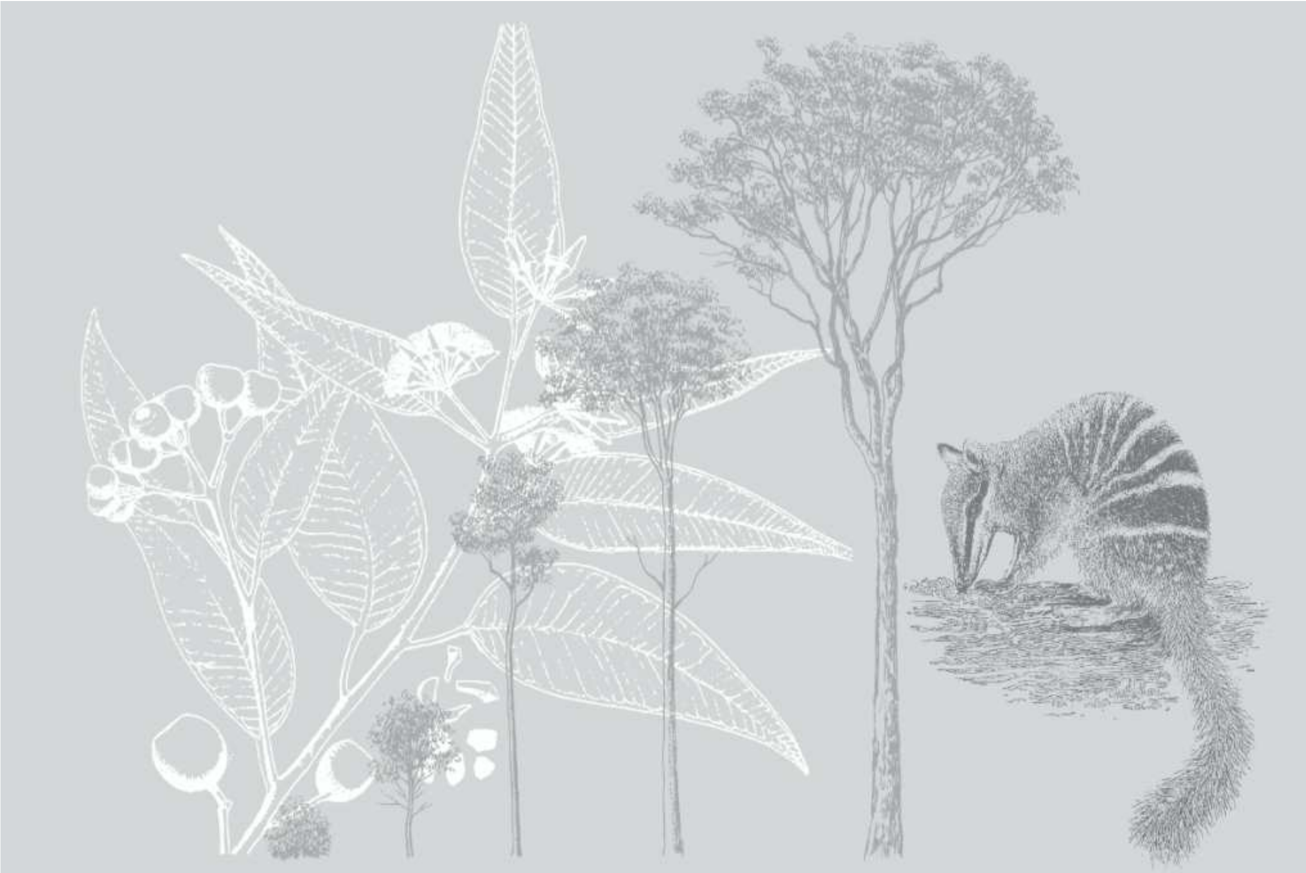
Silviculture Guideline for Jarrah Forest



Forest Management Series

Department of Parks and Wildlife
FEM Guideline No. 1

Department of Parks and Wildlife
17 Dick Perry Avenue
Technology Park, Western Precinct
Kensington, Western Australia 6151
Telephone (08) 9334 0300
Facsimile (08) 9334 0498
Website: www.dpaw.wa.gov.au
Email: info@dpaw.wa.gov.au

Author
Bob Hagan and Dr. Danielle Wiseman, Ecosystem Health Branch, Department of Parks and Wildlife

Acknowledgments
The authors would like to acknowledge the significant work completed by Deidre Maher in the development and writing of these guidelines.

The authors would also like to acknowledge the contributions made by many people including Jack Bradshaw, Gavin Butcher, Paul Brennan, Dr. Lachie McCaw, Dr. Martin Rayner, Alan Seymour, Dr. Geoff Stoneman and Kim Whitford.

Reference details
The recommended reference for this publication is: Department of Parks and Wildlife 2014, *Silviculture Guideline for Jarrah Forest*. Sustainable Forest Management Series, FEM Guideline 1.

This Guideline supersedes:
SFM Guideline 1 2004 Silvicultural Practice in Jarrah Forest

when applied in conjunction with:
Silvicultural Reference Material for Jarrah Forest (2014)
Silviculture Manual for Jarrah Forest (2014).

Cover illustration: Developed by Clare Martin, Strategic Development and Corporate Affairs, Department of Parks and Wildlife

Deirdre Kaye Maher
20 June 1967 - 13 August 2011

Deirdre Kaye Maher was a wife, mother, friend, passionate forester and community member. Deidre began the consultation and development of these guidelines before her illness and contributed a great deal to these guidelines.

Deirdre's career with the Department of Conservation and Land Management (CALM), later the Department of Environment and Conservation (DEC), began in 1990 as a junior officer at Manjimup at a time when women were a rarity in forestry, and District field operations in particular. Deirdre soon became familiar with what was required and quickly gained the respect of contractors and crews by never trying to be "one of the boys", but by being proud to be a woman in a predominantly male workplace.

It was during the early years of her career that Deirdre developed her love of silviculture, especially the intricacy of jarrah forest management. In 2007 Deirdre was appointed Senior Silviculturalist with DEC and worked out of the Bunbury office for over three years. Her experience and attention to detail earned her great respect and staff soon found out that work completed to Deirdre's satisfaction would stand up to any scrutiny inside or outside the Department.

Deirdre was much loved by her husband Tony, and their children Leah and Michael. Deirdre passed away too young, with so much more to contribute to the science of forest silviculture, a knowledge and skill that will become increasingly important for sound management of the forests of the south-west Western Australia in the face of changes in climate and community expectations.

Table of Contents

1. Framework for this guideline

Purpose

The purpose of this document is to provide guidance on the application of silvicultural practices in those parts of the jarrah forest that are subject to timber harvesting. Guidelines are generally not prescriptive, but provide the intent and guidance for forest managers.

Scope

This guideline deals with the silvicultural management of the jarrah forest available for timber harvesting and applies to State forests and timber reserves, and freehold land that contains indigenous vegetation and which is held in the name of the Conservation and Land Management (CALM) Act Executive body. The guideline contains some strategies which may not be strictly silviculture, but are integral to and/or managed as part of the silvicultural system. The guideline does not cover the identification of informal reserves or other areas from which timber harvesting is excluded, as this process occurs prior to the application of silviculture and is referred to in this document as the coupe planning process.

Context

This guideline provides the framework for operational practices which meets those goals and proposed operations of the *Forest Management Plan 2014-2023* (FMP) that are implemented through silvicultural practice. Legislative requirements are outlined in Appendix 1. Measures to protect soil, including suitable times to conduct timber harvesting operations, are addressed in *Soil and water conservation guideline,* Sustainable Forest Management (SFM) Series, Guideline No 5 (Department of Environment and Conservation 2009c) and subsidiary documents. Detailed guidance on the application of fire to meet silvicultural objectives to promote regeneration and protect established growing stock from damaging bushfires can be found in the *Jarrah Silvicultural Burning Manual*, SFM Series, Manual No 4 (Department of Environment and Conservation 2011). Current versions of all SFM guidance documents are available at http://www.dpaw.wa.gov.au/management/forests.

This guideline provides guiding principles, rationale and strategies, whereas supporting manuals and procedures are intended to provide detail regarding operational practices (Fig 1).

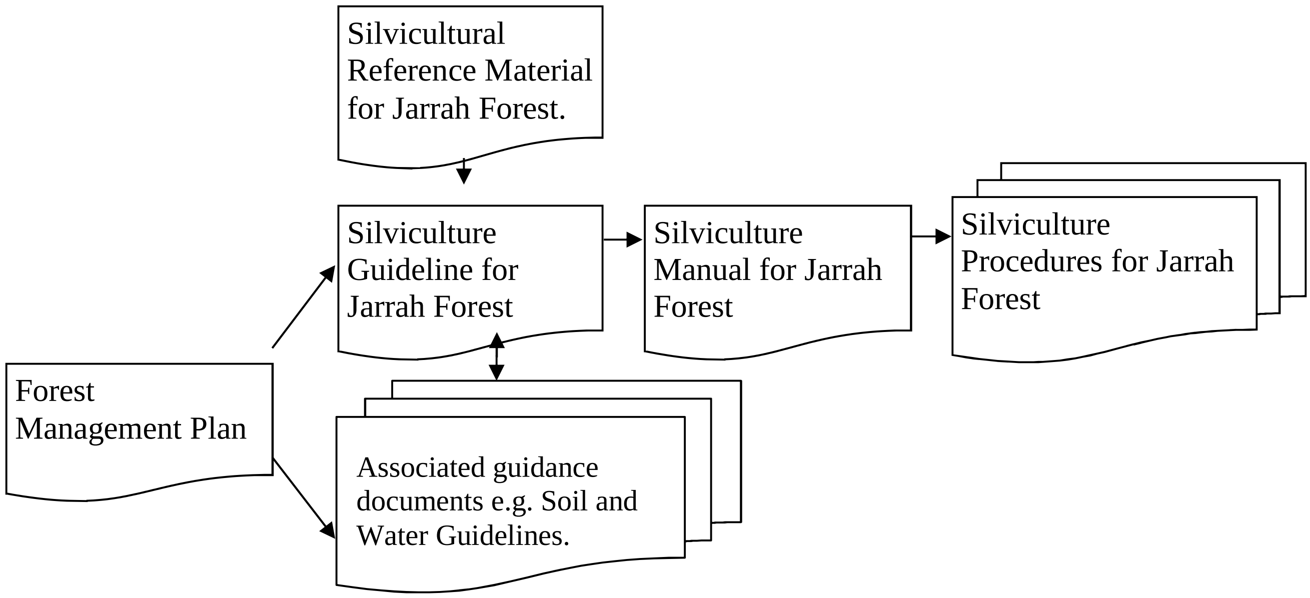


Figure 1. Diagrammatic representation of the hierarchy of documents guiding the application of silviculture in the jarrah forest.

Separate guidelines apply to karri forest and wandoo forest. Silvicultural practices for mixed jarrah/karri/marri forest are covered in the karri guideline.

The manuals and procedures which support the application of this guideline provide instruction on applying silviculture in the jarrah forest. It is important that forest officers have sufficient training and experience to be competent in applying the most appropriate silviculture in the jarrah forest, and to facilitate this, training is provided.

Custodianship and management of this guideline

This guideline is a controlled document. The custodian is the Manager of the Ecosystem Health Branch of the Forest and Ecosystem Management (FEM) Division of Parks and Wildlife (DPaW).

Application and scale of silviculture

What is silviculture?

Silviculture is the theory and practice of growing and tending forests to achieve management objectives. Historically more associated with timber production, contemporary silviculture encompasses economic, environmental and social objectives to achieve ecologically sustainable forest management. It is applied to achieve a wide variety of outcomes including soil and water protection, wood production, catchment management, habitat for wildlife, maintenance of aesthetics, and provision for recreation.

Objectives may be complementary to, or to some extent, in competition with one another. The silvicultural method(s) applied are therefore designed to achieve a balance between objectives, and those objectives may differ at the local and landscape scale in order to achieve the desired balance of objectives for the whole of forest.

Competition for water, nutrients and light affect the survival and growth of all stand development stages and the quantity of forest products that can be provided. Silvicultural methods of the jarrah forest have been developed to alleviate competition at various development stages, to maximise tree vigour and sawlog production, while maintaining conservation and other values. Jarrah forest is essentially uneven-aged, with relatively small patch sizes. Application of a single silvicultural method over a broad area is not usually appropriate to the condition of the forest, so a systematic process is used to guide decisions as to which silvicultural method to apply. Study and observation enabled the development of jarrah forest silvicultural methods, based on how the forest regenerates naturally after disturbance and how the trees grow and interact with each other and their surroundings. The *Silvicultural Reference Material for Jarrah Forest* (Department of Parks and Wildlife 2014), provides a summary of the scientific and observational information that underpins the jarrah silvicultural system.

There are four main silvicultural methods applied in the jarrah forest. In all methods the first requirement is to mark exclusion areas and legacy elements, after which the silvicultural method appropriate to the stand condition is applied.

1. Shelterwood - establish regeneration

The shelterwood method is applied in the jarrah forest when regeneration stocking is insufficient for regeneration release (gap creation). The shelterwood harvest retains suitable trees to act as a seed source and requires a reduction in overstorey competition and an appropriate level of soil disturbance, to enable seedling establishment and development of seedlings into ground coppice. The shelterwood area is burnt following harvest in a moderate intensity burn, to provide an ash-bed and to stimulate seed fall and seedling development.

Subsequent burns in the shelterwood stands are undertaken at appropriate times to facilitate ongoing seedling establishment and development. Stocking of seedlings, ground coppice, saplings and small poles is monitored. Once regeneration stocking is sufficient, a gap may be created.

2. Gap creation - release of regeneration

Gap creation is carried out in stands that have sufficient established, young regeneration. Once harvesting is completed, the stands are assessed and some un-merchantable trees may be culled to provide freedom from competition to effectively release the regeneration. Once the post-harvest culling has been completed, the silviculture burn is undertaken, either as a specific burn to reduce the slash from harvesting, or as part of a larger prescribed burn.

Once the regeneration has been released, the stands have a period of fire exclusion to allow the trees to reach a height and size that allows them to withstand a moderate intensity prescribed burn.

3. Thinning - to promote growth

Thinning is undertaken to reduce competition between regrowth trees and to accelerate growth on the trees that remain. Due to the difficulty in selling small and poor quality trees from jarrah harvesting operations, thinning is undertaken as both a commercial and a non-commercial operation.

Following thinning and follow-up culling, the stands are burnt as either a mild intensity post-thinning silviculture burn or integrated into adjoining prescribed burns.

4. Single tree selection – in high impact dieback areas

In the single tree selection method in high impact dieback areas, the treatment allows for a portion of the merchantable trees to be removed while retaining a sufficiently high basal area to avoid increasing surface soil moisture or temperature, which could favour disease development. Species that are not susceptible to dieback, and trees and understorey plants that appear to be resistant to dieback, are preferentially retained.

These areas are generally burnt in a mild intensity silviculture burn.

Due to past management practices or limits on culling of un-merchantable trees, some areas are treated as 'selective cut'. Selective cut stands are prescribed burnt in conjunction with burns for other purposes.

Towards the end of the previous FMP (2004-2013), a review of silvicultural practice was undertaken (Burrows *et al.* 2011) and a series of recommendations were made for changes to silviculture. The primary recommendation was to implement forest management to achieve a better water balance in a drying climate. Concern was raised over the impacts of human induced climate change, particularly decreased water availability and its effect on forest health and the health of associated ecosystems, especially aquatic ecosystems. This has been addressed within the current guidelines in Guiding principle 10 – *Promote ecosystem health and vitality through silvicultural management*, and Guiding principle 13 – *Silvicultural treatment of native forest may be used to maintain or enhance the flow of water to surface and ground water reserves*. The purpose of Guiding principle 10 is to apply silvicultural management to protect ecological values where potentially at risk because of the effects of human induced climate change. The purpose of Guiding principle 13 is to increase the flow of water to groundwater and surface reservoirs, which will enhance aquatic ecosystems but also potentially be available for consumptive purposes.

The review also recommended the practice of mechanical scarification be minimised and care be taken to retain the diversity of second-storey shrubs. These recommendations are incorporated in Guiding principle 5 – *Compositional diversity will be maintained in silviculturally managed forests*. Additionally, given ongoing declining rainfall in the south-west, leading to reduced risk of salinity associated with rising groundwater, the review recommended phased harvesting requirements be revised and this has been addressed in Guiding principle 12 – *Water quality will not decline as a result of silvicultural treatment*.

Other changes incorporated into the current silvicultural guideline concern changes to seed tree specifications (strategies 36 and 37), fire management (Guiding principle 8), improving adaptive potential (strategies 28, 29, 36, 37, 42 and 43), revised habitat retention requirements (strategies 15, 18, 19, 20, 21, 22, 23, 30, 33 and 35) and thinning (strategies 10, 11, 14 and 33).

Scales of management

The management of silviculture considers three scales which are as follows:

- *Whole of forest* – all land categories that are subject to the FMP.
- *Landscape* – A mosaic where the mix of local ecosystems and landforms is repeated in a similar form over a kilometre-wide area. Several attributes including geology, soil types, vegetation types, local flora and fauna, climate and natural disturbance regimes tend to be similar and repeated across the whole area. It could be a (sub) catchment or, for convenience, an administrative management unit such as a forest block or an aggregation of forest blocks. Landscape scale could span a few thousand to more than many tens of thousands of hectares.

  In this guideline, reference is sometimes made to Landscape Management Units (LMUs), which are based on mapping of vegetation complexes (see (Mattiske *et al.* 2002).
- *Local* – a discrete area of land to which one or more operations have been or are planned to be applied. It could span tens of hectares to perhaps a few thousand hectares. As a guide, for the purposes of this document, local scale is the average area of the forest blocks in the vicinity subject to, or potentially subject to harvesting in the three year harvest plan.

Silviculture is usually applied at the patch level with a silvicultural method selected appropriate to the condition of the stand. However, silviculture is also guided by the condition of the forest at the local and landscape scale and seeks to provide for ecologically sustainable forest management at the whole of the forest scale.

This document includes twenty five guiding principles that provide the framework of silvicultural practice in the jarrah forest. A guiding principle is a statement that communicates a basis for management decisions. This guideline has been prepared to accompany the FMP and is consistent with the settings adopted in the FMP.

2. Summary of guiding principles for silviculture in the jarrah forest

Guiding principles for biological diversity	
1.	Knowledge of natural disturbance regimes will be used to guide the size and intensity of silvicultural practices to ensure they contribute to the maintenance of landscape heterogeneity.
2.	Silvicultural practices will contribute to maintenance of connectivity.
3.	Key structural features will be retained as legacy elements in silviculturally managed forests.
4.	Natural regeneration will be used wherever possible.
5.	Compositional diversity will be maintained in silviculturally managed forests.

Guiding principles for ecosystem health and vitality	
6.	Promote resilient stands on sites with high levels of overstorey mortality or stress through silvicultural management.
7.	Promote resilient ecosystems through the management of *Phytophthora* dieback.
8.	Prescribed fire will be used to protect fire sensitive regeneration and reduce high fuel loads that may result from silvicultural practices.
9.	Silvicultural management will be used to maintain forest nutrient cycling processes.
10.	Promote ecosystem health and vitality through silvicultural management.

Guiding principles for soil and water	
11.	The extent and severity of harvesting disturbance on soil values will be minimised and damaged soil remediated.
12.	Water quality will not decline as a result of silvicultural treatment.
13.	Silvicultural treatment of native forest may be used to maintain or enhance the flow of water to surface and ground water reserves.

Guiding principles for climate change and carbon cycles	
14.	Forests will be managed to maintain forest carbon stocks, provide forest products and contribute to the mitigation of climate change.

Guiding principles for productive capacity	
15.	The most appropriate silvicultural method will be applied to each stand to support short and long term productivity.
16.	Regeneration and tree growth will be enhanced through actions to alleviate competition on regeneration and selected trees.
17.	Silvicultural methods will reflect the site productivity and developmental stage of the forest.
18.	Where the canopy is removed in gaps the forest will be regenerated effectively and in a timely manner.
19.	Trees to be retained will be marked and protected from damage.
20.	Forest areas that are killed or damaged by fire or other agents may be restored or salvaged.

Guiding principles for heritage	
21.	Harvest disturbance will be managed to avoid adversely affecting Aboriginal cultural heritage values and sites.
22.	Harvest disturbance will be managed to avoid adversely affecting Australian cultural and natural heritage values and places.

Guiding principles for socio-economic benefits	
23	The capacity of forest areas will contribute to the social and economic sustainability of regional communities.
24.	Visual landscape management will be used to manage potential effects of silvicultural treatments on visual amenity.
25.	Post-harvest treatments will be prioritised according to the benefits likely to be realised.

3. Guiding principles for biological diversity

Overall objective

Conserve biodiversity and self–sustaining populations of native species and communities, and facilitate the recovery of biodiversity from harvesting disturbance operations.

Within the area covered by the FMP, biological diversity is supported through formal reserves, selected to be comprehensive, adequate and representative, the multiple use forest area, informal reserves, temporary exclusion areas (TEAS) and fauna habitat zones (FHZ), which together, represent a significant continuous area of forest cover. Habitat elements are retained in harvested areas through the application of silvicultural guidance. The small proportion subject to harvesting disturbance operations in any one year can re-establish from propagules existing on site, and/or be re-established using seed or seedlings selected for the site. To assist re-establishment, structural complexity and heterogeneity of the forest are maintained at multiple spatial scales, facilitating the movement of genetic material and individuals. Disturbance supports biodiversity so long as the scale and intensity of disturbance are appropriate.

Guiding principle 1

Knowledge of natural disturbance regimes will be used to guide the size and intensity of silvicultural practices to ensure they contribute to the maintenance of landscape heterogeneity.

Rationale

Jarrah forest is essentially uneven aged, with relatively small patch size. Even-aged stands are usually relatively small in area, however there are exceptions. Past silvicultural practices and/or large scale disturbances such as bushfires have created some large areas of even-aged regrowth. For the most part, natural and human disturbances have helped to create diversity in forest structure at a range of spatial and temporal scales. This complex diversity of structures across the landscape contributes to the biological diversity of the forest, with some species favoured by the habitat of early development structures, others by the later stages and others by a combination of two or more. Providing a mosaic of structural types across the landscape can encourage a wide variety of habitats and plant and animal communities, and thus, enhance ecosystem resilience.

Natural disturbances leading to changes in stand structures include stand replacing bushfire, storm damage, frost, drought, insect attack, and tree deaths in senescent stands. Adaptations to these natural disturbances enable the forest to respond and recover. Where canopy openings are sufficiently large, the forest regenerates and progresses to later developmental stages until the cycle starts over again.

The highest intensity disturbance in the forest is mining, converting the existing mosaic to a single development stage, with very little structural complexity and no legacy elements. Harvesting gaps to release regeneration also impacts on forest structure where the mature forest structure is converted to the establishment stage. However, the impact of harvesting disturbance is mitigated by the application of a number of strategies to ensure structural complexity is maintained - as outlined in Guiding principle 3.

The use of TEAS together with FHZ and the informal reserve network, allows for the retention of areas of forest undisturbed by timber harvesting within State forest and timber reserves. Once the forest has developed sufficiently to allow those species which have been displaced to re-occupy the regenerating forest, then structure modifying disturbance in the TEAS can occur.

Biodiversity monitoring of jarrah forest subject to timber harvesting has shown few significant impacts of harvesting on biodiversity (Abbott *et al.* 2011). Comparing unharvested reference areas and harvesting treatments (gap cutting, shelterwood, thinning and selective cut), only lichens and terrestrial vertebrates were found to vary significantly between treatments. The number of species of terrestrial vertebrates was greater in areas cut to selective cut or shelterwood than in unharvested reference areas. The number of and composition of lichen species declined temporarily in gap treatments, but after ten years had recovered to be similar to unharvested reference forest. Based on these results, the minimum time period for the retention of TEAS was set at ten years.

The absence of disturbance, or large or repeated stand replacing disturbances, may reduce ecosystem resilience by reducing the heterogeneity of the landscape. Silvicultural management strategies ensure that the forest landscape continues to provide a mosaic of development stages to maintain broad biological diversity. The intensity and size of harvesting disturbance and their separation in space and time are important considerations in managing biodiversity at a landscape scale.

Due to limited markets for non-sawlog jarrah and marri, some areas which would otherwise be regenerated are selectively harvested, although if markets become available much larger areas could be effectively regenerated. In this case TEAS can be used to ensure that the local impact of harvesting occurs at an acceptable level.

Strategies

General forest area:

1. During treemarking, silvicultural objectives will be selected for each stand based on the structural development stage (Fig 2.), regeneration status, existing impact of disease and practicality of management (this will also contribute to maintaining an uneven-aged structure at the local scale and will contribute to Guiding principle 2).

2. During treemarking, ensure gaps (regeneration release) are limited in size to no more than 10 hectares (this strategy also contributes to Guiding principle 2).

3. In areas of forest where the predominant silvicultural method applied was shelterwood (regeneration establishment) and where regeneration could be released across wide areas, structural complexity will be provided by TEAS or the use of alternative silvicultural methods. Depending on the visual landscape classification, the harvesting of TEAS may occur as soon as 10 years after the regeneration has been established.

4. When creating gaps, retain advance growth of varying ages.

5. When applying silvicultural treatments in forest isolated in agricultural landscapes, stage operations over time. Where the isolated area is less than 400 hectares, it will be managed in two approximate halves, with subsequent harvesting permissible after 10 years.

6. During treemarking, ensure the existing heterogeneity of forest structures are maintained through the application of a range of silvicultural methods. Application of a single silvicultural method to a continuous area representing greater than 60 per

cent of the local scale should be avoided. The exception is thinning, where variable density thinning should be applied to create heterogeneous structure. This also contributes to Guiding principle 2).

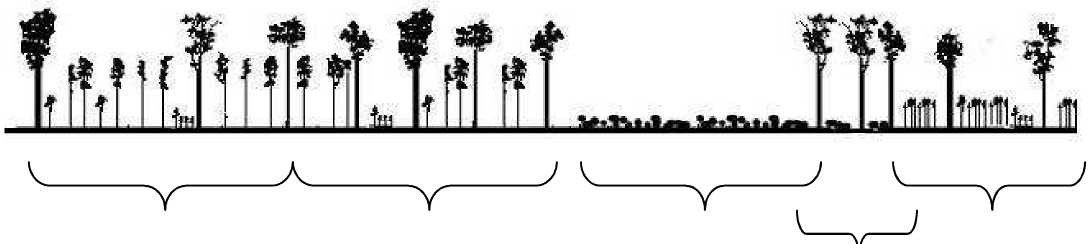


Figure 2. **A diagrammatic representation of jarrah forest development stages. The developmental stage is the predominant age in that stand, for example there may be mature trees present, but if the predominant age of trees in the stand is juvenile, then the areas is classified as juvenile.**

Additional strategies for forest subject to mining:

7. During the mine planning process, consider the retention of legacy elements, or ideally patches of retained forest within the mined area (this also contributes to Guiding principle 3).

8. During harvest planning, avoid greater than 40 per cent of the landscape scale area being in the establishment to immature developmental stages at any one time (Fig 2).

9. Treemarking will endeavour to manage the local scale management unit to retain the structural complexity (see Guiding principle 3). This includes giving consideration to marking additional legacy elements in areas immediately adjacent to mining rehabilitation, to increase their retention rate at the local scale.

10. During harvest planning, schedule thinning of the non-mined forest to coincide with periods of high water use in the mine rehabilitation.

11. During thinning of rehabilitated mine sites, apply variable density thinning to increase structural complexity and reduce water use.

Guiding principle 2

Silvicultural practices will contribute to maintenance of connectivity.

Rationale

Connectivity is the degree to which the landscape facilitates or impedes movement and or exchange of organisms, reproductive material or propagules. Connectivity is achieved by creating functional or structural linkage of habitats, communities and ecological processes. The exchange of individuals or genes among populations in different habitat patches influences both dispersal and genetic diversity and is an important consideration for persistence and resilience of populations, as well as for re-colonisation by those species displaced following disturbance. Connectivity is particularly important in light of human induced climate change, as species or communities may need to reposition themselves in the landscape. Connectivity can be supported in the multiple use forest area through maintaining a variety of habitat at multiple spatial scales. Informal reserves (such as stream zones), and other areas temporarily excluded from operations, such as FHZ, provide areas of forest within which silvicultural treatment is not applied. Heterogeneity at the landscape scale avoids the creation of barriers to biological and ecosystem processes, including the physical movement of species or their propagules within the landscape. Connectivity is also maintained through the imposition of limits to the application of silvicultural treatments. Some species have a preference for particular structural elements, so large areas of a single structure within the forest should be avoided. Therefore, silvicultural practices seek to mimic the size and intensity of natural disturbances to which native flora and fauna have evolved with (see strategies listed against Guiding principle 1).

The scale and intensity of harvest disturbance that would represent a barrier to biological and ecosystem processes varies from species to species, and the degree to which the disturbance alters the structure of the forest at the local scale. At the local scale, silvicultural treatments retain structural complexity to encourage the persistence and re-colonisation of treated forest (for example, the retention of habitat trees, logs, second-storey and overstorey elements see Guiding principle 3). The retention of these elements provides habitat for species which may have limited dispersal, such as endemic saproxylic communities occupying large diameter logs.

A potential risk to connectivity in the multiple use forest area is open cut mining, which has long lasting effects on the structure and function of the soil profile, hydrologic processes and vegetation. Connectivity can be supported by managing the forest surrounding mined areas to offer a means of dispersal around and re-colonisation of the disturbed area, until connectivity is re-established. Connectivity is maintained by the strategic location of retained forest within the mining envelope to retain structural complexity and heterogeneity at the local scale.

Strategies

12. During harvest planning, the application of TEAS will provide structural complexity locally and heterogeneity within the landscape. TEAS may act as both a refuge and source of individuals or genetic material for re-colonisation of mined areas (this strategy also contributes to Guiding principle 1).

13. During treemarking, legacy elements will be retained in harvested coupes to provide structural complexity and provide connectivity for species which require legacy elements for their life cycle (this strategy also contributes to Guiding principle 3).

14. In larger areas (>50ha) of even- aged forest where thinning is an appropriate silvicultural treatment to apply, variable density thinning may be used to increase structural complexity.

Guiding principle 3

Key structural features will be retained as legacy elements in silviculturally managed forests.

Rationale

The occurrence of late structural stage or long-lived structural elements of the forest such as over-mature trees mature second-storey trees and shrubs; thickets and large coarse woody debris (CWD) can be reduced in areas subject to timber harvest. Attention is required to ensure the retention of these important habitat elements of forests. These elements, referred to as legacy elements, are important contributors to complexity, connectivity and heterogeneity at the local scale.

Over-mature trees with hollows provide nesting and roosting sites for a wide range of hollow dependent species. To retain a supply of hollow bearing trees, some mature trees beginning to senesce must also be retained to supply tree hollows when the current cohort of over-mature trees collapse. This creates a cycle with collapsed trees providing ground hollows, habitat for fauna and substrate for saproxylic communities and cryptogams. All are important in maintaining the species richness of the forest.

Trees used by black cockatoos to nest and those that bear usable hollows are often large marri with a senescent crown (Whitford *et al.* 2001). Retention of legacy elements can mitigate the impact on biodiversity of the application of silviculture, by supplying a continuity of mature habitat across the landscape and reducing the recovery time following harvesting for fauna and flora populations reliant on these elements. The fauna distribution information system (FDIS) is used prior to harvesting to identify the likely presence of species in the harvest area and may recommend additional management actions for some species. For example, FDIS recommends the retention of additional ground habitat where numbats are present. Recommendations from FDIS may require modifications to silviculture such as marking of additional legacy elements. Significant physical damage to retained elements could reduce hollow numbers or threaten tree survival. Conversely, some damage to the crown of potential habitat trees may increase the likelihood of trees developing hollows.

Strategies

15. Silvicultural treatments will have regard for requirements outlined in FDIS where the presence of species vulnerable to timber harvesting and/or silvicultural burning is identified.

16. During treemarking, select trees to retain which have a moderate to high probability of bearing hollows (Whitford et al. 2001). Aim to retain both individual trees and groups of trees.

17. During treemarking in areas of gap creation and shelterwood, select trees to retain, in addition to those referred to above, which have the potential to develop hollows in the future.

18. During treemarking, retain some large logs (non-sawlog) and logs with pipe or hollows suitable for habitat where they are available.

19. During treemarking, protect underground cavities suitable as fauna refuges, where they are identified.

20. During treemarking and preparation for harvest, give preference for habitat marking to trees that include signs of significant use by, or nests of, threatened fauna species, where these have been identified during pre-harvest checks or observed by the tree-marker or other staff on-site.

21. Where it is practicable, retain large (>70cm dbhob) marri with a senescing crown in addition to the existing requirement for habitat tree retention. In those LMUs in the jarrah forest where large marri are relatively low in abundance (Darkin Towering, Eastern Blackwood, Eastern Dissection, Eastern Murray, Monadnocks Uplands Valleys, North Eastern Dissection, Northern Sandy Depression, Northern Upper Plateau, North Western Dissection, North Western Jarrah and Redmond Siltstone Plain), retain all marri 50-70cm dbhob with a healthy crown (potential for good seed production) and marri > 70cm dbhob, where practicable.

22. During harvesting operations, retain some large standing dead trees if they provide habitat value and it is safe to do so.

23. In salvage operations following natural disturbance, retain patches of standing dead or damaged trees where they provide habitat value and it is considered safe to do so.

Guiding principle 4

Natural regeneration will be used wherever possible.

Rationale

Natural regeneration is the preferred method of regeneration in the jarrah forest. Silvicultural management encourages the production of seed crops *in situ* and promotes the growth of existing seedling, lignotuberous seedlings and ground coppice where they exist. Where natural regeneration is not possible or natural regeneration requires supplementation, endemic species are seeded or planted. Regeneration aims to restore the area to a self-sustaining ecosystem, with a similar species composition to that which existed prior to harvesting disturbance.

Traditionally, regeneration operations requiring the use of supplementary seed or seedlings have strived to use 'local' seed. Where knowledge of the population genetic structure of a species exists or can be reasonably inferred, this should guide seed collection areas. Recently, guidelines for seed collection for regeneration (and rehabilitation) have moved away from the requirement for only using 'local' material, as the scientific basis for this has been increasingly questioned, and additional considerations for optimal regeneration outcomes are now recognised. Factors considered to be important for any seed collection strategy include: matching topographic and edaphic features; allowing for expected changes in climatic conditions between seed collection sites and regeneration sites; and the need to use good quality seed with sufficient genetic variability to help enhance the resilience of regeneration (Millar *et al.* 2007).

Seed collected for regeneration is usually collected from the same LMU as the area to be regenerated. Flexibility is required to facilitate desired outcomes – for example where disease is present, or rainfall has declined, it may be appropriate to consider the use of disease, and/or drought, resistant varieties of those same species. In this case, the best source of seed or seedlings may be from another area. Alternatively, if disease or drought resistant varieties are unavailable or unknown, then using mixed seed sources to maximise genetic diversity might be an appropriate alternative strategy. This would provide a broader source of variation, allowing for greater potential to adapt to new perturbations such as disease or environmental change.

Strategies

24. Fire will be used to stimulate seed fall, encourage the germination of soil-stored seed and prepare a receptive seedbed.

25. Use natural regeneration where reasonable and practical. Where natural regeneration is not reasonable and practical, use only species endemic to the area being regenerated.

26. Where there is knowledge of population genetic structure or it can be reasonably inferred, use this to guide seed collection areas.

27. Where population genetic structure is unknown and cannot be inferred, use seed collected from the same LMU (or neighbouring LMU) as the area being regenerated.

28. Seed collection for rehabilitation should prioritise the matching of climatic, edaphic and other environmental variables from the seed collection with the area to be rehabilitated.

29. Seed collection for highly disturbed sites, or sites subject to pest, disease or changed climatic conditions, should target resistant phenotypes or genotypes were they exist. Alternatively choose from a wide genetic base to facilitate adaptation.

Guiding principle 5

Compositional diversity will be maintained in silviculturally managed forests.

Rationale

Jarrah forest occurs over a wide range of climate and soil types. It occurs in mixture with marri (*Corymbia calophylla*) throughout its range and with wandoo (*Eucalyptus wandoo*) and powderbark wandoo (*E. accedens*) on the drier eastern edge; with WA blackbutt (*E. patens*), WA flooded gum (*E. rudis*) and/or bullich (*E. megacarpa*) occupying moister sites; and with karri (*E. diversicolor*) and yellow tingle (*E. guilfoylei*) in the cooler southern forests. Where mixed stands have or still occur, regeneration to a single species is inappropriate, as it would lead to simplification of species composition and may impair forest ecosystem resilience.

Marri grows with jarrah throughout its range. Regeneration of marri is more prolific on podsolic soils and on the red earths compared to the lateritic soils. The proportion of marri is higher in southern jarrah forest compared to the northern forest on the Darling Plateau, and is related to the differences in soils and climate. Marri regenerates similarly to jarrah, but is able, under favourable conditions to develop from seedling to sapling with a less pronounced lignotuber stage. In many stands the proportion of marri in the regeneration pool is much higher than that present in the overstorey. After regeneration release, the proportion of marri generally declines as the stand develops. The higher sensitivity of marri to fire, in comparison with jarrah appears to be the factor which favours increasing jarrah composition with stand age.

Within the jarrah forest, understorey and second-storey composition displays far greater diversity than overstorey and varies more with landform and climate. The silvicultural methods developed for jarrah forest favour the use of natural regeneration. To facilitate regeneration of overstorey species, a reduction in competition from second-storey species is sometimes required. Achieving the necessary level of reduction in competition should be balanced with the need to retain diversity in second-storey vegetation.

Second-storey trees and shrubs contribute to food resources and habitat for fauna and contribute to structural complexity. The silvicultural methods developed for jarrah often involve mechanical disturbance to vegetation and soil to reduce competition with jarrah advance growth, or to enable jarrah seedlings to establish. These disturbances can have short term impacts on understorey and second-storey species richness and abundance. Avoiding unnecessary mechanical disturbance to the soil helps to ensure a balance between achieving regeneration of the overstorey and the impact on other vegetation.

Where pure thickets of second-storey species occur (e.g. Balga, *Banksia* spp., *Gastrolobium* spp) they are an important part of floral diversity, habitat and food resource (e.g. nectivorous birds and mammals) and should be retained. When it comes to avoiding harvesting disturbance during silvicultural treatment, the more important second-storey species are those that are slow growing, long-lived and rely on capsule-stored seed for regeneration e.g. *Hakea ssp*, *Persoonia elliptica*, *P. longifolia*, and some sheoak species. Second-storey species that regenerate prolifically from soil-stored seed following soil disturbance or fire will be more easily replaced.

Appropriate fire regimes in jarrah will benefit regeneration and favour the development of a diverse stand composition. Thinning may also favour understorey and second-storey development by reducing competition for moisture and light from the highly competitive overstorey.

Where artificial regeneration methods such as planting or seeding are used, it is important to ensure that all components of the stand composition are represented in the regenerating stand.

Strategies

30. During treemarking, mark for retention some large individuals, groups or thickets of balga and second-storey species that are slow growing, long-lived and rely on capsule-stored seed for regeneration.

31. In regeneration operations, reflect the composition of the previous stand and consider the relative competitive ability of each species in the regeneration species mix.

32. During burn planning, consider the importance of fire regimes to regeneration, forest health and diversity.

33. During treemarking, apply thinning to over-stocked jarrah stands to allow understorey development.

34. When applying silvicultural treatments, aim for overstorey species composition in similar proportions as the original stand.

35. During post-harvest silvicultural treatment, soil treatments to reduce rootstock competition to establish overstorey regeneration, will target no more than 50 per cent of the harvested area, to ensure re-sprouting species are maintained as part of the

flora composition of the stand.

4. Guiding principles for ecosystem health and vitality

Overall objective

Use silvicultural treatment to mitigate the impacts of abiotic, biotic and anthropogenic stressors on the health and vitality of the forest.

Threats to the health and vitality of the forest will be identified and prioritised. Where possible, threats or damage from stressors will be avoided or mitigated through silvicultural treatment.

Guiding principle 6

Promote resilient stands on sites with high levels of overstorey mortality or stress through silvicultural management.

Rationale

Climate change has the potential to impact on forest health. Competition for water may lead to drought related deaths of trees and other vegetation, particularly on upper slopes, shallower soils and others with low water holding capacity. The predicted increased incidence of extreme weather events may also lead to an increase in tree deaths from bushfire, storm and frost. Disease and insect attack may also have detrimental impacts on forest health. Water stress may predispose trees to insect attack and compromise their ability to recover from damage. Thinning stands subject to water stress increases the resources available to the retained trees and associated vegetation. This can improve health and vigour and may reduce the potential risk of drought related deaths, and reduce vulnerability to pest insect and disease attack (Barry *et al.* 2011). Should 'Myrtle rust' enter Western Australia, both the increased vigour of trees due to thinning and the effect that a more open canopy has on relative humidity may reduce the incidence or intensity of infections.

Within any population there are individuals that display resistance or resilience to stressors. Silvicultural treatments should identify and retain these individuals to improve representation of resistant genes in the overall population.

Strategies

36. Individual trees or groups of trees that exhibit resistance to disease (*Quambalaria spp*, *Phytophthora spp*. etc.) or the effects of pest insect outbreaks (such as Jarrah Leaf Miner or Gumleaf Skeletoniser and borers) should be marked and protected from damage during timber harvesting operations.

37. Select seed trees to retain in shelterwood treatments based on their form and vigour, together with their capacity to provide a crop of seed.

38. Reduce stand density in stands subject to water stress to assist with adaption to a drier climate.

39. Adaptive management trials to investigate the rehabilitation of sites with significant tree deaths may be approved by the Manager, Ecosystem Health.

40. Establish adaptive management trials to investigate the effect of silvicultural treatments on the effects of frost damage to determine the most appropriate management on identified frost prone sites.

Guiding principle 7

Promote resilient stands through the management of *Phytophthora* dieback.

Rationale

Phytophthora spp. are recognised as important plant pathogens. Historically, *Phytophthora cinnamomi* has been the focus of disease prevention in the jarrah forest. Recently a number of other *Phytophthora* species have been identified in Western Australia, so reference is now made to *Phytophthora* dieback.

Timber harvesting that removes a proportion of the overstorey trees reduces site water demand and may lead to increased availability of soil water. It is hypothesised that this change in water availability, coupled with higher soil temperatures from reduced canopy cover, may increase *Phytophthora spp.* lesion growth in infected trees. *Phytophthora* dieback impacts on the forest vegetation differently depending on a number of factors, including the abundance and distribution of susceptible plant species, soil characteristics, drainage and climate. These factors can be used to predict the likely impact of the pathogen in different vegetation types should it become established. The predictions of impact are classified as either low, moderate or high. Low impact sites are those where few susceptible species are present and if the pathogen was introduced, it would be evident as a few scattered deaths in the understorey and second-storey. Moderate impact sites are those where deaths are predicted in most susceptible understorey and second-storey species and up to ten per cent of the overstorey. High impact sites are those with a major component of susceptible species, where deaths are predicted to occur in most susceptible understorey and second-storey and more than ten per cent of the overstorey trees. Very high impact sites are those with a major component of susceptible species, most of which have been killed by *Phytophthora* dieback and greater than 50 per cent of the overstorey trees are dead.

It is thought that less intensive harvesting disturbance on potential high impact sites may reduce the likelihood of generating conditions favourable to the activity of the pathogen and contribute to resilience. However reductions in rainfall since the 1970’s has led to declining soil moisture and groundwater levels, and both the observed rate of spread and decline due to infection from *Phytophthora* have reduced in many areas.

On sites where the current impact of the pathogen is very high, the ability of the site to recover from harvesting disturbance may be lower than in healthier areas of forest. Harvesting disturbance in these areas needs to be carefully planned and should be directed to ensuring that the site is rehabilitated with resistant species or genotypes.

Strategies

41. During harvest planning, exclude very high impact sites from machine entry.

42. On sites expressing high disease impact, manage access for harvesting and extraction patterns to promote resilience and assist site recovery by protecting regeneration, and individuals and species demonstrating field resistance to Phytophthora dieback.

43. During treemarking, the preference for selecting trees to retain in high disease impact on un-protectable forest areas, will be for healthy trees, tree species that are not susceptible to Phytophthora dieback, or individual trees that appear to be resistant to Phytophthora dieback.

44. Do not cull trees where the impact of dieback is predicted to be high.

45. Where possible, encourage and protect natural regeneration on high impact disease sites and/or incorporate dieback-resistant jarrah in regeneration.

46. Establish adaptive management trials to determine the effect of harvesting disturbance on, and most appropriate management of high impact sites.

Guiding principle 8

Prescribed fire will be used to protect fire sensitive regeneration and reduce high fuel loads that may result from silvicultural practices.

Rationale

The quantity of combustible material on the forest floor after timber harvesting and silvicultural treatments is, for a period above the range normally experienced through natural leaf litter and woody debris accumulation in a comparable stand. Timber harvesting removes tree boles in the form of logs; however the tree crowns, retained coarse woody debris and un-saleable material remain on the forest floor. The increased fuel load may increase the potential risk and intensity of unplanned fire, which may be detrimental to biological diversity and other values.

Silvicultural practice in the jarrah forest involves fire exclusion and protection of developmental stages which are fire sensitive. The period of fire sensitivity for regenerating jarrah is variable and depends on the intensity of the fire. Fire during early regeneration stages may kill jarrah. Fires may kill above ground shoots, but unless the fire is very intense the lignotuberous seedlings, seedling coppice and ground coppice will, re-sprout and continue to develop. However growth achieved prior to the burn will be lost and/or tree form may be affected. Fire is best excluded until the bark thickness of saplings is sufficient to withstand mild fire and the leading shoot tall enough to escape fire damage. Prescribed fire can be applied in forest adjacent to areas of regeneration to reduce the potential risk of bushfire during the fire sensitive development stages.

For a low intensity burn, the regeneration should have reached the sapling stage and be at least 15 cm in diameter. This typically equates to a fire exclusion period of between 10 and 20 years, after which time at least 125 stems per hectare have developed sufficient height and bark thickness to tolerate fire. At the conclusion of this period, fuel loads are usually high and the canopy height is low, resulting in an increased potential for high intensity fire.

In managing prescribed fire, the primary objective is reducing potential for bushfire, after which consideration is given to biodiversity conservation, forest silviculture, research and any other land management objectives. Prescribed burning objectives for silviculture include promoting regeneration, protecting growing stock, maintaining biodiversity values, nutrient cycling and achieving a mosaic of burnt and unburnt patches.

Strategies

47. During burn planning, include an assessment of the stocking of saplings that will withstand mild fire and/or the significance and sensitivity of regeneration where multiple objectives exist. This assessment will include assessment of sapling height and diameter to gauge their fire sensitivity.

48. During burn planning, if there is a low risk of escape, aim to reduce fuel loads in areas adjacent to fire sensitive regeneration in order to reduce the likelihood of bushfire during the fire sensitive period.

49. After harvesting operations, apply prescribed fire to reduce fuel loads.

50. After the initial fuel reduction burn, prescribed low intensity fire will be used in jarrah stands as soon as possible after the fire sensitive period for regeneration has passed.

51. During treemarking, ensure the marking of habitat trees for retention considers burn security and where practicable, avoid marking habitat trees near the burn boundary.

52. Silviculture burns will provide for a mosaic of burnt and unburnt patches.

Guiding principle 9

Silvicultural management will maintain forest nutrient cycling processes.

Rationale

The soils of the jarrah forest are generally infertile and growth of the forest is often limited by nutrients. Nutrient cycling within the forest conserves and recycles nutrients and prevents their loss from the system. Nutrient release from the breakdown of leaf litter occurs at a slow rate. Fire plays a positive role in nutrient cycling, although some nutrient (mainly nitrogen) is lost to the atmosphere by the burning of litter and understorey. However, fire releases organically-bound nutrients in the litter into available inorganic form and promotes the regeneration of nitrogen fixing understorey, which not only fix nitrogen from the atmosphere but also increase the rate of decomposition and mineralisation of the litter.

High intensity fires affecting large areas of the forest expose bare soil and can result in losses of nutrient from the forest system due to wind and water erosion of the nutrient rich surface soil. Prescribed burning can be used to reduce the likelihood of high intensity fires and so the risk of soil erosion.

The removal of nutrients in sawlogs constitutes only minor losses to the system, relative to the stores of readily extractable nutrients in the soil. However, excessive removal of biomass from forest stands has the potential to impact on soil organic matter levels and may impact nutrient cycling. Proposals that include the removal of fine branch and leaf material have greater potential to impact on soil nutrient and organic matter levels than those only removing larger woody material.

Strategies

53. Avoid excessive removal of leaf and fine branch material from forest harvesting

operations.

54. During burn planning, aim to manage fire regimes to minimise the extent of intense bushfires, which can result in large losses of nutrients from the ecosystem and accelerated soil erosion.

55. Minimise the potential of soil erosion by limiting soil disturbance during harvesting.

56. After harvesting, where possible or practicable, silvicultural burns should be planned to allow sufficient time for leaching of nutrients from the leaf litter produced by the harvest.

Guiding principle 10
Promote ecosystem health and vitality through silvicultural management.

Rationale

This guiding principle is also referred to as 'silviculture for ecosystem health'.

A key finding of the *Review of Silviculture in Forests of South-west Western Australia* (Burrows *et al.* 2011) was the opportunity that silviculture provides to assist forests to adapt to climate change. In summary, the report found that "*declining rainfall has significantly impacted water availability in the FMP area and predicted future climate change is likely to lead to further impacts. Further declines in streamflow and impacts on aquatic environments are likely. The impact of climate change needs to be closely, monitored with adaptive management strategies*." The purpose of 'silviculture for ecosystem health' is to enhance ecosystem health and function, and biodiversity, through enhanced water availability. Enhanced water availability is achieved by reducing the density of vegetation in the stand (and thus lowering transpiration demand).

Changes to groundwater and flow days may result in gradual changes to the health and distribution of ecosystems. More immediate, but localised effects may occur as a result of extreme weather events such as storms and heatwaves, with higher maximum temperatures, more hot days and more intense precipitation events considered very likely as a result of climate change (Arthrington *et al.* 2003).

Mitigating the effects of reduced rainfall and higher temperatures on the forest and associated communities will require adaptive action to help to align density and structure of the forest with current and future climate. Targeted action may protect susceptible ecosystems, retain water availability in some parts of the forest, improve the health of forest and associated ecosystems, reduce susceptibility to high intensity fire and allow for the persistence of ground and surface water dependent ecosystems.

A reduction in stand density reduces competition for water and has positive effects on vegetation health and vitality, increasing resilience to pest and diseases. A sufficient reduction in stand density increases the amount of water moving through the soil profile to groundwater and into streams. 'Silviculture for ecosystem health' aims to reduce the impact of declining rainfall on the forest and associated ecosystems. Declines in ecosystem health are associated with:

- loss of free water in the environment
- potential impact on forest health associated with water stress
- reduction in site carrying capacity

- loss of or reduction in riparian and aquatic ecosystems
- increased frequency and intensity of bushfire.

The strategies associated with this principle incorporate a number of management tools able to reduce inter-tree competition, move forests to a more appropriate carrying capacity, slow the loss of and/or maintain current riparian ecosystems and reduce fire intensity.

Areas that could be targeted for treatment are:

- areas with a high stand density that are subject to damage by insects or disease (except dieback) and where a reduction in stand density is likely to promote recovery from and/or reduce susceptibility to damage by insects or disease.
- catchments where a reduction in stand density is likely to maintain groundwater levels and streamflow so that these catchments can act as refuges from the hydrologic impacts of climate change.
- granite outcrops from the impacts of high intensity bushfire through stand density management and prescribed burning of surrounding areas.

Strategies

57. Identify ecological values or communities where the effects of climate change will escalate the threat to the value or community.

58. Prioritise ecological values or communities in relation to the potential risk associated with the:
    - likelihood and degree to which soil moisture, ground and surface water availability will decline in the areas in which the value or community occurs.
    - likely impact on the value or community of declining soil moisture, ground and surface water availability.
    - feasibility of conducting silvicultural treatment to reduce the potential for soil moisture, ground and surface water decline.
    - potential impact on other values of conducting silvicultural treatment to arrest soil moisture, ground and stream water decline.

59. Consider relevant species management plans, species recovery plans or catchment management plans to guide the application of 'silviculture for ecosystem health' treatments, depending on the value being addressed and the scale of the work proposed.

60. Introduce or modify burn plans to improve the health of and/or reduce the threat to identified values or communities.

The following strategies are existing practices, or modifications to existing practices, which may be used to enhance water availability.

61. Use an adaptive management approach to residual stand density to:
    - arrest or improve groundwater and/or streamflow to threatened communities or ecosystems
    - improve the health and vigour of second-storey and overstorey
    - reduce water use by reducing basal area (and consequently leaf area)
    - allow retained trees to develop to maturity at which time they are less water

demanding per unit of leaf area

- promote the recovery of trees following severe damage from disease or insect attack.

5. Guiding principles for soil and water

Overall objective

Protect soil and water resources in order to sustain the foundation for diverse, productive and healthy forest ecosystems, and to provide water for consumptive uses.

The effect of forest cover on soils and water quality is positive. By regenerating forests after harvesting, soils are stabilised, water and wind erosion is prevented and nutrient cycles are maintained. Water quality is maintained and water flow moderated. Harvesting disturbance, particularly roading, can be detrimental to soil and water values. Management controls on these operations should limit potential harm.

Guiding principle 11

The extent and severity of harvesting disturbance on soil values will be minimised and damaged soil remediated.

Rationale

Maintaining soil values is one of the most important elements of sustainability since soil health underpins the health of the ecosystem. Potential risks to soil health associated with harvest disturbance activities include:

- changes to soil structure; and
- loss of topsoil (soil erosion).

Soil structure can be adversely affected by soil compaction during timber harvesting and forest management activities, and by the mixing of soil profiles particularly when the soil is moist. These types of damage can reduce seed germination, seedling survival and plant growth. Profile mixing or topsoil removal cannot be remediated. The effects of compaction and mixing of soil profiles are controlled by restricting machine activity during moist soil conditions (Rab *et al.* 2005; Whitford *et al.* 2012). Compaction can be alleviated by shallow ripping or scarification for surface compaction, and deep ripping for compaction of the lower horizons.

The success of shelterwood operations is dependent on having a receptive seedbed to facilitate germination of seedlings, and some soil disturbance contributes to a receptive seedbed. However, soil damage not rehabilitated after timber harvesting can reduce seedbed quality and reduce regeneration. Soil treatments such as scarification and/or ripping with a machine can be used to rehabilitate damaged soils and improve the area of receptive seedbed available for regeneration. However, remediation works need to occur under the correct soil conditions to be effective. For example, ripping to alleviate compaction is of no value unless the soil moisture levels are such that ripping shatters compacted soils and may be detrimental if carried out under moist soil conditions.

Pushing of cull trees can result in soil disturbance where clay is brought to the surface with the root ball of the tree. Where there are a significant number of cull trees to be removed, this method can result in an unacceptable level of soil disturbance and should be avoided.

High intensity bushfire can lead to a loss of nutrients from the system, particularly in erosion events. Prescribed burning should seek to prevent high intensity bushfire.

Salvage harvesting operations after bushfire disturbance may require the use of erosion control structures.

Strategies

62. Timber harvesting activities will be managed in accordance with the *Soil and Water Conservation Guidelines*, SFM Series Guideline No 5, (Department of Environment and Conservation 2009c).

63. During harvesting operations, use a combination of harvest timing, extraction pattern design and surface water management structures (Department of Environment and Conservation 2009b) to limit erosion and compaction.

64. During post-harvest silvicultural treatments, cull removal will be conducted by felling or notching rather than pushing, to limit soil disturbance.

65. When reducing rootstock competition to assist establishment of overstorey regeneration in shelterwood operations, limit soil treatments to a maximum of 50 per cent of the harvested area.

66. After harvesting is complete, carry out timely remediation of compacted soils, landings, roads and tracks, to allow seed-fall onto a receptive seedbed or to facilitate planting.

67. During burn planning, aim to ensure burn cycles support nutrient cycling within the forest and prevent high intensity bushfire.

68. During salvage operations post-fire, incorporate erosion control structures.

Guiding principle 12

Water quality will not decline as a result of silvicultural treatment.

Rationale

Historically the main potential risk to water quality has been from groundwater rise dissolving and transporting salt stored in the unsaturated zone of the soil profile. The potential of silvicultural treatment of forested areas leading to a rise in groundwater was limited through phased harvesting requirements in salt sensitivity areas. As a result of reduced rainfall and declining groundwater levels over recent decades, salt sensitivity has been revised in the Departments Swan and South West regions and parts of the Warren region. Accordingly, the measures introduced for the protection of water quality under the previous hydrological regime (mainly higher groundwater levels), are now considered less relevant. Phased harvesting requirements are no longer required in these areas. The phased harvesting requirement for the moderate salt sensitivity part of the Warren Region will be retained as groundwater levels have not fallen to the same extent in this area (see Appendix 2). In addition the planning process for timber harvesting is to ensure that in partially cleared catchments categorised by the Department of Agriculture and Food (DAFWA) as having a high salinity risk there is consideration of the need for modified harvesting requirements. Groundwater monitoring will continue in current and historical salt risk areas in order that management of these areas can change should there be a return to a wetter climate.

All operations conducted during silvicultural treatment must be in accordance with *Soil and Water Conservation Guideline* SFM Series, Guideline No 5 (Department of Environment and Conservation 2009c) which guides all aspects of operations associated with silvicultural treatments to avoid or minimise potential effects on water quality.

A number of measures are implemented to control potential impacts on water quality from silvicultural treatments and the operations that accompany them. River and stream zones are excluded from harvesting disturbance as specified in *Guidelines for protection of the values of Informal Reserves and Fauna Habitat Zones* SFM Series, Guideline No 4 (Department of Environment and Conservation 2009a). The width of stream zones is dependent upon the stream order and ranges from 60 m for stream order 1-3 up to 400m for stream orders 5 and greater. River and stream zones provide protection from erosion and sedimentation. Additional guidelines around river and stream zones can be found in *Guidelines for protection of the values of Informal Reserves and Fauna Habitat Zones* SFM Series, Guideline No 4 (Department of Environment and Conservation 2009a).

Water quality can also be affected by contamination from chemicals (e.g. herbicides and fuel oils) if they are used incorrectly or spilled in the catchment.

Strategies

69. When planning silvicultural treatments, protect water quality from salinity in second order catchments *identified as having a high salt risk* (see Appendix 3), through increased stream reserve widths, and phased harvesting of the area available to be harvested, which includes i), retaining an unharvested area adjacent the watercourse, equal in area to 30 per cent of the upslope area available to be harvested, and ii), a minimum harvesting interval of 15 years.

70. When planning silvicultural treatments, protect water quality from salinity in second order catchments *in the moderate salt sensitivity zone* (see Appendix 2), through phased harvesting of the area available to be harvested, which includes i), retaining areas unharvested or at a basal area no less than 15m^2/ha, equal in area to 30 per cent of the area of the second order catchment, and ii), a minimum harvesting interval of 15 years.

71. During silvicultural treatments, all operations must be in accordance with *Soil and Water Conservation Guideline* SFM Series, Guideline No 5 (Department of Environment and Conservation 2009c).

72. Prior to silvicultural treatment, river and stream informal reserves must be demarcated and subsequently protected as specified *in Guidelines for the Protection of the Values of Informal Reserves and Fauna Habitat Zones* SFM Series, Guideline No 4 (Department of Environment and Conservation 2009a).

73. For the period of the FMP, continue ground water level monitoring in areas previously considered to be of low and moderate risk of salinity in order that management of these areas can adapt should there be a return to a wetter climate.

74. If using chemicals during silvicultural treatments, use good practices as guided by regulations and the *Code of Practice for the use of agricultural and veterinary chemicals in Western Australia* (Department of Agriculture and Food Western Australia 2007).

75. If using herbicides in water catchment areas, use must also be in accordance with

the *Use of Herbicides in Water Catchment Areas* (Department of Health 2007).

76. Pesticides will only be used where there is, in the view of the Department, no practicable alternative.

Guiding principle 13

Silvicultural treatment of native forest may be used to maintain or enhance the flow of water to surface and ground water reserves.

Rationale

This guiding principle is also referred to as 'silviculture for water production'.

The use of silvicultural treatments to increase the flow of water to surface and groundwater reservoirs was foreshadowed in the FMP 2004-2013. Furthermore, the *Soil and Water Conservation Guideline* (Department of Environment and Conservation 2009c) includes a guiding principle that silvicultural treatments and fire regimes may be used to enhance the quantity of water for surface and groundwater reservoirs. While the primary driver may be the maintenance of or increase in water yield, any treatments will first provide an increase in the availability of water to the environment, with benefits for ecosystem health and vitality.

Declines in streamflow have been significantly greater than declines in rainfall in south-western Western Australia. It is thought that prolonged reductions in rainfall have caused groundwater to disconnect from surface water, resulting in significant declines in streamflow (Hughes *et al.* 2012; Kinal *et al.* 2012). The implication is that where disconnection has occurred, the capacity to generate streamflow is greatly reduced. Where disconnection has occurred, groundwater would need to be recharged to the point of connection again before significant improvements in streamflow would be realised. The greater the delay in responding to declining groundwater levels, the less likely it will be that streamflow can be improved in the short term. Hydrologic process modelling (Croton *et al.* 2001a; Croton *et al.* 2001b) calibrated with the measured flow and rainfall data obtained from the gauging network, provides a sound understanding of the changing water balance in the northern jarrah forest.

The use of silviculture to manage water yield in forested catchments ('silviculture for water production') has been developed from research undertaken locally (Ritson *et al.* 1981; Stoneman 1986; Marshal *et al.* 1992; Stoneman *et al.* 1996; Bari *et al.* 2003; CSIRO 2009), nationally (Vertessy 1998; Erskine 2004; Feikema *et al.* 2006) and internationally (Douglas, 1983; Stednick 1996; Calder 1998; Kaye *et al.* 1999; Brown *et al.* 2004). There is potential to apply 'silviculture for water production' to increase water for consumption or irrigation purposes.

There are some general rules around forest management and water yield. Partially (thinning) or completely removing (gap creation) trees from an area will reduce interception of rainfall allowing additional infiltration and reducing transpiration, resulting in increased soil moisture and in some cases, a rise in groundwater and streamflow. However, the increases from a single treatment are transient and water yields can quickly decline to pre-treatment levels as the remaining trees and/or regeneration from stump and ground coppice grow. Unthinned even-aged stands of juvenile and immature regrowth have been demonstrated to use more water than more mature forest development stages. Within a catchment, controlling the amount of younger growth stages may be an option to manage water availability.

A series of 27 small catchment studies conducted in south-west Western Australia during the 1980s and 1990s examined the effects of a range of vegetation removal activities on water yield (Bari *et al.* 2003). Permanently clearing vegetation for agriculture resulted in sustained water yield increases of 20 to 30 per cent, depending on average rainfall, with a greater increase in higher rainfall areas. Forest thinning of high rainfall catchments increased water yield by a maximum of 8 to 18 per cent. The increase was dependent upon the characteristics of the catchment and the amount of vegetation removed. However, the increases from thinning were not permanent and water yields returned to pre-thinning levels after 12-15 years. Control of regeneration and stump coppice development has been shown to prolong the increase in water yield for up to 25 years ((Stoneman 1993); Kinal pers. comm.).

Thinning of both overstorey and second-storey species may decrease the structural complexity of the forest within the catchment. To achieve both increased streamflow and groundwater levels and have the least impact on structural complexity, the most intense thinning should be targeted in the areas of the catchment where rainfall can feed most directly into groundwater. The most beneficial areas to target can be determined by hydrological modelling, groundwater measurements, digital elevation models and professional advice. The beneficial areas will usually be found in the lower to mid-slope areas.

Areas lower in the landscape are frequently affected by dieback. When applying ‘silviculture for water production’ there may be a need to assess the potential impacts of further disturbing a disease-affected site against the potential detrimental effects associated with declining water availability. Where water production values are high or the disease impact is already high, measures to maintain a lower stand density to improve water yield may be considered acceptable.

In areas where ‘silviculture for water production’ is intended to be applied the proponent will first develop a catchment management plan. A catchment management plan is a strategic level plan that sets out the extent, intensity, sequencing and return cycle of operations, as well as identifying and managing the potential risks associated with applying ‘silviculture for water production’, along with the potential risks to environmental and social values of not addressing declines in water availability.

Strategies

77. Develop a catchment management plan to detail the treatments to be applied, the scale of treatment and the controls for potential risks to the environment. These catchment management plans are required where the proposed silvicultural treatments are outside of parameters provided for in the Department’s silviculture guidance, or where it is considered by the Department that an excessive proportion of the forest in the catchment may be left in the juvenile and immature stages of development as a result of a proposal.

78. When planning silvicultural treatment of native forest, or native forest areas subject to mining activities, consider the existing and likely future mosaic of development stages, particularly the higher water demanding juvenile and immature stages.

79. When planning silvicultural treatment to enhance water availability in areas of native forest within the envelope affected by mining activities, consider the existing and

likely future mosaic of development stages for both the native forest and mine rehabilitation.

80. Identify the areas of the catchment in which ‘silviculture for water production’ will have the most impact on water yield and target these areas for treatment.

81. Thin young stands (< 70 years old) to reduce water use and to accelerate their development into mature (and more water use efficient) stands.

82. Thin the catchment area to reduce transpiration and interception while taking care to retain enough canopy cover that large scale regeneration is discouraged.

83. Treat coppice and regeneration on an approximate return cycle of five to ten years, following silvicultural treatment, to retain gains in water availability.

84. Use prescribed burning and control coppice development, where practical, to limit understorey and second-storey development (and so leaf area).

85. Use prescribed burning to prevent the probability that stand-replacing fires will convert large areas of the forest to early development stages.

6. Guiding principles for climate change and carbon cycles

Overall objective

Within the constraints of a changing climate and the achievement of other goals of management, seek to adapt forest management to climate change and sustain the contribution of the forest to global carbon cycles.

Native forests contribute to climate change mitigation through storage of carbon in forests. Storage of carbon in forest products harvested from sustainably managed forests and use of those forest products can further contribute to mitigation of climate change.

Silvicultural management of the forest to retain its productive capacity in the face of climate change requires addressing potential damaging agents such as weeds, pests and diseases, protecting forest soils and adapting silviculture to address changes in water availability. These issues are addressed in Guiding principles for ecosystem health and vitality and Guiding principles for soil and water.

Guiding principle 14

Forests will be managed to maintain forest carbon stocks, provide forest products and contribute to the mitigation of climate change.

Rationale

Forests and forest products have an important role in global carbon cycles, predominantly as sinks. Carbon stocks in forests include biomass (litter, woody debris, stumps, roots, dry standing stems) and soil carbon pools.

Forest products are also part of global carbon cycles. Forest products may reduce carbon emissions if they displace the use of materials which are more carbon-intensive to produce, such as the use of timber rather than steel, concrete or aluminium in construction, or the use of non-sawlog material to replace fossil fuels to produce energy. Forest products store carbon, although the storage time of carbon in forest products varies, and is greatest in products that have a long 'in-service' or 'end-use' life.

Natural disturbances affect the carbon cycle and these disturbances are a major cause of carbon fluxes in forests. Bushfire and damage from insects, diseases and storms may play a large role in the carbon cycling in forests. The aim of forest management practices is to ensure that forests continue to be carbon sinks, sequestering at least as much carbon as they emit at the whole of forest scale. The potential for well managed forests to contribute to climate change mitigation is acknowledged by the Intergovernmental Panel on Climate Change, which states: *In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stock, while producing an annual sustained yield or timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit* (Nabuurs *et al.* 2007).

The cumulative impact of practices implemented at a stand scale contributes to both the rate of accumulation of carbon in forests and the quantity of carbon emitted. In native forests subject to harvest and subsequent regeneration, the impact of practices implemented at a stand scale are related to:

- *Quantity and timing of timber harvests*: the extent to which carbon stocks are modified at a point in time through harvesting practices is related to the proportion of area harvested, proportion of trees removed and the harvest interval. Effective regeneration and replanting mean that the area of forest available to store carbon is not reduced, and subsequent regeneration restores site carbon stores over time.

- *Low-impact practices*: reducing the harvesting disturbance of soil and remaining vegetation will help conserve soil carbon and the productive capacity and sequestration potential of the site. Soil carbon is mostly held in organic matter and measures to protect soils from disturbance are covered in the guiding principles for soil and water (Guiding principle 11, Guiding principle 12 and Guiding principle 13). However in terms of carbon stocks, as noted Australia's 'State of the Forests Report 2008' (Montreal Process Implementation Group for Australia 2008), in native forests subject to cycles of harvest and subsequent regeneration, change in soil carbon is believed to be insignificant since emissions caused by disturbance of soils during harvesting: are balanced in a given inventory period by re-accumulation through tree growth. This reasoning is also used in accounting rules set out by the United Nations Framework Convention on Climate Change.

Strategies

86. Protect forest soils during harvesting operations by following the *Soil and Water Conservation Guideline* SFM Series, Guideline No 5 (Department of Environment and Conservation 2009c).

87. Use silvicultural treatments to encourage the sustainable production of forest products with a long service life, and those that replace fossil fuels and high-embodied energy alternatives.

88. Ensure effective regeneration and where practicable, carry out rehabilitation of the forest, to maintain productive capacity, maintain the forest area and sustain the pool of carbon stored in the forest.

89. In post-harvest silvicultural treatments, limit culling of trees to a level required to maintain a healthy and productive forest that is actively sequestering carbon.

90. Aim for timely completion of all silvicultural burns, which will also help reduce the potential for and frequency of large-scale, high-intensity bushfires.

7. Guiding principles for productive capacity

Overall objective

Silvicultural management will be used to support the capacity of the forest to sustain a supply of goods and services in the long run.

Maintenance of productive capacity provides for the sustainability of the flow of some of the benefits from forests to society. Productive capacity includes both wood and non-wood resources. Maintaining productive capacity of forests available for timber harvesting involves maintaining the area of State forest and timber reserves and the area within State forest and timber reserves where harvest is permitted, and providing for harvesting on a sustained yield basis.

Guiding principle 15

The most appropriate silvicultural method will be applied to each stand to support short and long term productivity.

Rationale

Jarrah forest is essentially uneven-aged, with relatively small patch sizes, so jarrah forest silviculture aims to apply a grouped forest structure. A grouped forest structure applies even aged silviculture at the patch scale, while maintaining a heterogeneous forest structure at the local scale. A systematic process is used to guide decisions as to which silvicultural method to apply. Study and observation enabled the development of jarrah forest silvicultural methods, based on how the forest regenerates after natural disturbance and how the trees grow and interact with each other and their surroundings. Jarrah, like most eucalypts is intolerant of competition for light nutrients and water. Single tree selection has been used in the past, but the gaps created were not large enough to facilitate regeneration and the harvested trees damaged the retained trees during the harvest process. Jarrah silviculture aims to apply a silvicultural method at a scale large enough to allow for the ongoing regeneration and growth of the forest, but not so large as to create an even aged forest at the local scale.

Groups are chosen based on the natural structure of the forest and treated according to their development stage and regeneration status. Natural group size may be modified by silvicultural treatment if the natural or historical groups are too large or small to adequately retain heterogeneity or facilitate regeneration. There are three key silvicultural methods which can be applied to groups; being thinning, gap and shelterwood. The exception is in high impact dieback forest where a selective cut is applied.

Areas of high impact will be mapped prior to treemarking. All areas mapped as high impact dieback are treemarked according to the dieback selective cut. Outside of these areas, the first silvicultural objective to consider applying to a stand is thinning. Thinning can be applied to juvenile or immature stands and may be applied to vigorous mature stands. When stands are well into the mature stage, consideration is given to cutting to gap or applying a shelterwood.

Where thinning is not appropriate, application of the correct silvicultural method is dependent upon the identification of regeneration status. Gaps are applied to mature stands where there is sufficient advance growth present to develop into a fully stocked regrowth stand. Where insufficient advance growth is present, shelterwood is applied to assist its establishment. Incorrect application of either the gap or shelterwood method has implications for sustained yield. If the shelterwood method is applied in an area with sufficient regeneration, then twenty to thirty years of potential growth is lost, as the existing regeneration could have (instead) been released. If the gap method is applied where there is insufficient regeneration, the area will be poorly stocked and less productive than it could be.

Shelterwood stands are burnt after harvesting to promote seed-fall, to develop a receptive seed-bed for seedling establishment, and to stimulate the growth of lignotuberous seedlings. A substantial crop of seed in the tree crowns is required for successful establishment of regeneration in shelterwood. Estimates of seed crops are best carried out once capsules have begun to form. Seed forecasting is important in informing the decision about the timing silvicultural burns to optimise the potential of the seed crop to establish regeneration. Burning too early or too late can delay the production of regeneration and as seed crops are only formed every few years, delay regeneration development.

Strategies

91. For harvest planning, maintain maps of forest structure and use pre-harvest regeneration surveys to assist in the selection of the most appropriate silvicultural method and group size.

92. Prior to treemarking, carry out an advance burn where practicable to facilitate the identification of regeneration.

93. During treemarking, aim for a grouped forest structure.

94. During treemarking, be aware of high impact dieback areas and apply a ‘single tree selection in dieback’ to these areas.

95. During treemarking for regeneration establishment operations in shelterwood areas, ensure vigorous trees, of good form with mature characteristics (dbhob>50cm) and sufficiently spreading crowns to provide seed are selected for retention.

96. Areas planned for a regeneration establishment burn should have a formal capsule and seed crop survey completed, to ensure that an adequate seed crop is available, prior to the burn being undertaken.

Guiding principle 16

Regeneration and tree growth will be enhanced through actions to alleviate competition on regeneration and selected trees.

Rationale

Competition for water, nutrients and light impacts on the survival and growth of all development stages of the forest and the quantity of forest products that can be produced. Silvicultural methods for the jarrah forest have been developed to alleviate competition at various development stages, to maximise tree vigour and sawlog production.

To establish regeneration using the shelterwood method, stand density and sometimes second-storey density is reduced to increase the chance of seedling survival, particularly in the first summer. Seedlings that develop under a canopy become part of the pool of lignotuberous advance growth and do not proceed through later development stages until a gap is formed in the canopy, either from death or decline, or by removal of the trees during silvicultural treatment and/or harvesting. Release of regeneration by cutting a gap in the overstorey should not be carried out until a sufficient number of ground coppice or later advance growth forms of regeneration are present. Because of competition effects, the size of the gap must be sufficiently large to allow regeneration to progress to maturity.

Silvicultural thinning reduces stand density, and aims to keep trees actively growing and prevent severe competition, or stagnation in growth. The juvenile stand experiences significant competition from the time of crown closure, at about eight years after release, and this continues throughout the life of the stand. When the stand experiences severe competition, growth rates decline and many trees cease to grow, some die. This natural thinning process occurs at a slow rate. Silvicultural thinning hastens the natural thinning process to improve growth of the retained trees and reduces the time taken for retained trees to reach maturity and sawlog size. Variable density thinning may be used in uneven-aged stands, to ensure that each tree has sufficient space to develop (in even aged stands variable density thinning is applied with a different objective (see Guiding principle 2).

Regeneration patch size and shape influence the level of competition experienced by individual trees within the patch. Small gaps experience the highest level of influence from edges, so competition from surrounding trees reduces as patch size increases. Similarly, retained legacy elements compete with adjacent trees and regeneration and this is influenced by the density and pattern of these legacy elements. The footprint of competition is greatest from wide spaced, larger individual trees, compared with trees with a clumped distribution, for a given density of legacy elements.

Strategies

97. During treemarking, retain habitat trees in groups where required to reduce the suppression of regeneration.

98. During treemarking, aim for a gap diameter at least four times tree height to reduce edge competition. The minimum diameter of a gap is two tree heights, but this should only be used where extending the gap size would result in unacceptable removal of productive forest.

99. During silvicultural treatment, use thinning to promote growth on retained trees. Variable density thinning may be applied to uneven-aged stands to ensure each tree is released from competition.

100. During treemarking aim to maintain stand density near the optimum for tree growth, consistent with changes in water availability.

101. During post-harvest silvicultural treatment, competition from understorey, second-storey and overstorey may be reduced, but only to prevent suppression of the regeneration.

102. After harvesting, undertake treatment in areas cut to gap, targeting a reduction in the overstorey to less than 20 per cent crown cover.

Guiding principle 17

Silvicultural methods will reflect the site productivity and developmental stage of the forest.

Rationale

Site productivity refers to the maximum density of forest that can be supported before it becomes limited by nutrients and water. Areas of high site productivity exist where rainfall is high, soils are deep and relatively fertile and evaporation is low. Lower site productivity is found in areas with lower rainfall, shallower soils or soils with lower nutritional value, and where evaporation is high. The jarrah forest occurs over a geographically large area and site productivity varies across its distribution, particularly from west to east, reflecting changes in the soil type and available water. Changes in site productivity are often reflected in changes in vegetation. Broad scale structure mapping of the jarrah forest has provided height categories which can be used to infer the site productivity.

The degree to which site productivity is utilised depends on stand age and basal area. Young stands have less access to available water than mature stands, because root systems are not fully developed. At the same time, young stands have a greater capacity to increase growth in response to reduced competition. The total biomass is limited during the younger development stages and increases as the stand matures (i.e. a uniform juvenile stand consisting of trees at the sapling stage would be expected to support less biomass than a fully stocked uniform stand consisting of pole-sized trees). Thinning schedules take stand development stage into account and target density will vary between stages.

Strategies

103. Regeneration stocking targets will recognise that the forest has areas of high, moderate and low site productivity.

104. Use historical maps of stand top height to indicate site productivity for the application of relevant thinning schedules.

105. Thinning schedules for even-aged regrowth and retained densities in shelterwood will recognise that the total biomass that can be supported increases as the stand progresses from one development stage to the next.

106. Periodically review classification of site productivity in light of forest inventory to ensure the correct stocking and thinning schedules are applied.

Guiding principle 18

Where the canopy is removed in gaps, the forest will be regenerated effectively and in a timely manner.

Rationale

Where the gap silvicultural method is applied, timely regeneration is important for,

- sustained yield
- carbon storage and sequestration
- ongoing provision of habitat for overstorey forest dwelling species
- visual amenity

Timely regeneration is dependent upon the coordination of harvesting, post-harvest treatments, site preparation, seed crop and silvicultural burns. Scheduling of operations is complex and subject to the availability of resources and suitable weather conditions. This complexity can lead to delays in regeneration.

Where regeneration is not achieved in a timely or effective way, the reasons behind this should be recorded. Where possible the information recorded should be used address delays or failure in regeneration to improve regeneration outcomes in the future.

Strategies

107. Post-harvest regeneration treatments should be completed as soon as practicable after the cessation of forest harvesting in that coupe.

108. Post-harvest silvicultural treatments will be conducted prior to burning where possible.

109. After regeneration, monitor stocking to determine if and where remedial action is required.

110. Where regeneration is delayed or remedial action is required, document where known the reasons for delay or regeneration failure.

Guiding principle 19

Trees to be retained will be marked and protected from damage.

Rationale

Silvicultural practices in the jarrah forest involve the retention of trees for various purposes depending on the silvicultural method that is selected. Trees may be retained to grow on for future timber values, provide hollows for habitat, as a seed source, as cover to protect water values, or for other reasons.

Harvesting operations have the potential to damage retained trees, both directly and indirectly. Direct damage results from harvest machinery coming into contact with retained trees. Indirect damage results from the impact of falling trees. Both can result in damage to the bark and cambium, broken limbs and potentially the toppling of the trees marked for retention.

While some damage may be unavoidable, levels of damage should be minimised. Some damage to the bark and cambium or broken limbs is acceptable in retained habitat trees, as it can add to the habitat value over time. However, damage that kills or destabilises a habitat tree should be avoided.

Avoiding damage to crop trees, especially in thinning, requires care as the trees may be closely spaced and machine operators have limited area to manoeuvre. However, damage to the bark or cambium of crop trees can cause a decline in wood quality. Therefore, avoiding damage to crop trees is important if the value of the crop is to be maintained.

Damage to retained trees may also occur during post-harvest burns. The radiant heat generated by the combustion of fine fuel from tree crowns in combination with larger debris has potential to damage or kill trees. The likelihood of damage varies with the amount of heat exposure, the length of time the tree is exposed to the heat and the bark thickness of the tree.

Strategies

111. Treemarking is to be undertaken in advance of harvesting operations and trees are to be marked for retention in accordance with the silviculture manual. In first thinning of regrowth stands, consideration may be given to the use of trained machine operators to identify trees for retention without prior marking.

112. During treemarking, give consideration to the location of retained trees with respect to the likely felling direction and ensure gap size is sufficient such that trees can be felled without causing undue damage to retained trees (this strategy also contributes to Guiding principle 19).

113. During harvesting operations, monitor the level of damage to retained trees to help ensure it does not exceed the allowable level.

114. During harvesting operations, ensure debris is removed from trees selected for retention when the combination and arrangement of fuels is such they would otherwise be potential for damage to wood or other values during post-harvest burns.

Guiding principle 20

Forest areas that are killed or damaged by fire or other agents may be restored or salvaged.

Rationale

While it is unlikely that most bushfires will kill healthy jarrah saplings or small poles, there is potential for damage to the bole or the growing tip. Damage of this nature can seriously reduce the value of the tree for future sawlog production. Fire damaged trees are pre-disposed to insect, fungal and termite attack, which can also lead to mechanical failure in the tree, constituting a safety concern. The value of the damaged regrowth can be improved through coppicing the stems and allowing them to regrow.

It is predicted that climate change will lead to more frequent extreme fire weather conditions. Unplanned fires that occur during extreme weather conditions can result in the death of mature trees. Provision of forest products may be adversely impacted, both by increasing time to stand maturity where stand-replacing fires occur and where fire damage reduces the volume, and quality, of sawlogs (and other logs) available. While fire deaths and declines in wood quality may reduce yields, this may be partially offset where salvage harvesting occurs.

If sizeable patches of forest are killed or degraded, there is often significant benefit to a range of values by regenerating or rehabilitating affected areas. Salvage harvesting of these sites allows for useable wood to be recovered and provides an opportunity to commence the process for regeneration or rehabilitation. However, as the wood of dead trees degrades quite quickly, achieving this requires that the usual assessment, planning and approval processes be undertaken in a timely fashion.

Strategies

115. All stands that are burnt with moderate to high intensity fire, should be assessed for damage.

116. After natural disturbance events which result in tree death or damage, harvesting may be used to salvage forest products and facilitate regeneration and/or rehabilitation of the disturbed areas. Facilitate salvage harvesting as soon as possible after the disturbance event to reduce log degrade and promote regeneration.

117. Harvesting to facilitate salvage forest products may be approved by the Director Sustainable Forest Management, on a case-by-case basis.

118. During salvage operations, retain legacy elements where they exist (see Guiding principle 3).

119. After natural disturbance events and salvage operations, regenerate and/or rehabilitate areas left understocked.

8. Guiding principles for heritage

Overall objective

Protect and maintain Aboriginal and other Australian cultural heritage.

Cultural heritage is a generic term which refers to the qualities and attributes that are present at places which have aesthetic, historic, scientific or social significance for past, present or future generations. These qualities or attributes may be seen in the physical features at a place (such as travel routes, buildings or relics), or can be associated with the intangible qualities such as the association with or feelings for a place by a community. Identifying intangible qualities will require consultation with the people or communities who hold these feelings or associations. The identification and protection of cultural heritage sites is primarily addressed during the harvest planning and approval process.

Section 56 of the CALM Act, prescribes the management objectives for each category of land to which the CALM Act applies, and management plans for lands managed by the Department may enable management activities to conserve, protect, preserve, maintain or restore cultural heritage. The CALM Act requires that the management of lands and waters include the objective to protect and conserve the value of the land to the culture and heritage of Aboriginal persons.

In relation to other Australian heritage, the *Heritage of Western Australia Act 1990* provides the legislative guidance. The crucial factor in applying the requirements of this Act is that there must have been human activity associated with the place.

Heritage issues are addressed in the harvest planning and approvals process, and the strategies listed below are complementary to this.

Guiding principle 21

Harvest disturbance will be managed to avoid adversely affecting Aboriginal cultural heritage values and sites.

Rationale

The jarrah forest was traditionally occupied by the Noongar people, who are the original custodians of the land. A large number of Aboriginal sites have been recorded within the plan area. These are places of importance and significance to Noongar people and to the cultural heritage of Western Australia. They are significant because they link Noongar cultural tradition to place, land and people over time. Noongar people have a rich and intimate connection with the country within the plan area, which includes knowledge of, rights to, and responsibility for these sites and for protecting the culture and heritage values of these sites.

Scarred or modified trees that mark trails or other sites of significance to Noongar people occur throughout the forest. The locations of the trees that exist today are not all known or registered. Staff conducting silvicultural operations should be aware of the need to conserve cultural heritage and be trained to be able to recognise potential cultural heritage sites, report them and take action to avoid disturbing them until they have been assessed. Trees or sites encountered during silvicultural operations that have potential heritage value need to remain undisturbed until their suitability for registration can be formally determined.

Strategies

120. During treemarking, look for and report items that may be evidence of Aboriginal use of a site such as scarred or modified trees, and prevent damage to them until they can be assessed.

121. During rehabilitation planning, consider use of seed from endemic “bush tucker” plants as part of the seed or seedling mix.

Guiding principle 22

Harvest disturbance will be managed to avoid adversely affecting Australian cultural and natural heritage values and places.

Rationale

Throughout the forest there are places providing examples of early settlement and harvesting activity such as remnant tramways, cuttings, old bridges and loading ramps. Pre-harvesting checks of databases are conducted to conserve known cultural heritage sites. However, not all places with other Australian heritage value are currently known and staff conducting silvicultural operations should be able to recognise potential cultural heritage places, report them and take action to avoid disturbing them until they have been assessed. It is important to protect places of significant value that may be encountered in harvesting operations.

The Department maintains a Significant Trees Register. Listed trees can be identified through pre-harvest checks to ensure they are located and protected from harvesting disturbance. Trees encountered during silvicultural operations that have characteristics of significant trees need to remain undisturbed until their suitability for registration can be formally determined.

Strategies

122. During treemarking, ensure the curtilage of registered heritage places is demarcated or the silvicultural method is adapted to conserve heritage values.

123. During treemarking, mark for retention and ensure sufficient protection of trees of cultural significance, and significant trees. Candidate and nominated significant trees should remain undisturbed until they can be formally assessed for registration.

124. Ensure that any proposal to disturb a blazed location reference tree is approved by the Department prior to the disturbance taking place.

9. Guiding principles for socio-economic values

Overall objective

Sustain social and economic benefits, through the provision of a range of goods and services valued by the community.

The jarrah forest provides a range of goods and services including clean and moderated flows of water, clean air, carbon sequestration (in the forest and forest products), minerals and petroleum, wood and non-wood forest products, basic raw materials, nature-based recreation and tourism, apiculture, wildflowers and seeds. Silvicultural treatments within the jarrah forest available for timber harvesting are designed to contribute to the provision of a range of goods and services valued by the community.

Guiding principle 23

The capacity of forest areas will contribute to the social and economic sustainability of regional communities.

Rationale

The jarrah forest forms part of a larger forest matrix that is important to regional communities and industry in Western Australia. Silvicultural management of the forest seeks to provide for employment and other benefits of the native forest timber industry with the ongoing provision of environmental values (Guiding principles for biodiversity, Guiding principles for ecosystem health and vitality, Guiding principles for Soil and Water, Guiding principles for climate change and carbon cycles), tourism and recreation, and other values. Silvicultural methods that are designed to provide for non-timber objectives are often at an economic and/or efficiency cost to the native forest timber industry. The design of silvicultural practices should seek to balance the achievement of environmental outcomes with economic and social outcomes.

Silvicultural management can also be applied to benefit environmental and social values outside the scope of the timber industry. For example the application of silvicultural principles can be used to rehabilitate cleared or degraded forest, mitigate potential fire risk while maintaining biodiversity, manage water catchments for water and environmental values and manage the impact of infrastructure projects such as power lines on forest values.

Strategies

125. Liaise with companies involved in large scale mining and infrastructure projects to ensure that regeneration strategies, and species mixes, are able to provide for both natural values and commercial opportunities.

126. When applying an adaptive management approach, balance the delivery of social, economic, and environmental values by evaluating the likely merits of changes to silvicultural methods.

127. Where possible, preference will be given to achieving silvicultural objective through commercial rather than non-commercial means.

Guiding principle 24

Visual landscape management will be used to manage potential effects of silvicultural treatments on visual amenity.

Rationale

Priorities for management of visual amenity in forest areas are based on the mapping of visual resource values and visitation and/or road usage patterns. Where a landscape has both high visual quality and high visitation, it is assigned a high priority for visual landscape management, and modified practices are used. Higher levels of landscape alteration are permitted where there are reduced visual resource values and lower usage patterns. Silvicultural treatments can alter the landscape in terms of visual amenity. Well planned silvicultural practice can reduce visual impact by introducing variations of gap size, thinning intensity, felling cycle, rotation length and treatment method.

Strategies

128. During harvest planning, manage the visual amenity from major roads and recreation sites by applying the requirements appropriate for the allocated visual management zone.

129. During harvest planning, extend rotation length, where necessary, to allow mature forest characteristic to develop to maintain visual amenity from major travel routes.

130. During harvest planning, extend the cutting cycle adjacent to major travel routes, where necessary, to allow the scenic quality to recover from harvesting disturbance.

131. During treemarking, limit gap size, or where necessary, design the gap shape to reduce the visual impact of harvesting.

132. When conducting post-harvest treatment adjacent to major travel routes, do not create standing dead trees that would reduce the visual quality of the view-shed and that may pose a potential risk to passing traffic in storm or fire events.

Guiding principle 25

Post-harvest treatments will be prioritised according to the benefits likely to be realised.

Rationale

Timber harvesting has occurred in the jarrah forest since the 1800s, however past practices did not always have a clear silvicultural objective. Typically for the jarrah forest, there have been insufficient markets for the full range of log sizes and qualities to effectively thin or regenerate the forest area and follow up non-commercial treatment has often been necessary to complete thinning and/or provide for effective regeneration. The availability of funding for non-commercial treatment has been spasmodic and the use of follow-up treatments to promote the grouped structure that is advocated in current silvicultural practice has frequently not occurred. As a consequence, there are areas of forest which have been selectively harvested for sawlogs, which currently contain few trees with the potential to produce sawlogs, and some have inadequate regeneration. The available funding for regeneration, post-harvest treatment and fire protection operations is finite, and is not sufficient to retrospectively treat all areas with unsatisfactory outcomes from past management. Priorities therefore need to be set to ensure the best return on investment of available funds.

Mining leases cover much of the northern jarrah forest. Where timber harvesting is scheduled in areas which will subsequently be cleared for mining, there is unlikely to be a return on money invested in post-harvest treatments. Productivity increases as a result of post-harvest treatments are unlikely to be realised if the area is cleared for mining within ten years of timber harvesting.

Strategies

133. Use site productivity and knowledge of future infrastructure construction or mining operations to assist in prioritising post-harvest treatments. Prioritise those areas where the silvicultural objective can be achieved and where the treatments will provide a return on investment. Do not conduct post-harvest treatments in areas identified to be mined or cleared within ten years.

134. When using culling to achieve thinning for a wood production objective, only release those trees of crop tree quality.

10. Appendices

Appendix 1: Legislative requirements

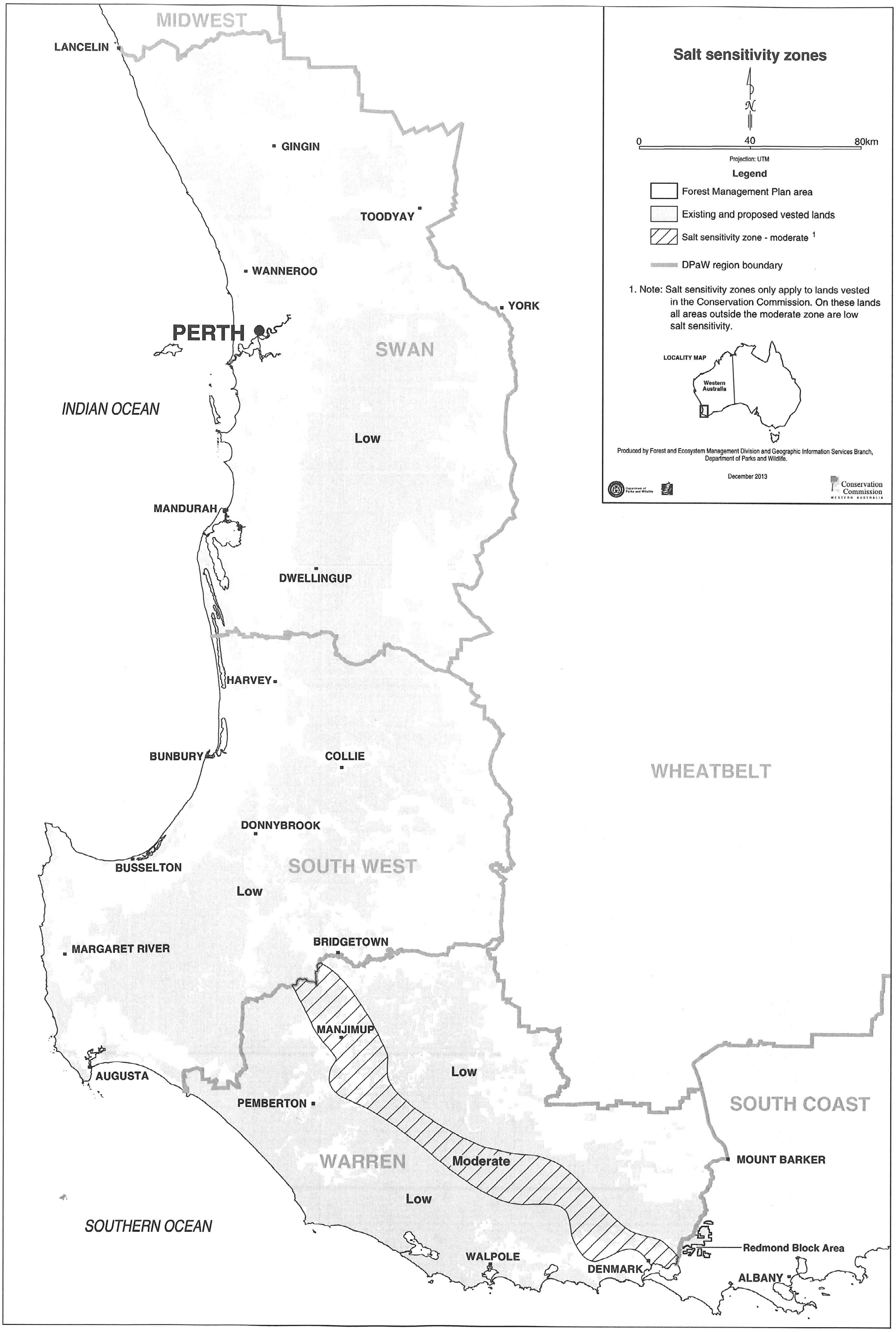
The legislative controls in relation to silviculture in Western Australia are found in the relevant State and Commonwealth Acts and regulations. The following table summarises the relevant government legislation.

Title of Act or Regulation	Relevance of legislation	Responsible agency
Aboriginal Heritage Act 1972	Under this Act the Department is required to report and protect Aboriginal heritage sites and ensure that sites are protected. This Act is also relevant under section 24 of the Mining Act, the Minister for Mines may consent to mining, including exploration activities, subject to conditions that may be intended to protect environmental and cultural heritage.	Department of Indigenous Affairs
Agricultural and Veterinary Chemicals (Western Australia) Act 1995	Covers the use and control of pesticides, including the requirement to use pesticides in accordance with label requirements or "off label" permits. Regulations related to pesticide application will be covered through compliance with the *Code of Practice for the use of agricultural and veterinary chemicals in Western Australia* (Department of Agriculture and Food Western Australia 2007).	Department of Agriculture and Food WA
Bush Fires Act 1954	Provides regulation of the control of bushfire and the use of prescribed fire.	Department of Fire and Emergency Services
Biosecurity and Agriculture Management Act 2007 **(BAM Act)**	Prescribes certain statutory obligations to the Department concerning biosecurity matters generally, and particularly with respect to the management of pathogens that cause forest diseases, through the CALM Act. The management and control of weeds in Western Australia is guided by the BAM Act and the *Agriculture and Related Resources Protection Act 1976* (it is intended that the BAM Act will replace the Agriculture and Related Resources Protection Act and some other Acts in the near future, which may bring some changes to management requirements).	Department of Agriculture and Food WA
Conservation and Land Management Act *(CALM Act)*	Establishes the Conservation Commission as an independent controlling body and provides for the functions of the Conservation Commission including: to have State forest, timber reserves and conservation reserves vested in it; and to prepare management plans for those lands as prescribed in Part V of the CALM Act, according to certain purposes and objectives. It also provides for the Department to manage land vested in the Conservation Commission according to available resources and management plans.	Department of Parks and Wildlife

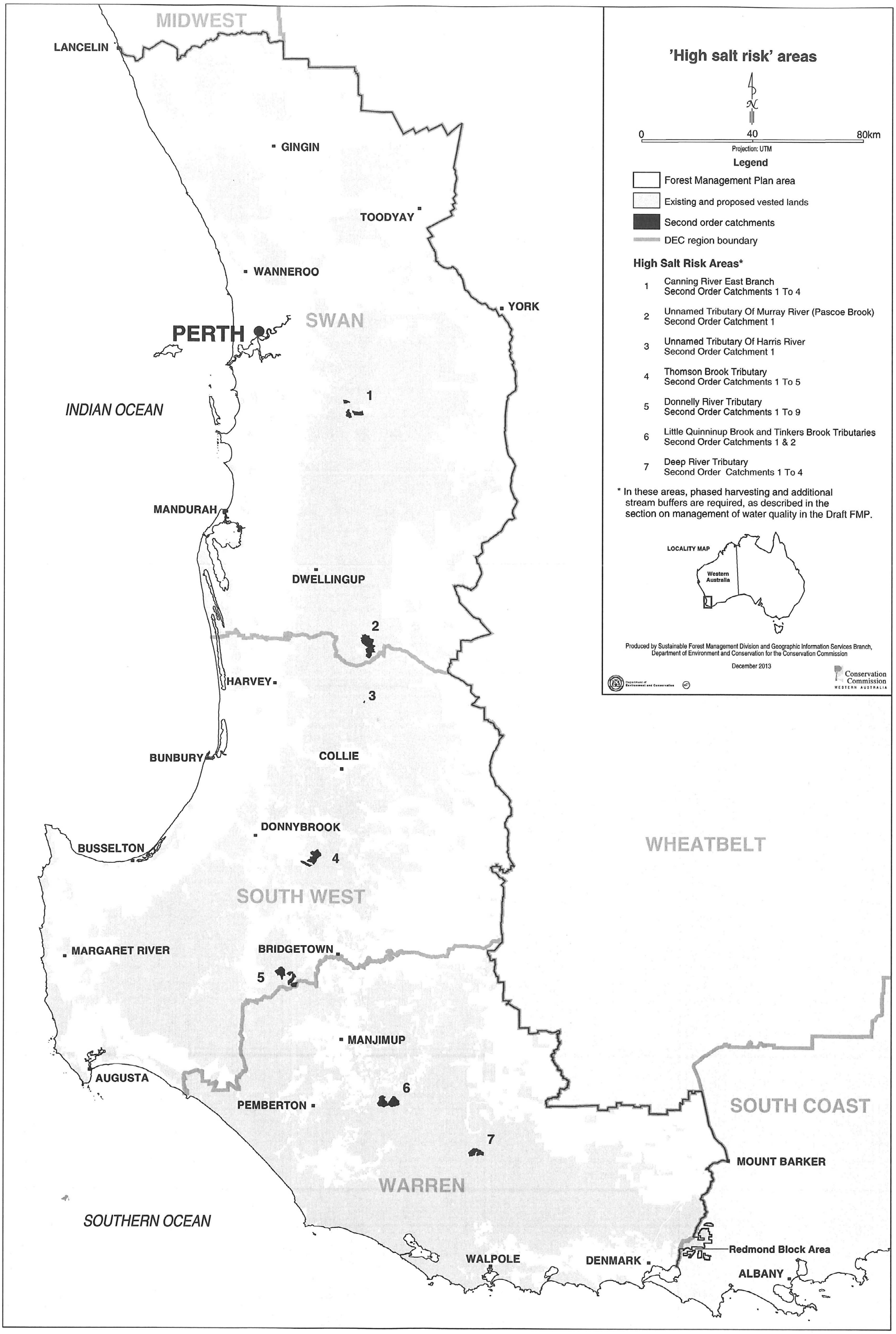
Title of Act or Regulation	Relevance of legislation	Responsible agency
Country Areas Water Supply (CAWS) ***Act 1947***	Governs the construction, maintenance and administration of reticulated supplies of water to country areas, to safeguard water supplies, and influences the Department's activities in gazetted catchments.	Department of Water
Emergency Services Act 2005	Sets out the emergency management arrangements for the State and requires that a number of emergency response plans be maintained. The response plan for bushfire is Westplan Bushfire, which sets out the Department's role in bushfire suppression operations as a 'Controlling Agency'.	Department of Fire and Emergency Services
Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)	Contains provisions relating to the protection of nationally-listed threatened species and ecological communities. In that part of the plan area covered by the Regional Forest Agreement (RFA), the Commonwealth and State governments have agreed that the CAR reserve system and the forest management system, meet the requirements of that Act for the protection of threatened flora and fauna and ecological communities (RFA clause 56). Therefore, the provisions of the EPBC Act for environmental assessment are not triggered for forestry operations.	Department of Sustainability, Environment, Water, Population and Communities (Commonwealth)
Environmental Protection Act 1986 *(EP Act)*	Provides for the protection of the environment across the State. Relates to the prevention, control and abatement of pollution and environmental harm. It is to ensure the conservation, preservation, protection, enhancement and management of the environment, and may relate to any contamination caused by hydrocarbons from machinery and pesticides.	Department of Parks and Wildlife and Environmental Protection Authority
Forest Products Act 2000 *(FP Act)*	Provides for Forest Products Commission with the responsibility for the harvesting and regeneration of native forest and plantations in State forests and timber reserves, and for the sale of forest products (a subset of CALM Act forest produce) and some associated industry development matters.	Forests Products Commission
Health Act 1911	Applicable to pesticide use within a public drinking water source area. The conditions for pesticide use in these areas are specified in the Department of Health *Public Service Circular 88 Use of herbicides in catchment areas*, and also relevant to this is the Department of Water *Statewide Policy 2 Pesticide Use in public drinking water source areas*.	Department of Health
Heritage of Western Australia Act 1990	Provides for the registration and protection of places of historic interest on lands as 'heritage places'. This Act is also relevant under section 24 of the Mining Act, the Minister for Mines may consent to mining, including exploration activities, subject to conditions that may be intended to protect environmental and cultural heritage.	Heritage Council of Western Australia

Title of Act or Regulation	Relevance of legislation	Responsible agency
Metropolitan Water Supply, Sewerage and Drainage Act 1909 (MWSSD Act)	With the CAWS Act (above) and their associated by-laws are used to proclaim Public Drinking Water Source Areas (PDWSA). These may be referred to as water reserves, catchment areas or underground water pollution control areas. There are also requirements that relate to the use of pesticides in PDWSA (see *Health Act*, above). All operations in PDWSA are required to be in accordance with *Statewide Policy No.2 Pesticide use in PDWSA*.	Department of Water
Rights in Water and Irrigation Act 1914	This Act covers the use of water in the plan area, and permits (related to the disturbance of beds and banks) and licences (for the taking and use of water) are required within proclaimed areas.	Department of Water
Soil and Land Conservation Act 1945	This Act provides for the conservation of soil and land resources and provides mechanisms for the mitigation of the effects of erosion, salinity and flooding. This Act covers crown land.	Department of Agriculture and Food
Wildlife Conservation Act 1950	This Act provides for the conservation of native flora and fauna throughout the State.	Department of Parks and Wildlife

Appendix 2: Salt Sensitivity Zones



Appendix 3: High Salt Risk Areas



11. Acronyms

Acronym	Definition
CALM	**Conservation and Land Management**
CWD	**Coarse woody debris.**
Dbhob	**Diameter at breast height over bark.**
DEC	**WA Department of Environment and Conservation (now DPaW)**
DPaW	**WA Department of Parks and Wildlife**
FDIS	**Fauna Distribution Information System**
FHZ	**Fauna Habitat Zone**
FMP	**Forest Management Plan 2014-2023.**
LMU	**Landscape management unit**
TEAS	**Temporary exclusion area.**

12. Glossary

Term	Definition
Advance growth	A term used to describe the established regeneration stages of jarrah, including established seedlings, coppice, saplings and poles.
Adaptive management	A process of responding positively to change. The term adaptive management is used to describe an approach to managing complex natural systems that builds on common sense and learning from experience, experimenting, monitoring, and adjusting practices based on what was learned.
Basal area	The sum of the cross-sectional areas of trees in a given stand measured at 1.3 metres above the ground. It is usually expressed as square metres per hectare.
Biological diversity (Biodiversity) **(described in CALM Act)**	The variability among living biological entities and the ecosystems and ecological complexes of which those entities are a part and includes: (a) diversity within native species and between native species; (b) diversity of ecosystems; and (c) diversity of other biodiversity components.
Biological diversity component **(described in CALM Act)**	Includes habitats, ecological communities, genes and ecological processes.
Bole	The tree trunk from the ground to the crown break. The bole does not include the major branches supporting the crown.
Catchment	The land area drained by a single stream, river, or drainage network.
Clearfell	A silvicultural method in which all, or nearly all trees in a defined area are removed at one time to allow regeneration to establish and develop (note legacy elements are marked for retention, and some non-commercial trees may still remain on site).
Coarse woody debris	Dead woody material such as boles and branches on the ground or in streams.
Coppice (noun)	A shoot (or shoots) arising from adventitious buds at the base of a woody plant that has been cut near the ground or burnt back.

Term	Definition
Coppice (verb)	The act of cutting near the ground or burning back a woody plant to encourage a shoot (or shoots) to arise from dormant buds at the base of the plant. Often completed to encourage the development of a new vigorous coppice stem.
Coupe	An area of forest that is planned for timber harvesting as a single unit. It may contain more than one silvicultural objective, such as a number of discrete gaps and areas of thinning.
Crop tree	A tree selected to retain during a harvest operation, to be grown on for many years to become a component of a future commercial harvest
Culling	The reduction in the density of unwanted vegetation, usually to reduce competition to retained crop trees or for establishing or releasing regeneration.
Department, or the Department	The Western Australian Department of Parks and Wildlife.
Dieback **(*Phytophthora* dieback)**	In the south-west of Western Australia a disease of plants caused by infection by the soil-borne organisms of the genus *Phytophthora*, of which *P. cinnamomi* is the most widespread.
Disturbance	Any relatively discrete event in time that disrupts ecosystems, communities, or population structure and changes resource availability or the physical environment. Disturbance may be natural (e.g. lightning caused fire) or human induced (e.g. timber harvesting).
Ecologically sustainable forest management	Forest management and use consistent with the principles described in section 19(2) of the CALM Act.
Ecosystem	A community or an assemblage of communities of organisms, interacting with one another and the environment in which they live.
Endemic	Flora or fauna that is confined in its natural occurrence to a particular region.
Evapotranspiratio n	Loss of water from an area of land through the transpiration of plants and evaporation from the soil.
Even-aged stand	A forest stand dominated by trees of a similar age. In native forests, this includes stands where the non-dominant age classes comprise less than 15 per cent crown cover.
Exotic species	Any species growing or living outside its natural range of occurrence. Normally this refers to species purposely or accidentally introduced into countries or regions where they do not historically occur.

Term	Definition
Fauna	The animals inhabiting an area; including mammals, birds, reptiles, amphibians and invertebrates. Usually restricted to animals occurring naturally and excluding feral or introduced animals. With respect to the Wildlife Conservation Act(Section 6), fauna is: (a) any animal indigenous to any State or Territory of the Commonwealth or the territorial waters of the Commonwealth; (b) any animal that periodically migrates to and lives in any State or Territory of the Commonwealth or the territorial waters of the Commonwealth; and (c) any animal declared as fauna pursuant to subsection (2), and includes in relation to any such animal – (d) any class or individual member thereof; (e) the eggs, larvae or semen; (f) the carcass, skin, plumage or fur thereof, but does not include any prescribed animal or prescribed class of animal.
Fauna Distribution Information System	Departmental database of taxonomy, conservation status of fauna species and advice on management practices.
Fauna Habitat Zone	FHZs are patches of forest systematically distributed across the landscape which are temporarily excluded from timber harvesting.
First and second grade sawlog jarrah	A log cut from the bole of a jarrah tree that is a minimum of 2.1 metres in length, has a minimum under bark diameter of 200mm and has a minimum of 30 per cent millable timber on the worst end face.
Fire regime	The history of fire use in a particular vegetation type or area including the frequency, intensity, season and scale of burning over a period of time. It may also refer to proposals for use of fire.
Flora	The plants growing in an area; including flowering and non-flowering plants, ferns, mosses, lichens, algae and fungi. Usually restricted to species occurring naturally and excluding weeds. With respect to the Wildlife Conservation Act (Section 6), flora is any plant (including any wildflower, palm, shrub, tree, fern, creeper or vine) which is: (a) native to the State or (b) declared to be flora pursuant to subsection (4), and includes any part of flora and all seeds and spores thereof.
Floristic	Of or relating to flowers, a flora, or the biogeographical study of plants
Forest	An area, incorporating all living and non-living components, that is dominated by trees having usually a single stem and a mature or potentially mature stand height exceeding two metres and with existing or potential crown cover of overstorey strata about equal to or greater than 20 per cent.

Term	Definition
Forest block	A named administrative subdivision of the forest, varying in size from about 3,000 to 8,000 hectares.
Forest ecosystem	An indigenous ecosystem with an overstorey of trees of more than 20 per cent crown cover. These ecosystems should normally be discriminated at a resolution requiring a map-standard scale of 1:100,000. Preferably these units should be defined in terms of floristic composition in combination with substrate and position within the landscape.
Forest products	As for the purposes of both the CALM Act and the Forest Products Act: trees or parts of trees: timber, sawdust or chips; charcoal, gum, resin, kino or sap; and firewood, located on public land or sharefarmed land.
Forest regeneration	The renewal of a forest arising from planting or from seed or the young plants on a site. The process by which a forest is renewed.
Formal reserve	See 'Reserve – Formal'
Gap (regeneration establishment)	A discrete opening in the overstorey canopy that reduces competition and allows seedlings to become established and or develop.
Global carbon cycles	The carbon cycle is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth.
Ground coppice	A growth stage where the lignotuber and root system have grown to the point that if surrounding competition is sufficiently reduced, the plant is capable of dynamic growth into a sapling. In jarrah, the lignotuber may be between five and 10 centimetres in diameter and the plant may take 20 years to reach this development stage under native forest conditions.
Group selection	The removal or retention of trees in relatively small groups with the object of creating a gap or retaining a group of younger trees to grow on. While there is no specific size of the group, the size of the gap must be large enough to create a suitable microclimate for regeneration and/or growth of younger trees, and allow for later felling without causing undue damage to surrounding trees.
Guideline	A document type that guides and directs actions for achieving consistency and required standards. Guidelines permit some flexibility in their application.
Habitat	A component of an ecosystem providing food and shelter to a particular organism.
Habitat tree	A tree selected to be retained in a coupe because it has features attractive to wildlife particularly for hollow nesting birds and animals.
Heritage	Something inherited from a past generation that is valued.

Term	Definition
High salt risk	Refers to certain river systems within the historic intermediate rainfall zone (based on data up to 1978) that are least disturbed and as such, are presumed to have the most intact aquatic ecosystems and consequently are the most environmentally sensitive to rises in saline groundwater.
Immature stand	The stand development stage beginning with the main lateral spread of tree crowns and finishing with the start of a mature stand.
Impact - dieback	The effect on vegetation from the presence of *Phytophthora* species, referred to as either predicted or current impact.
Informal Reserve	See 'Reserve – Informal'.
Land category	Section 5 of the CALM Act specifies the categories of land to which the Act applies and section 6 defines those land categories. For the purposes of the plan the land categories are; State forest, timber reserves, national parks, conservation parks, nature reserves, any other land reserved under the Land Act 1933 and vested by order under that Act in the Conservation Commission and any other land other than excluded waters, reserved under Part 4 of the Land Administration Act 1997, the care control and management of which are placed by order under that Part with the Conservation Commission.
Landform	All the physical, recognisable, naturally formed features of land having a characteristic shape. Includes major forms such as a plain, mountain or plateau, and minor forms such as a hill, valley or alluvial fan.
Landscape Management Unit	An agglomeration of vegetation complexes and ecological vegetation systems, as defined and mapped by (Mattiske *et al.* 2002), to form more compact management units that recognise the underlying ecological characteristics.
Landscape scale	For the purposes of this guideline - a mosaic where the mix of local ecosystems and landforms is repeated in a similar form over a kilometres-wide area. Several attributes including geology, soil types, vegetation types, local flora and fauna, climate and natural disturbance regimes tend to be similar and repeated across the whole area. It could be a (sub) catchment or, for convenience, an administrative management unit such as a forest block or an aggregation of forest blocks. Landscape scale is usually tens of thousands to a few thousand hectares.
Legacy elements Also Legacy habitat elements	Refers to existing key habitat features, such as hollow bearing trees and logs which may take many decades to replace and which are retained after harvesting or remain after natural disturbance, which provide refugia and enrich the structural complexity of the new stand.
Lignotuber	A woody swelling formed at the base of some eucalypts that has the ability to produce new shoots when the existing ones are destroyed.

Term	Definition
Local scale	A discrete area of land to which one or more operations have been or are planned to be applied. For the purposes of this guideline – the average area of a forest blocks in the vicinity.
Mature stand	The stand development stage beginning with the formation of large persistent branches forming the outline of the crown as the crown reaches its maximum size, and finishing with the commencement of a senescent stand.
Monitoring	A process of repeated measurement or observation, for specified purposes of one or more elements, usually according to prearranged schedules in space and time, using comparable data collection methods. Often used to assess a management program, condition of the environment and/or resources being managed, to help determine if desired activities, processes, outputs and outcomes are being achieved.
Natural regeneration	Regeneration through lignotubers or seed produced on site as opposed to planting or applying seed from collections.
Overstorey	Species comprising the upper canopy layer of the forest. Common overstorey species include *Eucalyptus marginata, Corymbia calophylla, E. wandoo, E. patens and E. diversicolor.*
Patch	A group of trees resulting from a natural regeneration event or past management, such as gap creation and regeneration. May also refer to a particular, relatively small area of forest and/or other vegetation type(s).
Pest	Troublesome or destructive animals including insects, either introduced or native.
Pesticides	Includes herbicides, insecticides, fungicides and related products registered for use in pest control.
Phytophthora cinnamomi*, or *P. cinnamomi	Water mould. The pathogen that causes most *Phytophthora* dieback disease.
Policy	A document containing principles and rules that outline an organisation's position and which guides decisions and actions taken in the conduct of its activities.
Prescribed burning	The controlled application of fire under specified environmental conditions to a predetermined area and at the time, intensity and rate of spread required to attain planned resource management objectives.
Regrowth forest	Native forest which is dominated by similar aged stems that have not reached the mature growth stage, originating from previous harvest events, such as gap creation, or other disturbances, such as bushfire.
Regeneration (noun)	Jarrah regeneration is composed of seedlings, lignotuberous seedlings, seedling coppice and ground coppice (see (Abbott *et al.* 1984)).

Term	Definition
Rehabilitation	The process necessary to return disturbed land to a predetermined surface, vegetation cover, land-use or productivity.
Reserve – conservation	An area set aside primarily for the conservation of natural ecosystems but which may allow a level of recreation consistent with the proper maintenance and restoration of the natural environment.
Reserve – formal	One of the land categories of national park, nature reserve, conservation park, or CALM Act sections 5(1)(g) or 5(1)(h) reserves for the purpose of conservation.
Reserve – informal	An area set aside for conservation under an approved management plan; has had opportunity for the public to comment on changes to reserve boundaries; able to be accurately defined on a map; and is of an area and design sufficient to sustain the values it seeks to protect.
Resilience	The capacity of an ecosystem to withstand external pressures and, over time, return to its prior condition, including its ability to maintain its essential characteristics such as taxonomic composition, structural forms, ecosystem functions and processes (adapted from Thompson *et al*., 2009, who cite Holling, 1973).
Riparian	Pertaining to the banks of streams, rivers or lakes.
Rotation	The period between regeneration establishment and the final harvest.
Salt sensitivity zone	The Swan and South West regions and parts of the Warren Region are classified as low salt sensitivity and other parts of the Warren Region are classified as moderate salt sensitivity (see Appendix 2).
Salvage harvest	The removal of forest produce and/or forest products following an unplanned disturbance event to recover economic value that would otherwise be lost. Salvage operations require approval by the Department. By their nature, salvage harvest areas may not appear on the three or one year harvest plan(s) that pre-date operation.
Saproxylic	Saproxylic organisms are those which are dependent on dead or decaying wood (or dependent on other organisms that are themselves dependent on dead wood). They may be dependent on dead or decaying wood for part of or the entirety of their life cycle.
Second-storey	The structural layer between the shrub and herb storey and the overstorey (canopy). In the jarrah forest, this layer often includes species such as *Banksia litoralis, B. grandis, Allocasuarina spp., Xylomelum occidentale, Persoonia longifolia, Melaleuca* spp. and *Acacia acuminata*.
Seed tree	A tree left standing for the purpose of providing seed for the regeneration.

Term	Definition
Senescent crown (for selecting trees bearing hollows)	The development stage that follows the mature tree stage and precedes natural death, usually involving a decreased ability to repair damage and degradation. Characterised by a dominance of dead branches in the tree crown together with the formation of new branches from epicormic buds. Senescent crowns in large trees are likely to bear usable hollows for large hollow dependent fauna. They are found in trees 50 – 70cm, but more often ≥ 70 cm, dbhob, with a crown senescence rating ≥ 4 (Whitford *et al.* 2001), and with highest likelihood at a crown senescence rating of 7. Likelihood of bearing usable hollows is reasonable with higher dead branch order scores (≥ 4 and increases with a dead branch order 7 to 9; (Whitford *et al.* 2001)), and crowns with evidence of hollow entrances (smallest entry dimension >10cm in diameter) into low order branches (orders 1, 2 & 3 - branches leading to, or close to the bole).
Senescent stand	The development stage that follows the mature stand and precedes natural death, usually involving a decreased ability to repair damage and degradation. Characterised by a dominance of dead branches in the tree crown, together with the formation of new branches from dormant buds.
Shelterwood (regeneration establishment)	A jarrah silvicultural treatment that involves a partial reduction in the density of overstorey trees and action to establish regeneration under the remaining mature trees.
Silvicultural burn	The planned burning of forest residues after harvesting to establish forest regeneration.
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.
Silviculture for ecosystem health	The application of silvicultural management to protect threatened ecological values or communities where the effects of climate change will escalate the threat to the value or community.
Silviculture for water production	The application of silvicultural management to increase the flow of water to surface and groundwater reservoirs which will support aquatic ecosystems, but also be available for consumptive purposes.
Site productivity	The inherent capacity of forest land to grow woody biomass of a particular species.
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.
Structure	When applied to a forest, is the horizontal and vertical distribution of the alive and dead vegetation.
Stool coppice	A growth stage where shoots have developed from a stump cut off at ground level.

Term	Definition
Suppression	The process whereby a tree or other vegetation loses vigour and may die when growing space is not sufficient to provide photosynthate or moisture to support adequate growth.
Sustained yield, or Sustained timber yield	The first and second grade sawlog yield that a forest can produce for an extended period (to at least the year 2070) at a given intensity of management.
Taxa (taxon)	A defined unit (for example, species or genus) in the classification of plants and animals.
Temporary exclusion area (TEAS)	An area that is excluded from timber harvesting for a particular period of time.
Thinning	A felling made to reduce the density of trees within a stand. Usually undertaken to improve the growth of trees that remain by reducing competition, without either permanently breaking the canopy or encouraging regeneration. May also be undertaken to enhance forest health, water production or achieve another objective.
Threatening process	Those processes which may result in the long-term reduction of biodiversity. Examples include predation and habitat change by introduced animals; competition and displacement by introduced plants and destruction and modification of habitat.
Timber	Sawn or other products derived from first and second grade jarrah and karri sawlogs.
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.
Treemarking	The procedure in which trees are marked for retention (or removal) prior to timber harvesting or other operations in a forest.
Understorey	Herb and shrub layer. This vegetation layers occurs beneath both the overstorey and second-storey.
Variable density thinning	Type of thinning used to introduce structural complexity into even-aged regrowth stands by for example, leaving un-thinned patches, retaining older trees and understorey and second-storey elements, creating small gaps and varying the spacing of trees in thinned areas. In stands containing a range of size classes it can also be used to vary the spacing of trees and the retained basal area in response to variations in trees sizes.
Vegetation complex	A combination of distinct site vegetation types, usually associated with a particular geomorphic, climatic, floristic and vegetation structural association.

Term	Definition
Very high impact (dieback)	Very high impact sites are those with a major component of susceptible species, most of which have been killed by *Phytophthora* dieback and greater than 50 per cent of the overstorey trees are dead.
Weed	A plant, often a self-sown exotic, growing where it is not wanted.
Weed – environmental	A naturalised non-indigenous plant species outside the agricultural context that adversely affects the health, survival or regeneration of indigenous species in natural vegetation communities.
Whole of forest scale	All land categories that are subject to the approved Forest Management Plan..
Wood	The material produced in the stems and branches of trees and other woody plants.
Wood products	All timber and other wood products, inclusive of sawlogs, firewood, chiplogs and other log products supplied to the wood products industry.
Yield	The amount of product produced from the forest by a particular management strategy.

13. References

Abbott, I. & Lonergan, O. 1984, 'Growth Rate and Long-term Population Dynamics of Jarrah (*Eucalyptus marginata* Donn ex Sm.) Regeneration in Western Australian Forest', *Australian Journal of Botany*, vol. 32, pp. 353-362.

Abbott, I. & Williams, M. R. 2011, 'Silvicultural impacts in jarrah forest of Western Australia: synthesis, evaluation, and policy implications of the ForestCheck monitoring project 2001-2006.', *Australian Forestry*, vol. 74, no. 4, pp. 350-360.

Arthrington, A., Booth, T., Colwell, P., Hennessy, K., Howden, M., Hughes, L., Jones, R., Lake, S., Lyne, V., McMicheal, T., Nicholls, N., Torok, S. & Woodruff, R. 2003, *Climate Change: An Australian Guide to the Science and Potential Impacts*, Australian Greenhouse Office, Canberra, ACT.

Bari, M. A. & Ruprecht, J. K. 2003, *Water yield response to land use change in south-west Western Australia*, Department of Environment, Western Australia.

Barry, K. M., Quentin, A., Eyles, A. & Pinkard, E. A. 2011, 'Consequence of resource limitation for recovery from repeated defoliation in Eucalyptus globulus Labilladiere', *Tree Physiology*, vol. 32, pp. 24-35.

Brown, A. E., Zhang, L., McMahon, T. A., Western, A. W. & Vertessy, R. A. 2004, 'A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation', *Journal of Hydrology*, vol. 310, pp. 28-61.

Burrows, N. D., Neyland, M. & Ruprecht, J. K. 2011, *Review of silviculture in forests of south-west Western Australia*.

Calder, I. R. 1998, 'Water use by forests, limits and controls', *Tree Physiology*, vol. 18, no. 8-9, pp. 625-631.

Croton, J. T. & Bari, M. A. 2001a, 'Using WEC-C, a distributed, deterministic catchment model, to simulate hydrologic responses to agricultural clearing', *Environmental Modelling & Software*, vol. 16, no. 7, pp. 601-614.

Croton, J. T. & Barry, D. A. 2001b, 'WEC-C: a distributed, deterministic catchment model — theory, formulation and testing', *Environmental Modelling & Software*, vol. 16, no. 7, pp. 583-599.

CSIRO 2009, *Surface water yields in south-west Western Australia. A report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project.*, CSIRO, Australia.

Department of Agriculture and Food Western Australia 2007, *Code of Practice for the use of Agricultural and Veterinary Chemicals in Western Australia*, Perth, Western Australia.

Department of Environment and Conservaiton 2011, *Jarrah Silvicultural Burning Manual*, Perth, WA.

Department of Environment and Conservation 2009a, *Guidelines for Protection of the Values of Informal Reserves and Fauna Habitat Zones*, Department of Environment and Conservation, Perth, Western Australia, SFM Series No. 4.

Department of Environment and Conservation 2009b, *Manual for the management of surface water*, Department of Environment and Conservation, Perth, WA.

Department of Environment and Conservation 2009c, *Soil and water conservation guideline*, Perth, WA.

Department of Health 2007, *Use of Herbicides in water catchment areas*, Perth, WA, Circular.

Department of Parks and Wildlife 2014, *Reference Material for Jarrah Forest Silviculture*, Department of Parks and Wildlife, Perth, WA.

Douglas, J. E. *Silviculture for Water Yield*, U.S. Forest Service, Franklin, North Carolina.

Douglas, J. E. 1983, 'The potential for water yield augmentation from forest management in the eastern United States', *Water Resources Bulletin*, vol. 19, no. 3, pp. 351-358.

Erskine, W. D. 2004, 'Water yield response to integrated native forest management in southeastern Australia', paper presented to Integrated Water Resources Management, Davis, California.

Feikema, P., Lane, P., Peel, M., Sherwin, C., Freebairn, A. & Salkin, O. 2006, *Hydrological studies into the impact of timber harvsting on water yield in state forests supplying water to Melbourne - Part 1 of Hydrological studies*, Victoria.

Hughes, J. D., Petrone, K. C. & Silberstein, R. P. 2012, 'Drought, groundwater storage and stream flow decline in southwestern Australia', *Geophysical Research Letters*, vol. 39, no. 3, p. L03408.

Kaye, J. P., Hart, S. C., Cobb, R. C. & Stone, J. E. 1999, 'Water and nutrient outflow following the ecological restoration of a ponderosa pine bunchgrass ecosystem', *Restoration Ecology*, vol. 7, no. 3, pp. 252-261.

Kinal, J. & Stoneman, G. L. 2012, 'Disconnection of groundwater from surface water causes a fundamental change in hydrology in a forested catchment in south-western Australia', *Journal of Hydrology*, vol. 472, pp. 14-24.

Marshal, J. K. & Chester, G. W. 1992, *Effect of Forest Thinning on Jarrah (Eucalyptus marginata) Water Uptake*, CSIRO, Western Australia.

Mattiske, E. M. & Havel, J. 2002, *Delineation of landscape conservaton units in southwest region of Western Australia*, Department of Conservation and Land Management, Perth, Western Australia.

Millar, M., Byrne, M. & Coates, K. D. 2007, *Seed Collection Zones for State Forest Management*, Department of Environment and Conservation - Science Division.

Montreal Process Implementation Group for Australia 2008, *Australia's State of the Forest Report*, Canberra, ACT.

Nabuurs, G. J., Maser, O., Andasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P., Karjalainen, T., Krankina, O., Kurz, W. A., Matusmoto, M., Oyhantacabal, W., Ravindranath, N. H., Sanz Sanchez, M. J. & Zhang, X. 2007, 'Forestry (9)', in B Metz, OR Davidson, PR Bosch, R Dave & LA Meyer (eds), *Climate Change (2007): Mitigation, Contribution of Working Group III to the Fourth Assessment report of the Intergovenmental Panel on Climate Change*, Cambridge University Press, UK, and NY, USA.

Rab, M. A., Bradshaw, F. J., Campbell, R. G. & Murphy, S. 2005, *Review of factors affecting disturbance compaction and trafficability of soils with particular reference to timber harvesting in the south-west forests*, Western Australia.

Ritson, P., Herbert, E. J. & Shea, S. R. 1981, *Groundwater hydrology studies in the yarragil catchment, Western Australia*, 66, Western Australia.

Stednick, J. D. 1996, 'Monitoring the effects of timber harvesting on annual water yield', *Journal of Hydrology*, vol. 176, pp. 79-95.

Stoneman, G. L. 1986, *Thinning a small jarrah forest catchment: streamflow and groundwater response after 2 years*, Brisbane, QLD.

Stoneman, G. L. 1993, 'Hydrological response to thinning a small jarrah (Eucalyptus marginata) forest catchment', *Journal of Hydrology*, vol. 150, no. 2–4, pp. 393-407.

Stoneman, G. L., Crombie, D. S., Whitford, K., Hingston, F. J., Giles, R., Portlock, C. C., Galbraith, J. H. & Dimmock, G. M. 1996, 'Growth and water relations of *Eucalyptus marginata* (jarrah) stands in responset to thinning and fertilisation', *Tree Physiology*, vol. 16, pp. 267-274.

Vertessy, R. 1998, *Predicting water yield from mountain ash forest catchments*, Monash University, Clayton Victoria.

Whitford, K. R., Stoneman, G. L., Seymour, A., Murray, P., Eaton, L. & Tanimoto, M. 2012, 'The effects of cording, timber load and soil gravel content on soil compaction during timber harvesting on moist soils', *Australian Forestry*, vol. 75, no. 2, pp. 107-119.

Whitford, K. R. & Williams, M. R. 2001, 'Hollows in jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) trees II. Selecting trees to retain for hollow dependent fauna', *Forest Ecology and Management*, vol. 160, pp. 215-232.