.
Reduce the size of remaining indicative FHZs and make available some of the area for timber production	Included. Significant increase in jarrah sustained yield level but minimal on karri because of location of the remaining zones.	Not included.
Use tree growth determined using either the 'medium' or 'high' severity climate change projections	Use 'medium' severity. Minor impact because most yield to 2070 is in trees already of a sawlog size.	Use 'high' severity. Minor impact because most yield to 2070 is in trees already of a sawlog size.

Reasons for the range in sustained yield levels

While some factors involved in the calculation of sustained yield are either 'in' or 'out' (e.g. area available) others may be varied, and consequently will vary the sustained yield according to the assumptions made about the extent of their implementation. These factors include the extent to which silvicultural objectives are achieved (e.g. delays in regeneration or the removal of cull trees can lower future growth and yield), the extent and intensity of thinning treatments (affects yield in the short and long term) and the capacity of industry to realise the predicted log volume (a broad market base that can accept logs of all quality can facilitate full recovery and a potentially higher sustained yield).

The assumptions concerning the level of utilisation achieved in the future and the extent, type and effectiveness of silvicultural treatments undertaken also contribute to the range in sustained yield levels.

Other bole volume

The level of availability of other bole volume (logs below sawlog specifications) is related to the level of sawlog production and the location and type of operations undertaken to produce them. For example, in a large thinning program of young regrowth or for harvesting concentrated in lower quality forest, the proportion of sawlogs to other bole volume will be much lower than it would be in higher quality forest.

The two scenarios in the Draft FMP make available the following range of other bole volumes:

Species	**Log grade**	**Range in average annual availability for 10 years (m^3)**	
		Scenario 1	**Scenario 2**
Jarrah	Bole logs other than first and second grade sawlog	495,000 – 710,000	463,000 – 528,000
Karri	Bole logs other than first and second grade sawlog	180,000 – 240,000	160,000 – 200,000
Marri	All bole logs	180,000 – 270,000	140,000 – 200,000

The higher end of the range for jarrah in Scenario 1 is associated with full implementation of the 'silviculture for water production' management option.

The quantity of other bole volume potentially available does not necessarily mean it will be harvested. Markets for logs below sawlog quality are limited and only a small proportion of other bole volume logs made available in the current FMP have been removed.

A stronger market for other bole volume has a positive effect on sustained yield, because it enables silvicultural treatments that favour growth to be better implemented, and since it can make some areas that might otherwise be unviable for harvesting, viable, and thus able to be included in the area available for the calculation of sustained yield.

3.6 Independent review of sustained yields

The development process for the current FMP included review by an expert panel of the process and calculations that produced the sustained yield levels. The Panel produced two reports, a summary of which can be seen in the document '*2.6 Independent review'*, in the Part 2 of this series.

The process and calculations for development of the sustained yields for the Draft FMP largely involve data and component systems that were previously reviewed by the expert panel for the current FMP. The introduction of the Woodstock™ forest modelling system has, however, been a new development since the earlier reviews.

It is intended to have an independent review of the sustained yield calculations developed for the 'Proposed FMP' that will be submitted for assessment by the Environmental Protection Authority in 2013. This is so the review captures the settings resulting from public consultation on the Draft FMP, the refined inventory datasets and full use of the Woodstock™ forest planning tool. The timing of the review is expected to be in early 2013.