

**A review of forestry impacts on
biodiversity and the effectiveness
of ‘off-reserve’ management
actions in areas covered by the
Tasmanian forest practices
system**

AJ Koch, A Chuter and SA Munks
Forest Practices Authority, Hobart



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Front page photograph: A view of a managed landscape in southwest Tasmania (A Koch).

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Glossary

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.

Biodiversity: The variability among living organisms from all sources (including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part). This includes diversity within species and between species and diversity of ecosystems.

Biodiversity Landscape Planning Guideline: A framework for the management of RFA priority species and their habitats at the landscape scale, developed to complete Milestone 19 of the RFA priority species project (http://www.fpa.tas.gov.au/research_and_monitoring/fpa_special_projects/rfa_priority_species_project).

Bulk density: Weight of a unit volume of a loose material (such as a powder or soil). That is, it is a measure of how compact a material is.

CAR Reserve: Comprehensive, Adequate and Representative reserve system, as defined in the Tasmanian Regional Forest Agreement 1997.

Class 4 stream: As defined by the Forest Practices Code, class 4 streams are streams with a catchment of less than 50 ha.

Clearfelling: The felling of all or nearly all trees from a specific area in one operation. The term applies to patches with a diameter greater than four to six times average tree height.

Conservation: The wise use of natural resources, on a sustainable basis, to meet the needs of both present and future generations.

Coupe: An area of forest of variable size, shape and orientation, on which harvesting takes place, usually to be harvested and regenerated over one or two years.

Culvert: A conduit, typically of manufactured piping or logs, that provides for passage of water.

DPIPWE: Department of Primary Industries, Parks, Water and Environment, which includes the Resources Management and Conservation Division and the Threatened Species Section.

Forest Practices Authority (FPA): The independent statutory body responsible for administering the *Forest Practices Act 1985* through the development and management of the Forest Practices System.

Forest Practices Code: A Code established under the *Forest Practices Act 1985* which prescribes the manner in which forest practices must be conducted in order to provide reasonable protection of the environment.

Forest Practices Officer (FPO): FPOs are employed either by forest owners or the forest industry to prepare and supervise the implementation of Forest Practices Plans. They are trained, authorised, directed and monitored by the FPA. Selected FPOs are authorised to certify FPPs.

Forest Practices Plan (FPP): A plan for forest operations, specified in Section 18 of the *Forest Practices Act 1985*. FPPs contain prescriptions and a map detailing how the planned operations will be conducted. FPPs must be consistent with the Forest Practices Code and be certified by an FPO before forest operations start.

Forest Practices System: The system established pursuant to the objective set out in schedule 7 of the *Forest Practices Act 1985*.

Forestry Tasmania: Responsible body for management of public land within the forest practices system.

Geomorphology: The study of the physical features of the surface of the earth and their relation to its geological structures.

Habitat: The biophysical medium or media (a) occupied (continuously, periodically or occasionally) by an organism or group of organisms; or (b) once occupied (continuously, periodically or occasionally) by an organism, or group of organisms, and into which organisms of that kind have the potential to be reintroduced.

Habitat tree: As defined in the Forest Practices Code, a habitat tree is a mature living tree selected to be retained in a coupe because it has features of special value for wildlife (e.g. hollows). Habitat trees should be selected on the basis of size and the presence of hollows or the potential to develop hollows over time.

Hydrology: The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Karst: A landscape that results from the high degree of solubility in natural waters of the bedrock. Underground drainage, sinkholes and limestone caves are the best known components of karst.

Landing: An area to which logs are pulled and where logs are loaded onto trucks. That is, it is the working area for cross-cutting, sorting and loading of logs but does not include areas used solely for stockpiling.

Land clearing: The removal and destruction of all native vegetation and vegetation types, including individual trees, woodlands, grasslands, forests and wetlands.

Native forest: Any naturally occurring forest community containing the full complement of native species and habitats normally associated with that community, or having the potential to develop these characteristics. Native forests include mature, regrowth and regenerating forests.

Monitoring: The regular observation and recording of activities taking place in a project or programme.

Monitoring – implementation: Monitoring which is used to determine whether prescribed management is actually conducted.

Monitoring – effectiveness: Monitoring which is used to determine whether the management specified has achieved its objective.

Old-growth forest: Ecologically mature forest where the effects of unnatural disturbance are now negligible. The definition focuses on forest in which the upper stratum or overstorey is in a late mature to senescent growth stage (JANIS 1997).

Partial harvesting: Harvesting systems which include the retention of some trees.

Planning tool: An instrument to deliver information to forest practitioners on the management approach for a particular value in areas covered by the forest practices system.

Plantation: A forest stand established by the planting of seedlings or cuttings of trees selected for their wood producing properties and managed intensively for the purpose of future timber harvesting.

Prescription: A detailed specification of the objectives, area, procedures and standards for a task to be undertaken.

Private land: A land tenure arrangement where the land is permanently owned and not leased.

Regeneration: The renewal of a tree crop arising from planting or from seed or the young plants on a site.

Regional Forest Agreements (RFAs): 20-year plans, signed by the Australian and certain State governments, for the conservation and sustainable management of certain areas of Australia's native forests.

Reserve – formal: Publically managed land tenures that can only be revoked with parliamentary approval.

Reserve – informal: Land protected through administrative instruments by public authorities.

Reserve – private: Private land managed under secure arrangements, including proclamation under legislation, contractual agreements such as management agreements and covenants, and reserves set aside under independently certified forest management systems.

Riparian: Pertaining to the banks of streams, rivers or lakes.

Rotation: The planned number of years between the establishment of a crop and its felling.

Saproxyllic: Species that feed on decaying wood.

Silviculture: The theory and practice of managing forest establishment, composition and growth to achieve specified management objectives.

Sinkhole: A closed depression draining underground in karst, of simple but variable form (e.g. cylindrical, conical, bowl or dish-shaped), from few to many hundreds of metres in dimensions.

Snig track: A track along which logs are pulled from the felling point to a nearby landing.

Soil erodibility: The inherent susceptibility of a soil to erosion (detachment and movement of soil particles or aggregates) by processes such as rainfall, runoff, throughflow, wind and frost.

State forest: Forest on Public land which has been designated multiple-use forest by Parliament, under the *Forestry Act 1920*. This land, which includes purchased land, is managed by Forestry Tasmania.

Stand: A group of trees or patch of forest that can be distinguished from other groups on the basis of size, age, species composition, condition or other attribute.

Structure: When applied to a forest is the vertical and spatial distribution of the vegetation.

Threatened: When used in association with a species, population or community indicates that it is listed under the *Threatened Species Protection Act 1995* or the *Environment Protection and Biodiversity Conservation Act 1999*.

Acronyms

CAR Reserve: Comprehensive, Adequate and Representative reserve system

CFA: Community Forest Agreement

DPIPWE: Tasmanian Department of Primary Industries, Water and Environment

FPA: Forest Practices Authority

FPO: Forest Practices Officer

FPP: Forest Practices Plan

RFA: Regional Forest Agreement

SMART: Specific, Measurable, Achievable and Aligned, Resourced, and Timed

WHS: Wildlife habitat strip

WHC: Wildlife habitat clump

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DRAFT

A review of forestry impacts on biodiversity and the effectiveness of ‘off-reserve’ management actions in areas covered by the Tasmanian forest practices system

Summary

- This document was prepared for the Independent Verification Group to assist its review of the High Conservation Value areas identified as part of the Tasmanian Inter-government Agreement.
- Ecological theory has identified several key aspects of a comprehensive system for managing forest biodiversity. Reserves are one key element for maintaining biodiversity, but there are limitations in how effective reserves can be. Another key element of a comprehensive system is management in areas outside of reserves. In Tasmania forestry activities in areas outside of formal reserves are regulated through the forest practices system. The forest practices system requires a variety of management practices to be applied across the forest estate to help achieve the objective of the *Forest Practices Act*. The objective of the *Forest Practices Act* is to “achieve sustainable management of Crown and private forests with due care for the environment...”
- The main impacts of native forestry on the environment that we identified were (1) alteration in forest age structure, (2) alteration of aquatic systems, (3) alteration of soil structure and productivity, and (4) habitat fragmentation and introduction of exotic species. We provide a summary of the research that has been done looking at these impacts, and how these impacts relate to biodiversity. Some species are directly or indirectly impacted by forestry in ways not covered by these four main impacts. The impact on particular species is mentioned, but not covered in detail in this report.
- It is important to assess how effective forest management is in mitigating the impacts of forestry. We provide a summary of research assessing the effectiveness of current management actions. The management actions we considered were: implementation of streamside reserves, wildlife habitat strips, wildlife habitat clumps, coupe dispersal, specific soil management practices, weed and disease management, remnant management, karst management, and species-specific management prescriptions. The amount of research that had been done varied greatly between management practices and none of the practices were comprehensively assessed. Results of research to date indicated that the current prescriptions are effective in maintaining habitat for a range, but not always all, biota.
- The effectiveness studies done are generally small-scale and targeted and do not consider the larger, cumulative and additive impact of forestry and other land-use activities at the landscape-scale. To assess this landscape-scale impact it is important to do species trend monitoring as well as the more targeted effectiveness monitoring studies. There are some species trend monitoring studies carried out by DPIPW, but a more systematic and comprehensive trend monitoring program needs to be initiated by the State.

- We conclude that the current management actions delivered via the forest practices system, despite their limitations, play an important role in ameliorating forestry impacts and maintaining forest biodiversity. This review highlights the importance of having a range of approaches to maintain forest biodiversity, and the need for a landscape-scale assessment of biodiversity management. The forest practices system has an adaptive management approach, with research and monitoring as a key component to ensure the management system continues to improve.

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1. Introduction

Tasmania's forests are highly valued for their unique biodiversity. They contain many different plant communities, over 900 vascular plant species, 131 vertebrate fauna species and several orders of magnitude more species of invertebrates, non vascular plants, fungi and algae. The forestry industry produces products from these forests that are widely used by society. Wood products are arguably very sustainable, because trees can continue to be grown over time. However, harvesting and some of the associated forestry practices can have significant impacts on the biota of an area. Consequently in Tasmania, as elsewhere, management strategies are adopted to minimise the impacts that forestry can have on the environment.

A number of principles to guide the development of biodiversity conservation strategies in production forest environments are provided in the ecological literature (Lindenmayer & Franklin 2002; Lindenmayer et al. 2006). These principles are:

- maintenance of connectivity;
- maintenance of landscape heterogeneity;
- maintenance of stand structural complexity;
- maintenance of the integrity of aquatic systems by sustaining hydrologic and geomorphological processes;
- use of natural disturbance regimes to guide human disturbance regimes.

These principles are necessarily broad. How these principles are addressed will determine how effectively biodiversity is maintained in that landscape. For example, landscapes may vary greatly in the size, distribution and abundance of the different landscape elements. Thus different landscapes can be described as being 'heterogeneous', but these landscapes can differ greatly in how well they maintain particular forest biota.

To address the principles that are outlined above, the ecological literature identifies the following as three important elements of a comprehensive approach to maintaining biodiversity in production forests (Lindenmayer & Franklin 2002):

- Large ecological reserves
- Landscape-level matrix management strategies
- Stand-level matrix management strategies.

While reserves are a critical component of a conservation management system, there are limitations to how well reserves maintain biodiversity, which is why landscape-level and stand-level management strategies in the matrix outside of reserves are also important.

1.1 Limitations of reserves as a management strategy

Reserves are areas where anthropogenic activities are restricted. Formal reserves are publically managed land tenures that can only be revoked with parliamentary approval. Informal reserves are land protected through administrative instruments by public authorities. Private reserves are private land managed under secure arrangements, including proclamation under legislation, contractual agreements such as management agreements and covenants, and reserves set aside under independently certified forest management systems.

Reserves are typically subject to minimal human disturbance and thus they provide an important refuge for many species that are sensitive to disturbance. However, the distribution and ecological requirements of native biota is extremely diverse. This means that reserves are not a comprehensive conservation strategy for maintaining biodiversity. The limitations of using a formal reserve system alone to try and achieve conservation objectives are discussed in Lindenmayer and Franklin (1994), but we give a summary of the key points below.

- A limited area is available to allocate to reserves.
- Most reserves are relatively small.
- Reserve networks are often not representative of the broader landscape (i.e. reserves are frequently located in lower productivity environments).
- There are social and economic impediments to the expansion and management of reserve systems.
- Habitat for highly mobile taxa, such as migratory or nomadic species, may not always be captured in reserves.
- Reserves are unlikely to capture all species with fine-scale or patchy distribution patterns.
- The limited size of most reserves means it may be difficult to capture sufficient habitat for territorial species with large home ranges.
- Instability of abiotic and biotic conditions within reserves
- Reserves can potentially impact the habitat value of other areas. For example intensification of matrix exploitation may occur once reserve systems are established, which can degrade productivity on matrix lands and reduce the contribution the matrix makes to conservation (Lindenmayer & Franklin 2002).
- Forest biodiversity changes between young and old forests, so a range of age classes are required to maintain biodiversity. Disturbance is typically minimised in reserve areas, meaning they provide limited habitat for some taxa.
- Funding for management within reserves is frequently limited.

While reserves are a critical part of a biodiversity management strategy, they should be regarded as only one aspect of a comprehensive management strategy for maintaining forest biodiversity (Lindenmayer & Franklin 2002) and need to be complemented by management of areas outside of reserves.

1.2 The Tasmanian forest practices system

Tasmania has a complex legislative and policy framework that delivers a variety of mechanisms to conserve forest biodiversity. These include the establishment of an extensive reserve network and complementary management actions for biodiversity outside of reserves.

The Tasmanian forest practices system contributes to the conservation of biodiversity in areas outside of reserves by delivering management actions for activities covered by the Tasmanian *Forest Practices Act 1985*. There are two primary elements to the approach:

- the maintenance of a permanent native forest estate to ensure that a forest resource base is maintained for all its various values, including biodiversity; and
- the regulation of forest practices under the *Forest Practices Code* and associated planning tools that take into account the requirements of current legislation, agreements, and recovery plan actions for biodiversity values.

The statutory objective of the forest practices system is to:

“achieve sustainable management of Crown and private forests with due care for the environment....”

The main tool for delivering the objective of the *Forest Practices Act* is the Forest Practices Code (hereafter referred to as ‘the Code’). Two of the general principles of the Code that relate to biodiversity are provided below.

- *Timber harvesting will be planned and carried out to minimise long term impact on the environment and to protect productivity of the site.*
- *Conservation of flora and fauna is assisted by the maintenance and restoration of habitat, the enhancement of opportunities for recolonisation of disturbed areas, and the linking of forest areas to allow genetic interchange.*

The Forest Practice Code and associated planning tools deliver a wide array of management prescriptions. Many of these prescriptions aim to help maintain biodiversity in the production forest landscape. An overview of the policies, processes and management actions that aim to help maintain biodiversity is provided in Chuter and Munks (2011a), and further details can be found at the FPA website (www.fpa.tas.gov.au) as well as several other publications (Koch 2007; Wapstra 2007a, 2007b, 2008b).

The management prescriptions outlined in the Code and associated documents contribute to achieving the principles of good forest management outlined above.

The development of scientifically-based management prescriptions may be limited by a lack of relevant information. It is therefore critical that an adaptive management system is applied, to ensure continual improvement. The process of adaptive management involves several steps, which are:

- To establish the management objective;
- To use research to inform the development of management provisions;

- To implement the management provisions;
- To assess how effective management is in achieving the objective; and
- To review and revise the management provisions.

Two types of monitoring are critical components of the adaptive management process; implementation monitoring and effectiveness monitoring. Implementation monitoring assesses whether the prescribed management is actually conducted. Effectiveness monitoring assesses whether the management achieves its objective.

Effectiveness monitoring, and then adapting management strategies as a result of research findings, is particularly important in areas that are intensively managed. The amount of land placed into formal reserves has substantially increased in Tasmania since 1996, largely as a result of a series of inter-governmental forest agreements (e.g. RFA, CFA). However, there has been no commensurate decrease in wood production from the remaining area of native forest. Consequently it is becoming increasingly important to assess the effectiveness of the forest practices system for maintaining biodiversity outside of reserves.

A review of the implementation of current Tasmanian forest management prescriptions is provided by Chuter and Munks (2011b) and a review of approaches to effectiveness monitoring in forestry areas is provided in Munks and Koch (2011). The current report reviews what is known about the effectiveness of the Tasmanian forest management prescriptions for biodiversity.

1.3 Aim and scope of this report

The main aim of the current report is to review both the broad impact of native forest operations on biodiversity and information on the effectiveness of current management in ameliorating that impact. A detailed review of the impact forestry operations have on biodiversity has not been possible due to the short time available for writing this report.

The effects of forestry activities on individual species and how the requirements of these species are taken into account in areas covered by the forest practices system are not covered in depth in this report, and only a few examples are given. More information on threatened species (and RFA priority species) is provided in other review documents including Recovery Plans and Background documents produced as part of the review of the Threatened Fauna Adviser (see

www.fpa.tas.gov.au/research_and_monitoring/fpa_special_projects/threatened_fauna_review).

The effects of plantation forestry on biodiversity have been covered in a recent review (Grimbacher 2011) and so will not be discussed in the current report.

1.4 Methods

The current review was conducted by using the Web of Knowledge database to search for articles that refer to both 'forest' and 'Tasmania', published between 1999 and the current day (the current version of the Code was released in 2000). The titles of all articles were

perused, but only articles considered relevant to the current review were read. Some searches were done for particular authors (e.g. Baker, S., Grove, S.). Additional articles were found from sources already known to the authors, or because they were referred to by other articles. This includes an earlier report that reviewed fauna conservation in Tasmanian production forests (Taylor 1991).

In this review we consider the following primary management actions, implemented via the forest practices system, in relation to the main impacts identified:

- Wildlife habitat strips
- Wildlife habitat clumps
- Coupe dispersal
- Streamside reserves
- Soil management actions
- Remnant management
- Karst management
- Weed and disease management actions
- Species-specific prescriptions.

For each action we gathered the following information:

- A description of the management practice (the Forest Practices Code or associated Technical Notes should be referred to for greater detail).
- The objective for the management practice, where available. The Code provides a set of principles and a basic approach, but clear objectives for each management prescriptions are not always provided. Where possible, we provide a copy of relevant words in the Code that may be interpreted as an objective. These ‘objectives’ do not generally follow the SMART (Specific, Measurable, Achievable and Aligned, Resourced, and Timed) format that is desired for clear objectives (Koch et al. 2011), meaning it can be difficult to assess how well the objective is achieved. Consequently when conducting this review we also consider the general objective identified in the literature, which is ‘maintenance of suitable habitat at multiple spatial scales’ (Lindenmayer & Franklin 2002), and the objective of the *Forest Practices Act*, which is to have ‘due care for the environment’.
- Outcomes of research that has assessed the effectiveness of the management action. The research done is rarely comprehensive, and much of the work has focused on wet forest areas subject to intensive silvicultural practices (e.g. clearfall, burn and sow) and areas of young regeneration (<15yo). The effectiveness of the provisions is likely to vary with silvicultural system, vegetation type, and may vary as the regenerating forest ages. We have tried to keep the summary of the results concise, while still providing sufficient detail to enable an understanding of the limitations of the research.

2. Impacts of native forestry on biodiversity, current management actions and their effectiveness

The impact of harvesting depends on the type of silviculture used, the taxa in question, the spatial and temporal scales of both harvesting and at which the impact is being assessed, and the context of the area surrounding a harvest operation. Although a full review was not possible within the time constraints of this project, forestry impacts on biodiversity can be broadly classified as follows:

- alteration in forest age structure;
- alteration of hydrological processes;
- alteration of soil structure and productivity;
- habitat fragmentation and introduction of exotic species.

In this section of the report we summarise the information gathered on these effects, current management actions to ameliorate their effect on biodiversity, and the effectiveness of these measures.

We also briefly cover species-specific impacts, providing some examples for threatened species. However a full review of this area was not possible.

2.1 Alteration of forest age structure

‘Natural’ forests (i.e. pre-European colonisation in the Australian context) typically have a range of ages that result from disturbance such as wildfire. The different age classes provide habitat for different species. One of the biggest effects of forest harvesting is that it generally alters the age class distribution of forests in a landscape, by increasing the abundance and distribution of younger forest and decreasing the abundance of older forest. It is therefore important to understand the ways in which mature forest and landscape heterogeneity influence the biodiversity of forested areas.

2.1.1 Reduction in mature habitat

There are many ways to define what is meant by ‘mature’. In this report we refer to trees and forest as being ‘mature’ when they start developing features typical of old forests. This definition is not influenced by the historic disturbance of an area (i.e. an area can have a history of disturbance but still be classified as mature if the relevant ecological features are present).

Trees and forests change as they age, and the changes can mean more or less habitat is available for different species. Given the reduction in availability of mature forest habitat in areas utilised for wood production, it is essential to consider how and why mature habitat is important.

Mature trees are more likely than younger trees to have:

- large trunk surfaces, which provide important habitat for species that forage on bark;

- large crowns, which provide a greater foraging resource for species that feed on the flowers and fruits of trees (Brereton et al. 2004);
- large branches, which are needed by some species for building nesting platforms (Wiersma et al. 2009);
- tree hollows, which provide important nesting/roosting/denning habitat for some species (Koch et al. 2008a).

Compared to younger forest, mature forest can:

- have more large mature trees, with the habitat features they provide;
- have more large logs, which have a different suite of fungi and invertebrates than small logs;
- be less prone to windthrow (Neyland 2004; Wood et al. 2008);
- have a different stand structure, microclimate and vegetation composition (Westphalen 2003).

A number of studies have compared the biodiversity of young (post-harvest) and old forest. Most of these studies have been conducted in wet forest, and many suffer from limited replication. Despite these limitations it is clear that for most taxa different species display a range of different responses. That is, some species have highest densities in recently harvested areas, some in older areas, some at forest edges, and some species show no difference in density with forest age. Some generalisations for the different taxa are provided below.

- Species richness and abundance of **birds** is generally higher in mature than in regrowth forest, but the change in species richness appears to be largely a result of the change in abundance rather than due to the exclusion of many species. However there is often a sequential and gradual change in bird assemblages as a patch of forest ages and develops the features found in older forest, with some species preferring younger forest and other species older forest. The assemblage composition in harvested areas can approach that of unharvested areas within a relatively short period of time, particularly if mature habitat is available within the harvested area. (Hingston & Grove 2010; Lefort & Grove 2009; Taylor et al. 1997; Taylor & Haseler 1995).
- Many herbivorous **mammals** reach greatest densities on forest edges associated with harvesting, burning or cleared land. As with birds, some species occur at greater densities in younger forest, while other species require features such as hollows found in older forest (although some hollow-using species like pygmy possums can use alternative denning sites in younger forest), and some species have equivalent densities in harvested and unharvested areas. Most mammals are relatively mobile and so can move between young and old forest patches to cater for their habitat requirements (e.g. foraging in younger forest and denning in hollows in older forest). (Cawthen 2011; Duncan & Taylor 2001; Flynn et al. 2011; Stephens et al. 2012; Taylor 1991; Taylor & Savva 1988).
- The occurrence of **amphibians** is more related to the type of waterbody in an area rather than vegetation type. One common species has been found to occur at higher

densities on forest edges, with similarly low densities in logged areas and intact forest suggesting an overall positive impact of forestry for some species. However, there may be a reduction in reproductive output in logged areas for other species. (Baker & Lauck 2006; Lauck 2005; Lauck et al. 2008; Taylor 1991).

- **Reptiles** are affected by the density and occurrence of gaps in the canopy, due to their thermoregulatory requirements. We found no Tasmanian studies examining the impact of forest age on Tasmanian reptiles. Many species preferentially use rocky areas which are less likely to be harvested. It is therefore expected that forestry will have a minimal impact on most species. (Taylor 1991).
- The assemblage of aerial, ground-dwelling and saproxylic **invertebrates** can be very different in young and old trees and forest (even comparing 100 year-old trees to oldgrowth trees). The diversity of species is generally (but not always) higher in older trees/logs/forest, but for some taxa the species assemblage is influenced more by geographic distribution than tree or forest age. Even heavily modified landscapes such as plantations can host a variety of native species. The impact of harvesting on some species can be influenced by site management, such as the availability of post-harvest slash and stump residue. (Baker 2006; Baker et al. 2009b; Bar-Ness et al. 2006; Bonham et al. 2002; Grove & Forster 2011; Michaels & Bornemissza 1999; Wardlaw et al. 2009; Yee et al. 2006).
- There is some, but minimal difference in **plant** diversity between young regenerating sites and old sites, particularly in sclerophyllous forest. The plants most likely to have a reduced abundance after harvesting, at least in the short to medium term, are epiphytic ferns and rainforest species. (Baker & Read 2011; Brown 1996; Courtney et al. 2005; Hickey 1994; Neyland & Lasala 2005; Packham et al. 2002; Tabor et al. 2007; Wapstra et al. 2003a).
- Mature and young regrowth forests both have rich, but distinctly different **fungal** floras. Different genera occur on different substrates (soil, leaf litter, coarse woody debris, other dead wood, dead and living trees), which vary in availability between young and old forests. The different wood rot fungi in young and old trees can influence the diversity of invertebrates in the wood. Both mature and regrowth forests contain ectomycorrhizal species, but species richness is greater in mature forest. (Gates et al. 2011a; Gates et al. 2011b; Gates et al. 2011c; Gates et al. 2005, 2009; Hopkins et al. 2005; Packham et al. 2002; Ratkowsky & Gates 2009).
- The species richness of **bryophytes** increases with tree diameter. While most of the species found in eucalypt regrowth forest are also found in mature eucalypt forest, the reverse is not always the case (although some species are more typical of young forest). Typically there are a few highly frequent species in young forest (most of which do not persist in later stages), a large number of species start establishing in middle-aged forests, and some die out with their short-lived hosts in old growth forest. Liverworts are more prominent in older forest. Many bryophytes have associations with fallen branches, logs and soil and the availability of these substrates may determine species richness. The recovery after logging of an understorey similar in vascular plant composition and structure to that present before logging is

considered critical in regaining the pre-logging cryptogamic flora, especially with respect to specialist species. (Browning et al. 2010; Hodge et al. 2009; Jarman & Kantvilas 2001; Kantvilas & Jarman 2004; Turner et al. 2011; Turner & Pharo 2005).

- **Lichens** are considered to be among the species most sensitive to harvesting. They are mostly consumed by fire and so few survive after forestry burns. Recovery by lichens after logging is limited by the availability of suitable substrate such as residual tree stumps. The species richness of lichens increases with tree diameter and forest age. (Baker & Read 2011; Browning et al. 2010; Kantvilas & Jarman 2006).

2.1.2 Change in spatial arrangement of age classes (age structure heterogeneity)

Mature trees and forest provide important habitat for a large range of species (see above). Post-harvest regrowth stands are generally more uniform in tree age than oldgrowth forest or forest resulting from natural disturbance (Turner et al. 2009). Therefore in-coupe retention of old trees, and the distribution and intensity of harvesting will influence the spatial occurrence of mature habitat. It is generally considered important to have mature forest distributed across the landscape for a number of reasons: to provide suitable habitat for dispersal-limited species that are dependent on mature forest features; to provide a refuge for species until the harvested area provides suitable habitat; and to assist recolonisation of the harvested area. For many species with limited dispersal ability (e.g. some lichens, bryophytes, epiphytic ferns, plants, and flightless invertebrates), the distance from the harvested area to mature forest, as well as the availability of suitable habitat in the harvested area, is likely to determine whether and when they will recolonise the harvested area (Grove & Forster 2011; Hodge et al. 2009; Kantvilas & Jarman 2006; Tabor et al. 2007). Many taxa demonstrate a high level of species turnover within short distances (hundreds to thousands of metres), even within undisturbed forest (Baker et al. 2007a; Bar-Ness et al. 2006). This emphasises the importance of maintaining a mosaic of mature and young forest in production forest landscapes.

2.1.3 Current management actions

Wildlife habitat clumps and *wildlife habitat strips* are management actions delivered via the Forest Practices Code and associated planning tools that specifically target retention of mature forest at different spatial scales.

The intended objective of a *wildlife habitat strip* is interpreted from the Forest Practices Code to be:

“Wildlife habitat strips should be retained to maintain habitat diversity” (Forest Practices Board 2000).

Wildlife habitat strips are prescribed in the Forest Practices Code as follows:

“As a guide, strips of uncut forest 100 m in width, based on streamside reserves but including links up slopes and across ridges to connect with watercourses in adjoining catchments, should be provided every 3-5 km. These strips should connect any large patches of forest which are not to be harvested, such as formal and informal reserves.”

Wildlife habitat strips were established in state forest in the late 1980s (Jennings & Wardlaw 2006) and only rarely is the location of a wildlife habitat strip adjusted. Wildlife habitat strips are implemented primarily on state forest and are believed to be comprised largely of mature habitat, although no formal study has been conducted (S. Munks, pers. comm.). Most wildlife habitat strips are located in riparian areas, effectively widening streamside reserves (Grove 2010).

Although not clearly stated as such, the current wording of the Tasmanian Forest Practices Code implies that the objective of a *wildlife habitat clump* is:

‘... to assist the maintenance of habitat required by hollow dependent fauna and enhance recolonisation of areas following harvest’ (Forest Practices Board 2000).

A recent review of the biodiversity provisions of the Forest Practices Code recommended a new objective (Biodiversity Review Panel 2009; Munks et al. 2009). This objective has not been endorsed, but the working draft is:

‘to ensure a continued supply of hollow-bearing trees at the stand level to assist in the maintenance of populations of hollow-using species across their range’

Wildlife habitat clumps are prescribed in the Forest Practices Code as follows:

Patches of mature forest (wildlife habitat clumps) containing habitat trees with nesting hollows and other oldgrowth structural elements should be retained in coupes with few retained areas (e.g. streamside reserves, areas reserved for other values, areas reserved for operational reasons etc.).

Within coupes where no burning or low intensity burning is intended (mainly partially harvested coupes), wildlife habitat clumps should be retained in areas which are not within 200 m of other retained areas. Clumps should be retained at a rate of approximately 1 clump every 5 ha and should contain a minimum of 2 to 3 habitat trees and where possible a range of trees and shrubs of other ages.

In coupes where high intensity burning is required to achieve regeneration or where cable harvesting is used (mainly clearfell coupes), wildlife habitat clumps should be retained along the boundary of the coupe where they can be protected from disturbance. As a guide retain clumps at approximately 200 m intervals along a coupe boundary in areas not within 200 m of other reserved areas. These clumps should be about 50 m by 20 m in size. Consideration should be given to retaining adjoining clumps when adjacent coupes are felled.

Greater detail is provided on how to implement these clumps in FPA Technical Note 7, and greater detail on identifying habitat trees is provided in the Hollows Booklet (Koch 2009). In dry forest areas, wildlife habitat clumps are generally about 0.1ha in size (Duhig et al. 2000).

Other management actions that also contribute to the maintenance of mature habitat by default include *streamside reserves*, areas retained for *specific species management*, or areas

set aside for the management of other values (e.g. visual or cultural management). Additional areas may also be retained for other reasons (such as areas that are not commercially viable), and these areas may also provide some mature habitat.

The Code requirements for *coupe dispersal* will also have some effect on managing age structure at a landscape scale, but the current provisions will only have an effect on vegetation cover, rather than structure, and do not provide for mature habitat.

The Forest Practices Code states:

In native forest to be harvested by clearfelling and subsequently managed as native forest, planning should incorporate a dispersed coupe design. To achieve this:

- *A regeneration unit or cutting coupe should not exceed 100 ha but the requirement for safe burning boundaries may over-ride this limit;*
- *The cutting sequence of regeneration units should where practicable be planned so that adjacent areas of native forest are not harvested until the dominant height of the regeneration of any adjoining coupe is at least 5 m and an acceptable stocking standard is achieved.*
- *Dispersed harvesting is desirable in non-clearfelling operations.*
- *Dispersed harvesting should be considered for plantations. Large blocks of plantation established at a similar time should be managed to improve dispersal over subsequent rotations.*

Although not clearly stated as such, the current wording of the Forest Practices Code implies that the objective of coupe dispersal is:

By dispersing harvesting in space and time any localised impact on natural and cultural values will be reduced.

The only strategy that clearly contributes to the management of mature habitat at the landscape-scale is the establishment of *wildlife habitat strips*. The combination of *wildlife habitat strips* and other management practices will often result in mature forest being distributed across the landscape. However, there is currently no policy in place to ensure the maintenance of age structure heterogeneity.

2.1.4 Effectiveness of management actions

We found a number of studies that provided information on the effectiveness of current management in ameliorating the impacts on biodiversity of age structure alteration due to wood production activities.

Wildlife Habitat Strips

Plants

Wildlife habitat strips adjacent to logged areas (12 year-old regrowth) have been shown to be largely comparable to extensive native forest in both floristic and structural composition, although some plant species may be negatively edge-effected (Duncan et al. 2008). When the

adjacent area is harvested the health of some trees may be lower in wildlife habitat strips compared to extensive forest, particularly for wildlife habitat strips located on ridges (Jennings & Wardlaw 2006). The integrity of some wildlife habitat strips can be compromised by windthrow, fire and weeds. Surveys of wildlife habitat strips adjacent to road edges, largely in plantation areas, found 19% of the wildlife habitat strips assessed had fire damage (mostly from regeneration burns), 44% had windthrow (which was more common if harvesting had occurred next to the wildlife habitat strips and on ridges) and 11% showed invasion by wildling pines (Jennings & Wardlaw 2006). However, severe damage from any one of these disturbance agents was low (i.e. it occurred in less than 5% of wildlife habitat strips examined). For example 60% of windthrow was solely understorey species. In the study conducted on wildlife habitat strips integrity, invasion by wildling pines was seen as the largest ecological concern (although the most common weed species were thistles, foxgloves and blackberry) (Jennings & Wardlaw 2006). Other issues were illegal harvesting and dumping of rubbish in some areas with public access, and damage to wildlife habitat strips during routine maintenance of the plantations (Jennings & Wardlaw 2006).

Birds

Wildlife habitat strips have been found to support a similar bird assemblage to extensive native forest, but how closely bird assemblages correspond varies with the size and location of the wildlife habitat strips. For example, bird species richness and total abundance was found to be lower in wildlife habitat strips (adjacent to 10yo regrowth) compared to extensive native forest in non-riparian sites (upper slopes and ridges), but no difference was found in riparian zones (MacDonald et al. 2005; MacDonald et al. 2002). Longer wildlife habitat strips were more similar to extensive native forest than shorter wildlife habitat strips (the range examined was 0.4-2.1 km), possibly due to the larger size of the retained area (MacDonald et al. 2002). Wildlife habitat strips width may also have increased the habitat value in non-riparian areas (many of the strips examined were narrower than the current requirement of 100 m), but wildlife habitat strips width was not a significant predictor of bird abundance (MacDonald et al. 2002). Therefore the width, but not the area, of most wildlife habitat strips appears to be adequate for maintaining birds in Tasmania. It has been proposed that strips need to be at least 15ha for them to have equivalent habitat value for birds as is found in extensive native forest (MacDonald et al. 2002).

Riparian and non-riparian areas have different bird assemblages, with more low nesting species and smaller birds in riparian areas and more hollow nesting species on slopes (MacDonald et al. 2002). This means the location of wildlife habitat strips may affect how effective they are. In one study the Superb Fairy Wren (*Malurus cyaneus*) on slope sites was the only species to have significantly lower numbers in wildlife habitat strips than in extensive native forest (MacDonald et al. 2002). Another study noted several other species that declined or disappeared from both logged areas and wildlife habitat strips (MacDonald et al. 2005). However, in general it appears that most bird species are found in wildlife habitat strips and the difference in bird assemblages between some wildlife habitat strips and extensive native forest appears to be a result of changes in bird abundance rather than exclusion of particular species (although this is difficult to confirm for rare species)

(MacDonald et al. 2002). Interestingly, one study found that community composition was more similar between the control area and the logged site than between the control area and the wildlife habitat strips (MacDonald et al. 2005). It was suggested that the presence of the wildlife habitat strip ameliorated the impact of harvesting and contributed to the retention of some bird species in the logged area (MacDonald et al. 2005).

Mammals

A study in dry forest found that brushtail possums (*Trichosurus vulpecular*) preferentially den in extensive areas of mature forest and wildlife habitat strips rather than in smaller patches retained within young regrowth forest (Cawthen 2007). Bats have also been shown to regularly roost in wildlife habitat strips, although the proportion of roost sites that were in wildlife habitat strips compared to the proportion in extensive native forest differed between species. One bat species, *Nyctophilus geoffroyi*, seemed to prefer wildlife habitat strips over extensive native forest (Cawthen 2011). We found no other studies that directly examined the value of wildlife habitat strips for mammals. However, mammals may be among the taxa least affected by forestry (as long as some mature habitat is available to provide resources such as tree hollows) (Duncan & Taylor 2001; Flynn et al. 2011; Stephens et al. 2012).

Terrestrial invertebrates

A number of studies have examined the effectiveness of wildlife habitat strips for maintaining ground-dwelling beetles. The species composition of ground-dwelling beetles differs between young regeneration and mature forest, between riparian and non-riparian areas (with lower diversity in riparian areas) (Baker et al. 2006), and between geographic areas (Baker et al. 2007b; Grove & Yaxley 2004). Consequently retention of mature habitat (particularly in non-riparian zones) and connectivity across the landscape is very important for beetle conservation. However, beetles are sensitive to edge effects (Baker et al. 2007b; Grove & Yaxley 2004, 2005), and about 50% of commonly collected mature forest beetle species were shown to be specialised to areas away from forest edges (Baker et al. 2007b). Edge effects were estimated to penetrate approximately 22m into upslope habitat (Baker et al. 2007b) and possibly as far as 65m into riparian areas. These results suggest that 100m wide riparian aligned wildlife habitat strips are entirely edge-affected, while upslope wildlife habitat strips contain 50% interior habitat for ground dwelling beetles when located next to recently harvested areas (1-5 yo) (Baker et al. 2007b). Upslope wildlife habitat strips are therefore expected to provide more habitat for interior-specialist beetles than riparian-aligned wildlife habitat strips (Baker et al. 2007b; Grove & Yaxley 2004, 2005). A study in damp eucalypt forest in northern Tasmania found that plantations, wildlife habitat strips and continuous forest supported a similar number of ground-dwelling beetles (Grove & Yaxley 2005). However species composition varied between sites and wildlife habitat strips supported some, but not all, of the species found in both intact forest and plantations (Grove & Yaxley 2005). A study in high altitude wet eucalypt forest found that the beetle assemblage in non-riparian wildlife habitat strips adjacent to 7-8 year old regrowth was similar to that found before harvesting, although five species showed significant (and inconsistent) changes in abundance (Grove 2010). Some mature forest dependent species have been found in wildlife habitat strips (Forestry Tasmania 1999; Grove 2010).

Summary

Most wildlife habitat strips are located in riparian areas, but species assemblages can differ between riparian and non-riparian areas (Baker et al. 2006; MacDonald et al. 2002) meaning the effectiveness of wildlife habitat strips can vary. For example, riparian wildlife habitat strips were found to be more effective for birds (MacDonald et al. 2005; MacDonald et al. 2002) and upslope wildlife habitat strips more effective for beetles (Baker et al. 2007b). This result supports the guidelines that state that wildlife habitat strips should be applied to a range of topographies (FPA 2010), although the location of wildlife habitat strips in upslope areas should be carefully selected to minimise negative impacts such as loss of canopy health and increased windthrow (Jennings & Wardlaw 2006). Evaluating the distribution and characteristics of wildlife habitat strips is a priority for the FPA monitoring program to enable an assessment of how well they represent upslope and riparian environments around the state.

The current width of wildlife habitat strips appears to be adequate for maintaining many species (e.g. most birds, MacDonald et al. 2002), but not all. The main mature-forest species for which wildlife habitat strips will not provide suitable habitat are those that are strongly edge-effected (e.g. some ground-dwelling beetles, Baker et al. 2007b). These edge-effects may at least partially result from the changes to environmental conditions in wildlife habitat strips. In wet forest areas it was found that for up to 15 years after logging there were changes in temperature and humidity within 10m of the edge, and changes in light intensity within 50 m (Westphalen 2003). Widening wildlife habitat strips or ensuring larger patches of mature forest are distributed throughout the forest estate may be necessary to ensure habitat for edge-effected species is maintained. However edge effects are likely to decrease as the surrounding forest regenerates. Therefore the habitat value of wildlife habitat strips for edge-effected species such as beetles is expected to increase with the age of the adjacent forest.

Wildlife Habitat Clumps

No monitoring has investigated the effectiveness of wildlife habitat clumps in wet forest. This is because in wet forest, where clearfell, burn and sow is the main silvicultural practice, these clumps are located on the boundary of the coupe, and are thus extremely difficult to locate post-harvest. However, a new form of silviculture for wet forest areas, known as aggregated retention, involves the retention of small patches of intact forest (i.e. aggregates) within the harvested area (Baker & Read 2011). These aggregates are generally larger than the wildlife habitat clumps in dry forest coupes, but are likely to perform a similar function in providing habitat for biodiversity as the surrounding harvested forest regenerates. A review of the biodiversity benefits of aggregated retention found that aggregates helps mature-forest species persist within harvested areas (Baker & Read 2011).

A long-term study of wildlife habitat clumps in dry forest has established that wildlife habitat clumps maintain a mixture of sizes and ages of trees and most wildlife habitat clumps have an intact understorey (Duhig et al. 2000; Munks et al. 2009). However tree mortality in wildlife habitat clumps can be high (20% of trees during the eight years after harvest), due to physical damage, windthrow and fire, and some additional loss from firewood harvesting (Duhig et al. 2000; Koch 2008). Consequently the habitat value of retained clumps can decline over time.

Only a few studies have examined the effectiveness of wildlife habitat clumps in aiding recolonisation of harvested areas. Brushtail possums were found to avoid denning in wildlife habitat clumps in young (8-10y), but not older (17y), regenerating forest (Cawthen & Munks 2011). A current study is finding that wildlife habitat clumps provide both roosting and foraging habitat for bats, but the value of the retained areas varies between species (Cawthen 2011). Current results suggest that *Nyctophilus geoffroyi* will breed in wildlife habitat clumps, but that *Chalinolobus morio* and *Nyctophilus sherrini* may avoid breeding in them (Cawthen, pers. comm.). Nest boxes erected in wildlife habitat clumps have been used by pygmy possums, indicating these species are willing to use the small retained patches if suitable denning sites are available (FPA, unpublished data).

No systematic study has examined the value of wildlife habitat clumps retained in dry forest for birds. However an unreplicated study in dry forest found more bird species in areas where mature trees were retained in the regrowth forest (Taylor et al. 1997). Another study in young plantations showed that retained trees can be heavily used by birds, and that trees vary greatly in the quality of habitat they provide (Koch et al. 2009). Thus retained older, native trees are expected to increase the bird diversity (or increase habitat quality for some species). However, bird species composition changes after logging and the retained trees may provide habitat for many, but not all species. Wapstra and Taylor (1998) found that re-use by birds of hollows in trees retained within the harvested area was 64% before logging and 14% after logging. One species not seen before logging (tree martin *Hirundo nigricans*) was observed nesting in the area after logging (Wapstra & Taylor 1998).

We found no other Tasmanian studies that considered how effective mature trees retained within a harvested area are in providing habitat for other taxa.

Summary

The research to date indicates that wildlife habitat clumps provide habitat for some species and hence aid recolonisation of the harvested area, thus meeting the ‘objective’ of the Code as it is currently stated. However, if harvesting rotation times decrease and forestry activities intensify across the landscape, then wildlife habitat clumps alone are unlikely to be sufficient to meet the newly-proposed objective for hollow management (Biodiversity Review Panel 2008) due to the long time required to produce hollows suitable for use by fauna. The research has revealed a high mortality of trees retained within coupes, the specific requirements of many species (e.g. hollow dimension requirements) and the reluctance of some species to use retained trees for at least a period of time after harvest. The Biodiversity Review Panel recommended that the strategy for managing hollow-bearing trees in the landscape be reviewed (Biodiversity Review Panel 2009).

Coupe dispersal

No formal assessment has been made on whether coupe dispersal is achieved and whether it is effective for maintaining biodiversity. However, the 2010 Forestry Tasmania Stewardship Report states: “In 2009, about 730,000 hectares, or half of the state forest was mature; about one million hectares, or seven-tenths of the state forest estate was mature or within 100 metres of mature forests; about 1.45 million hectares, or 97% of the state forest estate, was

mature or within one kilometre of mature forest; and about 40,000 hectares of the state forest estate is more than one kilometre away from mature forests. No state forest is more than 10 kilometres away from mature forest.” This report did not define what is meant by forest being ‘mature’ but the result suggests that, to some degree, age structure heterogeneity exists across the Tasmanian forest estate. Further work is needed to understand the historic, current and expected future age structure heterogeneity in Tasmania given current management practices.

Despite the lack of direct evidence, there has been some research suggesting that coupe dispersal will help maintain biodiversity. The integrity of wildlife habitat strips was found to be reduced if both sides are harvested within a short time frame (Baker et al. 2007b; Jennings & Wardlaw 2006). Furthermore, the species composition for many taxa changes as a forest ages, and can be very different between mature and regrowth forest (Baker 2006; Baker et al. 2009b; Browning et al. 2010; Gates et al. 2005; Hingston & Grove 2010; Kantvilas & Jarman 2004; Lefort & Grove 2009; Turner et al. 2011; Wardlaw et al. 2009), and recolonisation of an area by some taxa is expected to be related to the proximity to intact forest (Gates et al. 2009; Kantvilas & Jarman 2004). Therefore it is expected that coupe dispersal will aid recolonisation and maintenance of species diversity in the production forest landscape, despite the lack of direct evidence to support this.

2.1.5 Conclusion

Young and old forests differ in species composition for a variety of taxa, so the full range of forest age classes are needed in order to maintain forest biodiversity. The studies done have shown that retained areas of mature forest, which include wildlife habitat strips and to a lesser extent wildlife habitat clumps, provide habitat for native species that is more similar to extensive unharvested native forest than harvested areas. Wildlife habitat strips in particular are therefore likely to make an important contribution to maintaining age structure heterogeneity in the landscape, and thereby help maintain forest biodiversity.

However, not all mature-forest dependent species use small retained patches of mature forest when they are located next to recently-harvested areas. The value of retained mature forest (such as wildlife habitat strips) for mature-forest dependent species is expected to increase as the harvested area regenerates, but no data is currently available to assess this.

All studies done to date have assessed the effectiveness of management strategies at a local scale. Wildlife habitat strips are implemented across state forest and so are expected to contribute to age structure heterogeneity and biodiversity maintenance at the landscape-scale. The combination of wildlife habitat strips, coupe dispersal and other measures implemented for different reasons (e.g. streamside reserves), is expected to result in age structure heterogeneity across the landscape (and the limited reporting suggests this is the case). However the scale at which a ‘landscape’ should be assessed for heterogeneity and the age structure of the landscape that is required to maintain biodiversity is uncertain.

We conclude that the measures in place help maintain age structure heterogeneity, and therefore biodiversity, but the adequacy of current measures has yet to be examined at the landscape-scale.

2.2 Alteration of aquatic systems

2.2.1 Stream flow

Stream flow, which is related to the volume and speed at which water travels, can have a large impact on the physical and biological nature of a stream environment. An increase in stream flow can result in:

- greater bank heights;
- more exposed boulders;
- coarser sediments;
- a higher proportion of channels (rather than bars and pools);
- less in-stream particulate organic matter;
- a lower C/N ratio of stream sediments (Bunce et al. 2001; Davies et al. 2005b; Davies & Nelson 1994).

The flow of a stream is determined by a variety of factors, including vegetation cover, geology, topography, climate and soil depth of an area. Harvesting will usually increase stream runoff, and reforestation will decrease it (Taylor 1991; Vertessy et al. 2003). The degree to which a forest operation affects stream flow will depend on:

- the location of operation (how close to the stream);
- the proportion of the catchment area modified (planted or harvested);
- the age of the stand;
- harvest type;
- burning ;
- stocking rate (Department of Primary Industries and Water 2008; Vertessy 2000; Vertessy et al. 2003).

The duration for which harvesting can affect flow varies. However as a very general approximation, flows in regenerated native forest are expected to increase after harvest, reach pre-harvest levels after about 8 years, and then decrease for a longer period (possibly ~ 100y, Vertessy 1999; Vertessy et al. 2001).

2.2.2 Water quality

Harvesting and roading can affect water quality and in-stream biota for at least 15 years after harvest (Davies et al. 2005b), although the degree to which changes occur is likely to be influenced by the width and integrity of the riparian zone around the stream:

- Sediment loads can increase for up to several years, primarily due to road and snig tracks, and stream crossings (Taylor 1991).
- The level of organic matter in the water can change, due to an increase in woody debris in streams after harvesting, and a decrease in foliar input from younger forests (Bunce et al. 2001).
- An increase in light availability in the water, can increase water temperature and algae biomass (Clapcott & Barmuta 2010; Taylor 1991).

In headwater streams a change in stream flow and water quality after harvesting can cause changes in the composition and a decrease in the abundance of benthic macroinvertebrates (Davies et al. 2005a; Smith et al. 2009). The changes in habitat structure and invertebrates can in turn lead to changes in the abundance of other taxa, such as fish and platypus (Koch et al. 2006; Taylor 1991). These changes can persist for at least 15 years in some areas, but the extent of changes will depend on the initial stream attributes (Davies et al. 2005a; Davies & Nelson 1994; Smith et al. 2009).

2.2.3 Karst systems

Many caves (or karst areas) provide habitat for highly specialised and sensitive invertebrate species, both aquatic and terrestrial. Caves are typically fragile environments that are easily susceptible to disturbance, particularly to changes in the moisture regime (Clarke 1997). Changes in stream flow and water quality can have adverse impacts on cave fauna. Caves are typically very stable environments with high levels of endemism. Cave fauna are particularly vulnerable to changes in water quality or the moisture regime of the cave (Clarke 1997).

2.2.4 Current management actions

The main way in which in-stream impacts are minimised is by retention of *streamside reserves*.

The Forest Practices Code states:

Native vegetation will be retained intact in Class 1, 2 and 3 streamside reserves as defined in Table 8 [below], subject to other provisions in this Code permitting watercourse crossings and selective harvesting under certain conditions.

Class 4 water course: No logging machinery within 10m of stream bank except at defined crossing points.

Class 3 stream: 20 m streamside reserve

Class 2 stream: 30 m streamside reserve

Class 1 river: 40 m streamside reserve

While these are the management actions recommended in the Code, a Technical Note on class 4 stream management recommends a higher level of protection for some streams (up to a 20 m streamside reserve), with the level of protection depending on the erodibility of the riparian soil and the presence of defined erosion features (FPA 2004). Unharvested streamside reserve areas can be damaged during regeneration burns, which can affect their function (McIntosh & Laffan 2005).

The following words from the Forest Practices Code could collectively be used to determine the management objective of streamside reserves.

Water quality, catchment and channel stability, and biodiversity in aquatic ecosystems can be protected by minimising disturbance to watercourse channels and riparian (streamside) zones, and by reducing soil disturbance in and near watercourses. Potential downstream impacts also need to be considered.

Wider streamside reserves, including reserves on Class 4 watercourses, should be specified in Forest Practices Plans where necessary to protect:

- *significant recreational, water supply, landscape, habitat or conservation values (in particular threatened aquatic species, relict rainforest and karst);*
- *apiary resource (for example dense leatherwood stands);*
- *significant myrtle gullies at risk from myrtle wilt;*
- *local soil types with high or very high erodibility;*
- *fish spawning or nursery areas;*
- *areas at significant risk of windthrow;*
- *steep areas (over 20°) on rock types where the landslide threshold angle is exceeded.*

Some of the *soil management* provisions, such as stream crossings, also have implications for aquatic systems. The Code's *coupe dispersal* provisions will, to some extent, limit the amount of harvesting within a catchment within a particular time frame. However there are currently no provisions that specify a percentage of the catchment that may or may not be harvested, except for town water catchments. Such a threshold is recommended for catchments containing threatened fish, but is difficult to apply where there are multiple tenures and land-uses. The FPA is carrying out a project to develop a more defensible management approach for catchments containing threatened fish.

Karst management involves placing restrictions on the type and timing of harvesting that can occur, depending on the sensitivity of the karst system. A harvest-exclusion buffer is also applied around sinkholes. The primary words in the Code that relate to karst management are outlined below.

- *Fills will be contained so that fill material does not enter sinkholes in karst areas.*
- *Clearfelling will not be permitted on areas with vulnerable karst soils... unless authorised by the Chief Forest Practices Officer. Clearfelling should be avoided in other karst areas if high conservation or water supply values are present.*
- *In karst areas ground based systems will be limited to slopes below 20°. On vulnerable karst soils... harvesting on slopes above 9° will be restricted to uphill cable harvesting. No harvesting will be permitted on slopes above 20°.*
- *Harvesting on vulnerable karst soils... will only be permitted in dry season conditions.*
- *Snig tracks will not cross mapped caves that are near the surface, enter any karst depression..., or divert or enter any watercourse in a karst area.*
- *Landing size will be minimised in karst areas and landings will not be located near karst depressions or sinkholes.*
- *Landings in areas with vulnerable karst soils... will be drained into effective sediment traps which are properly maintained.*
- *Wider streamside reserves, including reserves on Class 4 watercourses, should be specified in Forest Practices Plans where necessary to protect: – ... karst.*
- *Burning near cave entrances and sinkholes will be avoided.*

- *High intensity burning will be avoided where degradation of significant karst features is likely to result, such as sites with vulnerable karst soils... on slopes above 12°.*

In addition to these words in the Code, the FPA also has a manual that provides detailed guidelines for sinkhole management.

There are no specific words in the Code that can be taken as a management objective for karst species. However FPA must be notified of all harvesting operations in karst environments, and routinely-applied prescriptions aim to minimise degradation of karst environments.

2.2.5 Effectiveness of management actions

Stream morphology

Harvesting can have direct or indirect effects on stream morphology. Direct effects include road crossings, disturbance of soils in the riparian area, the felling of logs into streams and burning of the riparian vegetation. Indirect effects result from changes in stream flow, which occur as a result of harvesting and tree growth within the catchment of a water course. Streamside reserves are expected to eliminate the direct effects of harvesting for class 1, 2 and 3 streams. Class 4 (headwater streams) are most likely to be directly impacted by forestry, due to the nature of the reserves on them (ranging from a minimum of a 10m machinery exclusion zone, to a maximum of a 20 m streamside reserve with intact vegetation, FPA 2004). Most of the studies to date looking at the impact of forestry on stream morphology have focused on headwater streams.

The need for some protection of headwater streams was demonstrated in a retrospective study of areas that were harvested before the class 4 stream machinery exclusion zones were introduced via the Code. It was found that headwater streams in clearfelled areas (without streamside reserves) had different geomorphology, sediment character and riparian vegetation structure 15 years after harvest when compared to minimally-disturbed streams (Bunce et al. 2001; Davies et al. 2005b). The degree of difference between the paired catchments increased with the intensity of the forestry disturbance in the cleared stream. The authors discussed the likely effectiveness of current class 4 stream management, and postulated that the direct effects of harvesting under current class 4 stream management were likely to be minimal (although indirect effects may still be significant) (Bunce et al. 2001; Davies et al. 2005b).

A study of class 4 streams in 20 year old plantation in a low erodibility area found there was minimal mineral soil exposure and increased surface roughness after harvesting, and that vegetation and litter cover decreased but slash cover increased (Neary et al. 2010). A different study found the incidence of erosion in headwater streams increased with the erosion hazard rating (McIntosh & Laffan 2005). This result indicates that class 4 machinery exclusion zones were adequate for protecting stream morphology in some, but not all streams. As a result of this study, current recommendations are for higher protection when erosion features are noted in streams or riparian zones (FPA 2004; McIntosh & Laffan 2005), and these recommendations are routinely applied.

Water quality

Several studies have looked at the effect of harvesting on water quality in headwater streams when class 4 streamside reserves are implemented. One study in wet forest found that 2-5 years after clearfelling the harvested streams had higher benthic metabolism, higher respiration, higher algal growth potential and higher decomposition potential, than control streams (Clapcott & Barmuta 2010). Another study in wet forest headwater streams found that measures of community respiration showed little change before or after logging (Barmuta 2007). Measures of primary production (i.e. photosynthetic activity) have been found to increase after logging in dolerite catchments, and reach maximal levels 5-7 years after harvest before declining to levels approaching those prevailing prior to logging (Barmuta 2007). Some measures of heterotrophic functioning change after harvest and either continue to change or maintain the initial step change for at least 14 years, suggesting that streams in dolerite catchments enter a new stable state with greater production of carbon by bacteria and a greater capacity to decompose cellulose than unlogged streams (Barmuta 2007). A study in wet eucalypt forest found that streams affected by clearfelling had an increased capacity to retain nutrients due to the biotic uptake associated with increased light and woody debris input (R. Burrows, unpublished data). Logging can result in elevated nutrient export so the increased capacity to uptake nutrients will help minimise nutrient loss. A study of class 4 streams in a 20 year old plantation in a low slope, low erodibility area found that post-harvesting turbidity levels were similar to pre-harvest levels (Neary et al. 2010).

The only study we found that examined larger class 2 streams was done in areas with streamside reserves that ranged from 0 to 50 m wide. This study found that stream temperatures were significantly enhanced when buffer widths fell below 10 m, presumably because of the almost complete removal of shading from riparian vegetation (Davies & Nelson 1994).

Biodiversity

There is some evidence that streamside reserves contribute to maintaining diversity of bird species in wood production areas. Bird species richness is higher in riparian than non-riparian areas (MacDonald et al. 2002) and so streamside reserves may make an important contribution to bird conservation. (For example a study of 26 grey goshawk nests found that 38% were located in streamside reserves; Brereton & Mooney 1994). However, the value of the riparian areas changes slightly after adjacent areas are harvested. A study in dry forest found that bird species richness and abundance was about 30% lower in riparian areas in harvested coupes than in control areas 10 years after harvesting (MacDonald et al. 2005). The decrease in species richness and abundance appears to be largely driven by the change in bird abundance, while species composition remains reasonably similar before and after logging.

The only study we found that examined the value of streamside reserves for mammals was a study on platypus occurrence in north-east Tasmania. Catch rates were lower in first order streams than higher order streams, and catch rates in headwater streams were lower in streams that had been harvested without retention of streamside reserves when compared to streams located in areas with minimal disturbance (Koch et al. 2006). In general, streams

where no platypuses were caught were more incised, had less organic material and more sand, less stable banks and more log barriers than streams in which one or more platypuses were caught (Koch et al. 2006).

Streamside reserves could be expected to have benefits for amphibians, due to their strong association with water bodies. However wet forest riparian areas were unfavourable habitat for *Crinia signifera*, a species that prefers standing water to flowing water (Baker & Lauck 2006). Another study found that larval survival of *Litoria ewingii* was lower in shaded ponds than unshaded ponds (Lauck 2005). These studies cannot be used to state that streamside reserves are of no value for amphibians, but there is no data available that confirms their importance.

Davies and Nelson (1994) examined the importance of streamside reserves for introduced trout (*Salmo trutta*) in class 2 streams with riparian buffers ranging from 0-50 m. They found that the number (but not biomass) of trout increased with the width of streamside reserves, up until a reserve width of 30 m. There was no difference in trout abundance between streams with streamside reserves >30 m wide and streams in unlogged catchments (Davies & Nelson 1994).

As with trout, aquatic macroinvertebrates in class 2 streams increased in abundance with width of streamside reserves, up until reserves were 30 m wide (Davies & Nelson 1994). For terrestrial beetles in wet forest it was shown that non-riparian areas can have greater species diversity than riparian areas (Baker et al. 2007a). In wet forest with a rainforest understorey the riparian/non-riparian transition zone ranged from 1-5 m up to 50-100 m (Baker et al. 2007a). Therefore how well the biodiverse non-riparian areas are captured in streamside reserves will vary between localities. The value of streamside reserves for ground-dwelling beetles is compromised because 40 m wide streamside reserves were found to be totally edge-affected when the adjacent area is harvested (Baker et al. 2009a). Despite being edge-affected, most ground-dwelling beetle species found in intact riparian areas are also found in 40 m wide streamside reserves (Baker et al. 2009a), with slightly fewer species found in narrow streamside reserves (Taylor et al. 2000).

A study of bryophytes in wet sclerophyll forest in northeast Tasmania found that bryophyte composition of riparian sites did not differ significantly from the surrounding forest, despite the preference of bryophytes for particular substrates (e.g. tree ferns, coarse woody debris, fallen tree ferns, soil, roots, rocks) (Pharo & Blanks 2000). Consequently streamside reserves are likely to provide habitat for bryophytes.

We know of no work that has considered the value of streamside reserves for fungi.

Karst management

A long-term study was conducted at Little Trimmer near Mole Creek (K. Kiernan, unpublished data). To our understanding this site was established to examine the impact of forestry, but the proposed harvesting did not occur (Wapstra 2008a). This study monitored water volume and cave fauna, but to our knowledge the data has not been examined. We

know of no other work that has looked at how effective current management is for protecting karst environments.

2.2.6 Conclusion

The studies examining the effectiveness of streamside reserves are not comprehensive. Most studies are short term (2-15 years after harvest), and the effectiveness of the reserves for maintaining biodiversity may increase as the harvested area regenerates. In addition, the studies have largely been conducted in wet forest areas.

Stream morphology and water quality studies have focused on headwater streams, as these were considered most heavily at risk from forestry. Limited work suggests machinery exclusion zones reduce the impact of forestry on class 4 streams, but do not maintain natural values in all class 4 streams 10 years after harvest. (The 'new' class 4 stream guidelines are likely to provide better protection for natural values, see FPA 2004). Minimal work has been done on higher order streams, but work that has been done indicates that current reserves adequately minimise the direct impacts of harvesting. However it is likely that streamside reserves will only partly mitigate the indirect impacts of harvesting, such as changes to stream flow.

Biodiversity studies focused on higher order streams, with wider streamside reserves. These results indicate that streamside reserves will provide habitat for a large proportion of taxa. However, the value of habitat can vary between riparian and non-riparian areas, meaning that retention needs to also occur in upslope areas. It was also found that riparian areas can be greatly edge-effected for some species, meaning that larger strips or retained patches should be considered as part of a comprehensive approach to landscape management.

In summary, class 4 streamside reserves will help protect the morphology of many streams and minimise changes in temperature that result from logging, which helps maintain habitat quality for some fauna. Streamside reserves that are 30 m wide appear to protect habitat for most aquatic and terrestrial fauna studied, but even these reserves are entirely edge-effected for some terrestrial fauna like ground-dwelling beetles when the adjacent area is harvested (i.e. for at least 5 years after harvest). However, despite being edge-effected, 40 m wide streamside reserves provide habitat for most riparian species examined (Baker et al. 2009a).

Given the lack of research, we can draw no conclusions on the effectiveness of karst management. This should be designated as a priority for future research.

2.3 Impact on soils

2.3.1 Soil compaction and displacement

Soil compaction can affect soil fauna and microflora, as well as soil hydrology and susceptibility to erosion (see Marshall 2000 for a discussion of the impact of harvesting on biological processes in forest soils). Erosion can increase sediment loading in aquatic systems, as well as cause a loss of soil biota. Soil biota contribute to nutrient cycling and plant health, and plant health and nutrient concentration can affect the diversity of above-ground biota (Braithwaite et al. 1984; Cork & Catling 1996; Recher et al. 1996; Wormington et al. 2007).

Machinery movement during a forestry operation can change the physical properties of the soil. The compactness (bulk density) of forest soils is naturally variable, but this variability can be greatly increased after a harvest operation (Pennington & Laffan 2004). Incorporation of litter and slash into the soil will often lower bulk density, while vehicles will increase bulk density. Forestry operations can also result in displacement and mixing of the soil through use of vehicles and equipment, movement of fallen trees, and increased erosion (Laffan et al. 2001). Cable logging has been found to disturb the soil less than other silviculture types used elsewhere in Australia (Laffan et al. 2001).

The routes on a forestry coupe that are used by vehicles are known as snig tracks. In a dry eucalypt site it was found that soil compaction and increased soil strength under snig tracks persisted 12 years after harvesting. In comparison, soil compaction at two wet forest sites was negligible after a year, but soil strength persisted at elevated levels due to soil displacement, resulting in low plant regeneration (Pennington et al. 2004; Williamson & Neilsen 2003).

A study of aquatic macroinvertebrates downstream and upstream of road crossings found differences in species composition, which were related to the proportion of fine sediments in the water. Sites with different drainage gradients varied in their accumulation of fine sediments. These results suggest that stream crossings impact aquatic macroinvertebrates, but the degree of impact varies between sites (Davies et al. 2001).

2.3.2 Soil productivity

Soil productivity influences plant growth (Jacobs 1955) and will affect the nutrient concentrations of the leaves. Foliar nutrient concentrations can in turn affect the distribution and abundance of fauna (Braithwaite et al. 1983; Braithwaite et al. 1984), meaning the overall biodiversity of an area could be influenced by large changes in soil productivity.

The removal of wood from a site has the potential to reduce the availability of nutrients in the soil. Despite the potential for this to occur, there are no consistent, unequivocal and universal effects of harvesting on soil productivity, although soil productivity does appear to decrease on certain sites if the canopy (branches and leaves) is removed as well as the stem (Thiffault et al. 2011). A review of studies conducted in the northern hemisphere found that a decrease in carbon is most likely to occur if soils are already poor in organic matter (<10 Mg/ha of C in a soil sample of 10cm thickness), and the effect may be stronger in more temperate

environments (Thiffault et al. 2011). The availability of phosphorus was also highlighted as potentially of concern (Thiffault et al. 2011).

Snig tracks have been associated with a decrease in organic carbon, total nitrogen and a change in total phosphorus (Laffan et al. 2001; Packer et al. 2006; Pennington et al. 2001; Pennington et al. 2004), but this change has not been found within the harvested area. In Tasmania forestry has been found to have a relatively benign impact on soil quality (chemistry and structure) compared to other land uses such as agriculture, but may potentially have a long term impact on organic carbon and aggregate stability (Cotching & Kidd 2010).

Native forest silviculture in Tasmania involves burning the canopy (branches and leaves) on site which will help recycle the nutrients back into the soil and thereby maintain productivity. McIntosh et al. (2005) found that long-term periodic burning had a profound effect on forest soils in Tasmania, to the extent of influencing vegetation types. The effects have probably taken place over several thousand years and, except where fires have produced significant erosion, fires associated with forest operations (e.g. regeneration burns) are unlikely to have a measurable effect on soil nutrients (McIntosh et al. 2005).

Current evidence suggests that native forestry will not negatively impact soil productivity, at least on more fertile sites. The impact of repeated, short-rotation harvesting that may occur if forestry activities intensify in particular areas has not been assessed.

2.3.3 Current management actions

The Code has detailed provisions for *soil management* which guide road construction, snig tracks, landings and stream crossings, including a requirement that the number of stream crossings be minimised. In addition, there are detailed prescriptions on slope limits and the type of harvesting that can occur on different soil types according to their susceptibility to erosion. See the Code for greater detail.

Words in the Code that could be interpreted as objectives for soil management are:

- *Management requirements to ensure adequate protection of values such as soils...*
- *Measures to ensure efficient harvesting and sustain site productivity*
- *Roads are a potential source of watercourse sedimentation and turbidity. Road design, construction and maintenance will aim to minimise that potential.*
- *Minimise soil exposure to lessen the potential for erosion*

2.3.4 Effectiveness of management actions

Most of the studies examining the impact of snig tracks and stream crossings examined sites managed according to an earlier version of the Code. The revision of the Code into its current form (Forest Practices Board 2000) was informed by a special review of the Code's soil and water provisions, which resulted in more rigorous prescriptions. Therefore the impact on soils of current operations is expected to be less than impacts reported in the studies outlined above (e.g. snig track compaction has been greatly reduced as a result of the routine use of cording and matting, P. McIntosh, pers. comm.).

Compliance surveys are conducted as part of routine FPA monitoring. Results show that incidence of erosion after harvesting is very low and compliance with soil prescriptions is very high (Forest Practices Authority 2011), and that compliance with management prescriptions reduces the risk of erosion (FPA unpublished data).

We know of no work that has examined the effectiveness of the soil management provisions for maintaining biodiversity.

2.3.1 Conclusion

The few studies (research and compliance checks) indicate that the impact of forestry on soils is minimal and the Code provisions are effective in minimising this impact. The studies to date suggest that the impact on soil productivity is not a concern but the impact of more intensive forestry that may occur in the future is uncertain.

2.4 Habitat fragmentation and the introduction of exotic species

Both roads and high-intensity silviculture (e.g. clearfall, burn and sow) create abrupt boundaries or edges, effectively fragmenting the forest landscape. The habitats on either side of the edge influence each other. In a study of intact forest next to a clearfall operation, edge penetration was less than 10 m for vegetation and microclimate (temperature and humidity) but 50 m for light intensity. These effects had not dissipated after 15 years (Westphalen 2003). Some species (e.g. herbivorous mammals, some frogs) preferentially use edge environments (Baker & Lauck 2006; Taylor 1991) or appear to be unaffected by edges (e.g. many birds and lizards, Jellinek et al. 2004; Lefort & Grove 2009). However, other species are negatively affected by edges, reducing the effective patch size of the uncleared areas (e.g. ground-dwelling invertebrates, fungi, bryophytes, Baker et al. 2009a; Baker et al. 2007b; Baker & Read 2011; Gates et al. 2005). Edges can increase tree loss due to wind throw, and affect canopy health of the retained forest (Jennings & Wardlaw 2006). However the effect of the edge goes both ways and the presence of intact forest can influence the cleared area. For example the intact forest can assist recolonisation of the harvested area by dispersal-limited species, such as some rainforest plants (Courtney et al. 2005).

The increase in roads that can occur as a result of forestry activities can, like most aspects of forestry, have both positive and negative effects on biodiversity. Some plant species increase in abundance near roads (Wapstra et al. 2003b), while roads can provide barriers that limit dispersion of some invertebrates (Taylor 1991). Roads can also act as conduits for weeds and diseases. For example weeds in wildlife habitat strips in dry forest are generally confined to road verges (Jennings & Wardlaw 2006), myrtle wilt was most common in wildlife habitat strips when roads were built in rainforest gullies (Jennings & Wardlaw 2006), and the occurrence of an amphibian pathogen was related to the presence of roads in the World Heritage Area (Pauza et al. 2010). While the transport of exotic species along roads is generally assumed to be passive, roads can also open an area to human use and so may also result in intentional introductions of species such as trout.

2.4.1 Current management actions

The Code requirements for *wildlife habitat strips* will help maintain connectivity, and potentially reduce habitat fragmentation in the landscape. Details of wildlife habitat strips as a management strategy have been covered above.

The Code also states that the impact of snigging and road construction should be minimised. However there are no prescriptions on the level of roading that is acceptable. In fact, the requirement for *coupe dispersal* may result in an increase in roading across the landscape.

Management actions in place for remnants may contribute to ameliorating the continued loss and fragmentation of habitats. The Forest Practices Code states:

In parts of the State where native forests occur mainly as remnants, consideration will be given to:

- *retention of native forest remnants to aid in the maintenance of local flora and fauna diversity and landscape values;*
- *restoration of habitat including widening and linking wildlife habitat strips, particularly where species and communities of high conservation significance are known to occur.*

Small and medium patches of forest are more common on private than public land (Michaels et al. 2010). Harvesting applications do not need to be submitted for patches under a hectare or where less than 100 tonnes is being harvested, unless harvest is planned on ‘vulnerable land’.

Words in the Code that could be interpreted as an objective for remnant management are:

to aid in the maintenance of local flora and fauna diversity and landscape values [in areas where native forest occurs mainly as remnants]

In terms of *weed and disease management*, there are prescriptions that detail how machinery should be washed in certain areas to prevent the spread of these exotic species.

Words in the Forest Practices Code relating to weed and disease management are:

- *Vegetation that is susceptible to *Phytophthora cinnamomi* (e.g. swamps, heaths, sedgeland, dry lowland forest on sandy or poorly drained sites, and low altitude rainforest on infertile sites), should be protected from accidental infection by the fungus by the implementation of hygiene measures.*
- *Patches of myrtle or rainforest that are to be retained should be protected from fire, damage and disease (notably myrtle wilt). This may require buffering of some patches (e.g. by extending streamside reserves) and avoiding or minimising damage during road construction or maintenance.*
- *Measures should be taken to ensure exotic weed species, (e.g. pampas grass, ragwort, blackberry and Spanish heath), do not become established in native forest, particularly reserves. Native forest most at risk includes areas adjoining plantations,*

and drier forest types in general. Machinery should be washed down before being transported from one area to another, particularly when moving from infested to uninfested areas.

- *Consideration should be given to the protection (e.g. by buffering) of native forests, particularly reserves, from incursion by adjoining plantation species. For example, dry forests may be invaded by radiata pine, and some planted eucalypts may hybridise with related species in adjacent native forest.*

Further details on management of *Phytophthora* (including required hygiene measures to minimise spread) are provided in FPA Flora Technical Note 8.

Words in the Code that could be interpreted as objectives for weed and disease management are:

- *Vegetation that is susceptible ... should be protected from accidental infection.*
- *Ensure exotic weed species... do not become established in native forest.*
- *Protect[ion]... native forests, particularly reserves, from incursion by .. plantation species.*

2.4.2 Effectiveness of management actions

Work has been done on the health and value of remnants, but primarily in agricultural areas. This work has shown that, irrespective of size or fragmentation, remnants can provide habitat for a range of biota including lizards (Jellinek et al. 2004), bryophytes (Pharo et al. 2005) and threatened flora (Kirkpatrick & Gilfedder 1995). For other taxa the value of remnants can increase with size. For example remnants larger than 20-30 ha had higher species richness and diversity of birds than smaller remnants (MacDonald & Kirkpatrick 2003), although small patches can provide important habitat for some threatened species (e.g. swift parrots, Brereton 1997). The condition of remnants can vary greatly, with weeds being a common issue (Bowkett & Kirkpatrick 2003; Gilfedder & Kirkpatrick 1998; Woolley & Kirkpatrick 1999). However even degraded remnants can provide important habitat, with a survey of remnants finding some threatened plant species only in remnants of poor integrity (Kirkpatrick & Gilfedder 1995).

No studies have examined the degree to which remnants are retained in forestry areas. The only study we found which examined remnants in forestry areas found that single trees and small patches in a young plantation (on previously-agricultural land) were used by birds, but the degree of use varied with tree attributes (Koch et al. 2009).

A 10-26 year study monitoring myrtle wilt found cumulative mortality of myrtle (*Nothofagus cunninghamii*) and sassafras (*Atherosperma moschatum*) ranged from 25 to 45% and 25 to 69%, respectively (Elliott et al. 2005). Mortality rates were higher in areas that were more heavily logged, but unharvested and logged areas showed a similar increase in tree mortality (Elliott et al. 2005). It is unlikely that hygiene measures were used when harvesting this area, but this study demonstrates the need for effective management that minimises the spread of diseases during forestry operations. The technical note on *Phytophthora* management was

released in 2009, but no monitoring has been done to see how well it is implemented or how effective management strategies are.

A study of roadside areas in wildlife habitat strips found incursion by pines from adjacent plantations in 11% of sites examined as well as considerable weed invasion from other species (Jennings & Wardlaw 2006). The degree to which buffers are implemented and how effective they are at reducing weed infestations is unknown.

2.4.3 Conclusion

Very little work has looked at the degree to which roads increase habitat fragmentation in Tasmania, and the impact this has on native biodiversity. A small number of studies have demonstrated that forestry practices may increase the occurrence of weeds and diseases, but no studies have examined the implementation or the effectiveness of current management. We recommend that this area of research is prioritised.

While studies to date suggest that preservation of remnants is likely to assist biodiversity, the degree to which remnants are retained in forestry areas and therefore the degree to which they help maintain biodiversity in fragmented landscapes is not clear.

2.5 Species-specific impacts

2.5.1 Impacts

Some species are impacted by forestry in ways that were not discussed above. These impacts can be positive, with some species flourishing after disturbance such as harvesting. Other species are negatively affected by forestry, either directly or indirectly. The negative impacts include a direct loss of individuals as a result of harvesting, a decrease in habitat quality (e.g. foraging resources), and loss of habitat (e.g. loss of key structure such as large old pieces of dead wood). A full review of the way in which forestry affects particular species is beyond the scope of this report, but more information on the impact of forestry on native threatened fauna can be found in a recent review of fauna management provisions that is available on the FPA website (FPA & DPIPWE 2011).

2.5.2 Management actions

The Forest Practices Code states:

Threatened species and inadequately reserved plant communities will be managed in wood production areas in accordance with procedures agreed between the Forest Practices Board and DPIPWE.

The conservation of threatened species and inadequately reserved plant communities may be achieved by reservation or prescription in accordance with the duty of care policy, voluntary arrangements such as the Private Land Reserve Program, or through legislative processes as mentioned above.

A large range of different management strategies are applied for the diverse range of threatened species. Management strategies are implemented if an operation occurs within the

known or potential range of a species, within a specified distance of a historic observation or within an area containing potential habitat. Species-specific management prescriptions are delivered via the Threatened Fauna Adviser (FPA & DPIPWE 2011) and via procedures agreed between FPA and DPIPWE (www.fpa.tas.gov.au/__data/assets/pdf_file/0019/58123/FPA_and_DPIPWE_agreed_procedures_2010.pdf).

Due to the diverse array of threatened species and species-specific management strategies, it is beyond the scope of the current report to outline the objectives for all strategies. Greater details can be found in a range of documents located on the FPA website (Biodiversity Review Panel 2008; Forest Practices Authority 2005; FPA & DPIPWE 2011). However, examples are provided below of species-specific management objectives and actions.

- *“to implement actions that will assist the maintenance of breeding pairs of the wedge-tailed eagle throughout its range, primarily through the maintenance of known nesting habitat”.*
- *“The objective (desired conservation outcome) for this species [swift parrot] is to maintain the integrity of breeding-habitat by ensuring that sufficient levels and spatial arrangement of important nesting-habitat and foraging-habitat are retained to support breeding in any given year and, in this way, contribute to the objectives of the National Recovery Plan for the Swift Parrot Lathamus discolor.”*
- *“to implement actions that will assist the maintenance of populations [of hydrobiid snails] throughout their ranges, primarily through the maintenance of potential habitat and protection of known localities”.*

2.5.3 Effectiveness of management actions

Three case studies examining the effectiveness of current management are outlined below.

Wedge-tailed eagles

Statistical models of eagle populations in the north-east of Tasmania showed that loss of current and potential future nest sites is likely to increase the extinction risk of this species, while reducing nest disturbance will decrease the risk of extinction (Bekessy et al. 2009). Research has shown that wedge-tailed eagle (*Aquila audax*) nests are less likely to be used and breeding pairs have a lowered reproductive rate if they are disturbed at a nest site. Current management involves placing a reserve around eagle nests and restricting forestry activities near the nest during the breeding season (Forest Practices Authority 2006). Breeding success increased when protection measures were applied around the nest (Mooney & Taylor 1996), indicating that current management helps minimise the impact of forestry on this species. Current research is being done to further examine the effectiveness of current management.

Giant velvet worm

A population viability analysis (PVA) indicated that continued clearfall harvesting with a low intensity burn would lead to a small decline in the population size of giant velvet worms (*Tasmanipatus barretti*) (Fox et al. 2004). Previous management in forestry areas specified

that high burning intensity could not be done in giant velvet worm habitat because it was likely to destroy key habitat features (FPA & DPIPWE 2011). One study found suitable habitat in logs was more prevalent in unharvested areas, intermediate in older regenerating forest, and lowest in younger regeneration, but giant velvet worms were found across the full range of sites examined (Yee et al. 2007). These results suggest that this species is affected by harvesting, and the regeneration burn, but that provided some habitat is retained these areas can be recolonised about 15 years after harvest.

Odixia achlaena

A study was done examining the distribution of *Odixia achlaena*. The results found that *Odixia* was prevalent in areas that had been disturbed, and concluded that this threatened species is not vulnerable to harvesting (Leaman 2004).

2.5.4 Conclusion

The effectiveness of current management has only been examined for a few species, but the results have been varied. Research has shown that targeted management in forestry areas is not required for some species (e.g. *Odixia*), that management is effective at reducing the impact of forestry on other species (although it may not be certain whether the impact is eliminated, e.g. wedge-tailed eagles) or that management should be adjusted. The results of research are used to revise management strategies under an adaptive management framework.

3. Species trend monitoring

Small scale studies examining the effectiveness of particular management prescriptions, like those discussed above, help determine the effectiveness of the forest practices system. However, these small scale targeted studies are only one of the elements needed for a comprehensive monitoring program. Single, small-scale impacts may have a minimal impact on biota, but the accumulation of these small impacts across the landscape may collectively result in a larger impact. Alternatively, the combination of management prescriptions that are used, which all have their limitations as discussed above, may collectively provide sufficient habitat to maintain biodiversity in the production forest landscape. Or forestry may not affect species directly, but may reduce species resilience to other disturbances such as wildfire or climate change. One of the only ways to assess these landscape-scale impacts is to conduct species trend monitoring, to determine how species distribution and abundance change over time.

While trend monitoring is needed to help determine the overall effectiveness of the forest practices system, it has limitations. For example, it can be very difficult to differentiate between significant trends and natural variations in populations, and long monitoring times may be required before an effect is noticed. Threatened and rare species can be difficult to monitor with sufficient power to detect changes in the populations. Trend monitoring is very general and so it is very difficult to determine if any changes observed are a result of forest practices or due to other changes in the environment (e.g. predation, climate change etc). Despite these limitations, trend monitoring is critical for identifying taxa of potential concern.

Very little long-term trend monitoring has been done in Tasmania. Most of the historic monitoring has focused on species that are harvested (e.g. ducks), culled or subject to pest control programs (e.g. some browsers). The interest in threatened species monitoring is gradually increasing, but of the 177 listed species, only 16 are being monitored (and 70% of these are marine species) (Driessen & Hocking 2008). Details of the threatened species that are monitored are provided in Driessen and Hocking (2008), but we highlight below a few of the key monitoring programs that are currently undertaken.

- Duck surveys have been conducted annually since 1985 and results indicate that these species are generally stable in numbers (DPIPWE 2009).
- A small number of state-wide bird surveys have been done as part of the national bird Atlas program. These surveys provide some limited data on potential trends, which vary between species (Barrett et al. 2003; Blakers et al. 1984).
- Long-term bird surveys are conducted by industry in the southern forests but the data has not yet been examined for species trends (S. Grove, pers. comm.).
- Annual monitoring (since 2007) of a number of wedge-tailed eagle nests has found that the rate of nest success is relatively consistent between years (Wiersma 2010).
- Swift parrot (*Lathamus discolor*) populations have been monitored for the last four years which has provided greater insight into their breeding range and habitat requirements (Threatened Species Section 2010; Webb et al. 2007).
- A recent survey of forty-spotted pardalotes (*Pardalotus quadragintus*) has detected a dramatic decline in abundance throughout most of their range (P. Bell, pers. comm.).
- Spotlight surveys for many mammal species have been conducted almost annually since 1985. Results suggest that the following species are increasing: forester kangaroo, Bennets wallaby, wombat, Tasmanian pademelon, brushtail possum. The following species appear to be stable in numbers: potoroo, spotted-tailed quoll, brown bandicoot. The following species appear to be declining: Tasmanian devil, eastern quoll, ringtail possum, barred bandicoot and bettong.
(<http://soer.justice.tas.gov.au/2009/image/531/index.php>)
- A road-kill survey was established for a number of years but this lapsed in 1996 (Driessen & Hocking 2008).
- Harvest return questionnaires provide some data on pest species (e.g. Bennetts wallaby, brushtail possum) (Driessen & Hocking 2008).
- A frog monitoring program was established in 2006. The modelled distribution of frogs using pre-1995 records were compared to models using records from 2006 onwards. No changes were evident for the *Litoria peronii* or *L. burrowsae*. For *L. raniformis* the known and predicted distribution declined in the current period when compared to the historic period, which may be related to climate change (Wilson 2010a, 2010b). *Crinia tasmaniensis* also showed a marked decline, with no records from the north half of the state in the more recent surveys. The decline in *C. tasmaniensis* is thought to be due to chytrid fungus (Wilson 2010a).

- Annual monitoring of ptunarra brown butterfly (*Oreixenica ptunarra*), originally conducted by DPIW from 1997-2003, is now only conducted by Gunns Limited as part of their northwest grassland management strategy.

3.1 Implications for assessing the effectiveness of the forest practices system

Insufficient trend data are available in Tasmania to assess the overall effectiveness of the forest practices system for maintaining biodiversity. Some of the species that are in decline are known to be affected by factors other than forest practices (e.g. the Devil Facial Tumour Disease), and forestry is not considered a primary contributor to these declines. Several of the species that are considered pests in forestry areas, such as brushtail possums, appear to be increasing. However, there is a concern about the impact of forestry on some species. Both swift parrots and forty-spotted pardalotes have a significant proportion of their range in areas that are subject to forestry activities. Both these species use tree hollows, which are expected to be lost in areas that are repeatedly harvested due to the long time required to form hollows (Koch et al. 2008b). Further work is being conducted by DPIPWE and the Australian National University to identify if, and how, these species are being impacted by forestry activities and how these species can be managed in the production forest estate.

The limited amount of data currently available has identified a few species of concern (e.g. swift parrots, forty-spotted pardalotes), but data are lacking for most species, making it difficult to assess how well the landscape is being managed. We recommend that more long-term trend monitoring studies are initiated.

4. General conclusions

Although this review revealed a range of potential negative impacts forestry has on biodiversity (as well as some positive impacts), there are management strategies in place that are likely to eliminate or greatly reduce the effect of almost all of these potential impacts.

Managing biodiversity is extremely complex due to the huge diversity in species distributions and ecology. It is therefore impossible to determine whether a system is effective for all species, because we know so little about so many of the species. What we can do is use a range of approaches to ameliorate the impact of forestry, and adopt an adaptive management approach to continually improve management as more information becomes available.

This review highlights the importance of managing the landscape to minimise the known impacts from forestry. It is clear that species composition changes as forests age, meaning that both young and old forests are important for maintaining diversity of species across a landscape. Given that forestry generally increases the availability of young forest and decreases the availability of old forest, it is essential to manage the distribution and abundance of mature forest in areas managed for wood production. This review also discusses the need for soil and water management for maintaining forest health and biodiversity, and the issue of habitat fragmentation. The potential barriers formed by roads and the role of roads in facilitating the spread of weeds and diseases were discussed.

Most studies on the impact of forestry and effectiveness of current management were small-scale studies examining areas that were recently harvested (typically <15 years). The impact of harvesting is likely to decrease as an area of forest regenerates, which may also increase the effectiveness of management strategies. Forest operations in Tasmania are planned for an average rotation interval of 65-90 years (Whiteley 1999), and little study has been done on the long-term effectiveness of management given the spatial and temporal heterogeneity of the impacts.

This review of the effectiveness of current forest management is limited in scope, but the research done clearly shows that current management practices are extremely important for maintaining biodiversity in the production forest landscape. All management practices have limitations, meaning they are individually unlikely to cater for the requirements of all species, but most were found to make important contributions to biodiversity management in the production landscape. The effectiveness of the coupe dispersal and karst management provisions were the least certain due to the lack of Tasmania-specific research. However there is strong indirect evidence that coupe dispersal is likely to be important for maintaining biodiversity.

Species are frequently influenced by the context in which they are found, and the combination of all the management practices in place may or may not be adequate in 'maintaining biodiversity'. Long-term species trend monitoring is needed to assess the cumulative effects of activities regulated through the forest practices system and other land-use activities, but very little such monitoring has been done in Tasmania. The limited work that has been done has identified a small number of species that may be at risk from current forestry activities, but the results are inconclusive and further research is required. For most species there is no monitoring data with which to assess the landscape-scale impact of forestry.

Given the complexity of managing forest biodiversity and the time required to obtain enough information to adequately assess the effectiveness of the forest practices system, it may be beneficial to use ecological theory to guide 'off-reserve' management. Some of the important features that need to be managed across the landscape, such as mature forest and riparian and upslope areas, have been discussed in this report. Many of the conclusions reached in this report support the recommendations for landscape management outlined in the literature, such as managing for connectivity, heterogeneity, stand structural complexity, and aquatic system health (Lindenmayer & Franklin 2002), and with the recommendations of the Biodiversity Expert Review Panel (Biodiversity Review Panel 2009). The FPA are currently working to design a system for landscape planning that takes these ecological principles and the recommendations of the Biodiversity Expert Review Panel into account (Chuter et al. 2011). Yet whatever changes are made to biodiversity management in Tasmanian forests, it will continue to be important to monitor how effective these changes are in maintaining biodiversity.

5. References

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