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From guiding principles for the conservation of forest biodiversity to on-ground practice: Lessons from tree hollow management in Tasmania

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ABSTRACT

A useful theoretical approach in the literature for those trying to conserve forest biodiversity involves a number of strategies to achieve maintenance of habitat for different species across multiple spatial and temporal scales. This approach emphasises the importance of implementing measures in off-reserve areas to complement reserve systems. This contrasts with both the traditional 'set-aside' approach to conservation and the primary aim of production forestry. Translating this risk-spreading approach into on-ground practice is often a difficult task.

Using the conservation management of habitat for hollow-using fauna in Tasmania's production forests as a case study, we explore the issues associated with adopting the theory and applying it to on-ground practice. The approach that has evolved is evaluated in terms of the strategies proposed in the literature. The inadequacy of the existing reserve system in Tasmania to fully cater for the conservation of threatened hollow-users, problems associated with the current 'off-reserve' measures, impediments to effective implementation and the use of an adaptive management framework are highlighted.

We provide some practical considerations to guide more effective implementation. This includes the development of measurable objectives, integration of conservation goals with silvicultural goals, development of clear and practical guidelines, effective training and communication programs and the development of a monitoring and an adaptive management process agreed to by all stakeholders. The ongoing success of such an approach depends on a high level of commitment by all involved to the overall goal of ecologically sustainable forestry.

1. Introduction

Many national and international agreements and legislation such as the Montreal protocols (United Nations, 1995) identify the conservation of forest biodiversity as a key component of sustainable forest management in cool temperate areas. The decline of forest species has been related to habitat loss and fragmentation (Fahrig, 1999). A traditional approach to conservation has been to 'set-aside' areas as reserves. However, an abundance of work highlights the importance of providing habitat in off-reserve areas (Braithwaite et al., 1984; Fischer and Lindenmayer, 2002; Polasky et al., 2005; Sergio and Pedrini, 2007). Management of habitat in such areas has been identified as a key strategy for conserving forest biodiversity (e.g. Norton and May, 1994; Scotts, 1994; Caughley and Gunn, 1996; Lindenmayer and Franklin, 2002; Lindenmayer and Burgmann, 2005).

A useful theoretical approach for those trying to conserve forest biodiversity has been provided by Lindenmayer and Franklin (2002, see also Lindenmayer et al., 2006). The guiding principles they propose include maintaining connectivity, landscape heterogeneity and stand structural complexity, and adopting 'risk-spreading' measures. To meet these principles across multiple spatial scales, they identify four main strategies: establishment of large ecological reserves, application of landscape level measures in off-reserve areas, application of stand level measures in off-reserve areas, and monitoring and adaptive management (Lindenmayer and Franklin, 2002).

While this theoretical framework is a logical approach, difficulties arise in applying the theory to practice. Our paper

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uses the issue of retention of an old forest habitat element, hollow-bearing trees, in Tasmania, Australia, as a case study to illustrate the problems associated with bridging the gap between theory and 'on-ground' practice. We provide a summary of practical considerations that have arisen from our experience that may assist others struggling at the 'coal-face' of forest biodiversity conservation in off-reserve areas.

2. Case study: management of the tree hollow resource in Tasmania's production forests

Tree hollows provide critical breeding and shelter sites for a wide range of fauna, including threatened species, in many forested areas around the world (Harestad and Keisker, 1989; Abbott, 1998; Law and Anderson, 2000; Heinsohn et al., 2003; Legge et al., 2004; Lohmus and Remm, 2005). Maintaining hollow-bearing trees is a critical part of conservation management (Smith and Lindenmayer, 1988; Abbott, 1998). Tasmania is Australia's island state that is approximately 6.85 M ha in area. Twenty-five percent of Tasmania's terrestrial native birds and 32% of Tasmania's terrestrial native mammals are known to use tree hollows to varying degrees. These include 12 endemic at the species or sub-species level, four listed as threatened on State and Federal legislation and seven introduced species (Koch, 2007).

Tree hollows are found most frequently in older, larger and more senescent trees (Lindenmayer et al., 1993; Koch et al., 2008b). The availability of the hollow resource is reduced by land clearance and loss of trees as they age and fall (Gibbons and Lindenmayer, 2002). Production forestry across large areas also impacts on hollow availability because rotation times are generally much shorter than the time required for hollow formation (Ball et al., 1999; Gibbons, 1999). In Tasmania, Koch et al., 2008a found that in two production forest types, dry and wet *Eucalyptus obliqua* forest, trees were more likely to have hollows of most use to fauna if they were >140 years old, but average harvest rotation reported for native eucalypt forest in Tasmania is between 65 and 90 years (Whiteley, 1999).

Management practices to ensure that a current and future source of hollows is available typically involve retaining and protecting hollow-bearing trees within a harvesting unit (Gibbons and Lindenmayer, 1996; Everett and Otter, 2004). However, there is evidence to suggest that a supply of trees with hollows cannot be ensured by only retaining trees which already have hollows and the hollow resource will decline with successive silvicultural treatments unless recruitment trees are also retained (Ball et al., 1999). In some parts of Australia, including Tasmania, the hollow resource may already be in short supply. A landscape approach to the conservation of hollow-dependent fauna is critical for maintaining viable populations. The harvest rotation interval, the relative placement of harvesting units and the amount, distribution and quality of retained trees all need to be considered.

In Tasmania, hollow-using fauna are identified as priority species in an agreed framework for the management of Tasmania's forests (Commonwealth of Australia and State of Tasmania, 1997). The Tasmanian *Forest Practices Code* (Forest Practices Board, 2000) is the main planning document that delivers the approach for the retention of hollow-bearing trees. This paper reviews and evaluates this approach in terms of the four strategies proposed by Lindenmayer and Franklin (2002): (1) large ecological reserves, (2) landscape-level measures in off-reserve areas, (3) stand-level measures in off-reserve areas and (4) monitoring and adaptive management.

3. Strategy 1: large ecological reserves

Large ecological reserves have been identified as playing a key role in biodiversity conservation (Lindenmayer and Franklin, 2002). Of the forest cover present in Tasmania in 1750 (pre-European settlement), 64.5% remained in 2006 (Forest Practices Authority, 2007b). However, approximately 40% of Tasmania's area, encompassing approximately 30% of remaining eucalypt forest or woodland, is currently captured in the State reserve system (DPIW, 2001, 2006; Commonwealth of Australia and State of Tasmania, 2007) (Fig. 1). This level of forest reservation is extremely high by both national and international standards (McDermott et al., 2007) and forms a critical part of conservation strategies for biodiversity within Tasmania.

Although Tasmania's reserve system includes forest types that contain tree hollows, its distribution is such that a management strategy based on the reserve system alone is unlikely to maintain Tasmania's hollow-using fauna throughout their ranges. These reserves are concentrated in the unpopulated south-west. Large 'gaps' without large formal reserves occur in the rest of the State (Fig. 1). There is unequal reservation of forest types, both by community and location. Of 51 formally recognised forest communities, only 35 meet the CAR (Comprehensive, Adequate and Representative) reserve requirements by having at least 15% of their pre-European settlement (1750) extent protected in reserves (Commonwealth of Australia and State of Tasmania, 1997; Forest Practices Authority, 2007b). A large proportion of the forest that is unreserved is potentially available for timber harvesting and is therefore unlikely to provide habitat for hollow-using fauna in the future unless managed appropriately. Given the diversity of species' requirements, it is particularly important that habitat for hollow-using fauna is conserved in areas of the state where forest is poorly reserved and in those forest types that are not adequately captured within the CAR reserve system.

An analysis of the reservation status of habitat for two threatened species, the swift parrot (*Lathamus discolor*) and masked owl (*Tyto novaehollandiae castanops*) illustrates the inadequacy of the reserve system alone to cater for hollow-using species. Both species are listed as Endangered under State and Federal legislation (Tasmanian *Threatened Species Protection Act 1995*, Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*) due to small population size and loss of habitat (Bell et al., 1997; Swift Parrot Recovery Team, 2001). Swift parrots breed only in tree hollows, largely in south-eastern Tasmania. The specific location of breeding sites varies annually according to the availability of flowering *Eucalyptus globulus* and *E. ovata* trees which provide essential foraging habitat (Brown, 1989; Swift Parrot Recovery Team, 2001). An estimated 17.6% of the core breeding range of swift parrots is captured in formal reserves (Fig. 2a), but only 2.2% is captured by reserves containing *E. globulus* or *E. ovata* (DPIW, 2001; DPIW, 2006). Similarly, masked owls breed in large hollows found in old growth trees in forested or agricultural areas. They have large home ranges (Bell et al., 1997) and only 11.5% of their core breeding range is captured by formal reserves (Fig. 2b).

Although the reserve system in Tasmania undoubtedly makes a significant contribution to the conservation of forest biodiversity, it is clear that measures outside of the reserve system are extremely important to ensure an ongoing supply of habitat for hollow-using fauna.

4. Strategy 2: landscape level measures in off-reserve areas

The landscape scale may be defined as an area over which local ecosystems and landforms are repeated over several kilometres (Forman, 1995). Landscape level measures recommended for conservation of forest biodiversity include protecting special features (e.g. sites important for threatened species), selecting the spatial and temporal pattern of harvesting, and establishing landscape level goals and limits (Lindenmayer and Franklin, 2002).

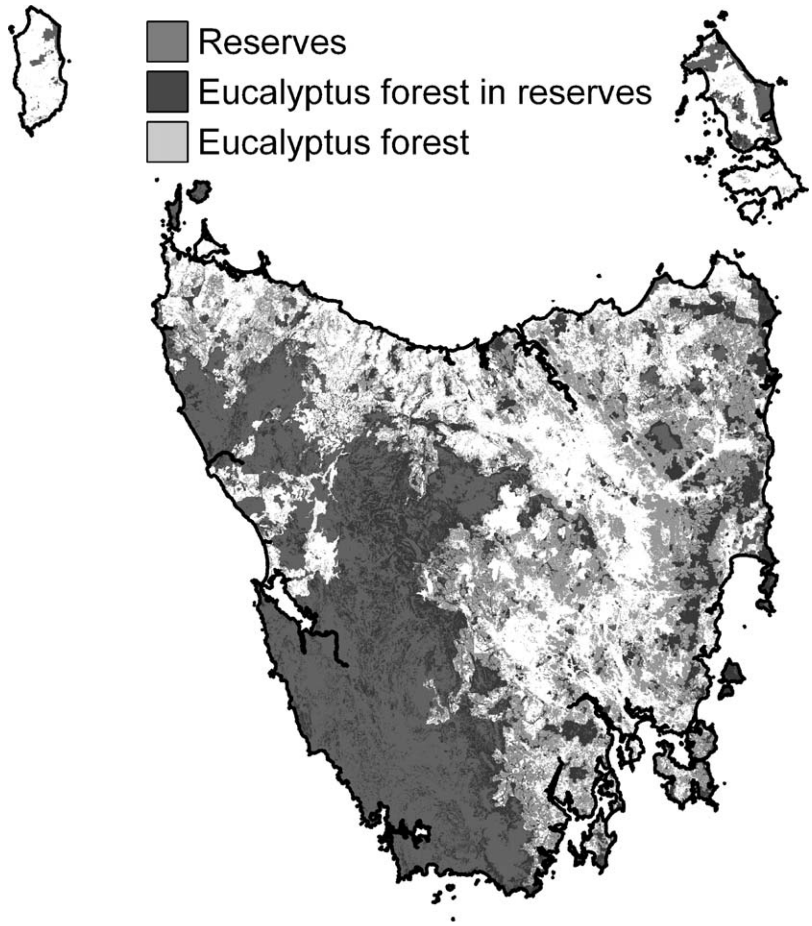

Fig. 1. The location of eucalypt forests and formal reserves in Tasmania (DPIW, 2001, 2006, 2008).

In Tasmania's production forests the landscape scale may equate to a notional contextual area around a planning node in the order of 5–10,000 ha or a drainage basin or an entire bioregion. Currently, there are no measures prescribed in the Tasmanian *Forest Practices Code* (Forest Practices Board, 2000) that are specifically designed for the management of the hollow resource at this scale. However, a variety of patches of forest are retained as 'informal reserves', e.g. streamside reserves, wildlife habitat strips, areas retained specifically for threatened species, areas excluded because of operational constraints (Fig. 3). Some of these informal reserves contribute to the Tasmanian CAR reserve system. Other areas are established for a particular harvest area as part of management prescriptions delivered via the Tasmanian *Forest Practices Code* (Forest Practices Board, 2000). The *Forest Practices Code* provides some guidance on when these informal reserves should be applied, particularly in the case of wildlife habitat strips, special values and streamside reserves. However, these guidelines largely apply when the features in question are found in a planning unit as opposed to being part of a broader strategy for landscape level retention. The main exception to this is the implementation of wildlife habitat strips to maintain habitat diversity (Taylor, 1991b). This network of retained forest complements the formal reserve system at the landscape scale and undoubtedly captures the hollow resource to some extent, contributing to the connectivity of such habitat across the landscape. However, some of these 'informal reserves', particularly those established as part of management prescriptions for a particular harvest area, can be 'moved' around the landscape and so they vary in the security of the resource they provide.

With regards to the spatial and temporal dispersion of harvesting operations, a basic approach identified in the Tasmanian *Forest Practices Code* is that "dispersed coupes [harvesting units] should be considered" (Forest Practices Board, 2000). However, the only specific guidance provided on when and how this should be done relates to forests harvested by broadscale clearfelling (as compared to other forms of less intensive silviculture). For these forests it is specified that, where practicable, adjacent areas of native forest should not be harvested until the dominant height of the first area harvested is at least 5 m and an acceptable regeneration stocking standard is achieved. It is also specified that a harvesting unit should not exceed 100 ha in size (Forest Practices Board, 2000). While these constraints to harvest area and cutting sequence may go some way to maintaining landscape heterogeneity, the degree to which they assist with the maintenance of the hollow resource into the future is questionable. For example, the current lack of clear guidelines and objectives for landscape level management mean that areas may be harvested in close proximity according to these minimum standards, which would create large 'gaps' in some areas of the landscape that contain few hollow-bearing trees (Munks et al., 2007). Practical guidelines are clearly required on how to design and implement an appropriate spatial and temporal harvesting regime that identifies minimum levels of 'mature' forest required in a landscape unit. Landscape level monitoring (e.g. annual GIS-based analyses of changes to forest cover) is also required to ensure that the guidelines are being implemented and, equally importantly, that they are achieving their aims.

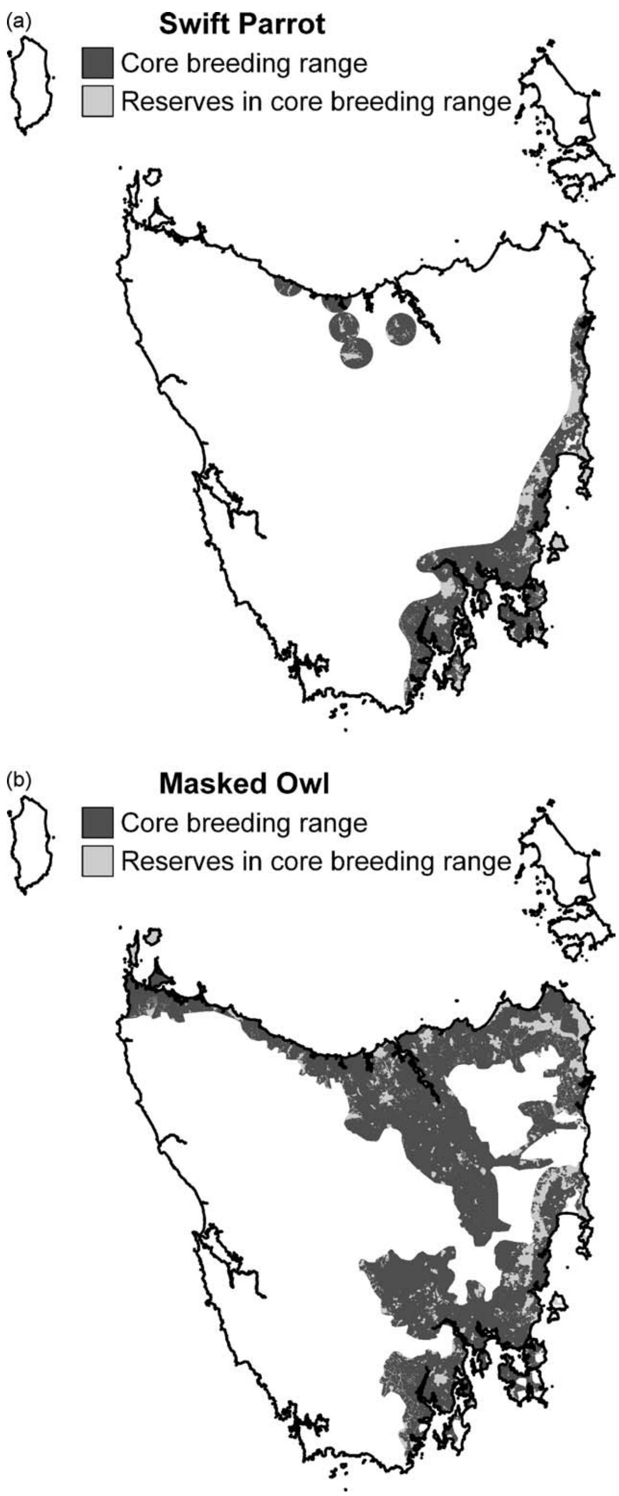

Fig. 2. The core breeding range of (a) swift parrot and (b) masked owl and the level of formal reservation within this area. The core breeding range encompasses the area, within the known range, thought to be of highest importance for the maintenance of breeding populations of the species.

The further development of landscape level measures for the maintenance of the hollow resource would be greatly assisted by the development of suitable goals or limits. The current forest policy framework lacks clearly stated objectives or goals for the management of particular environmental values, at any spatial scale, in off-reserve areas. Not only are explicit goals or objectives helpful for ensuring good management practices, but they set a measure against which the success of these practices can be monitored and judged (Gibbons, 1994). A current review of the *Forest Practices Code* has involved, to some degree, an attempt to establish a primary objective for hollow management–'To provide a continued supply of hollow-bearing trees at multiple spatial scales to ensure populations of hollow-dependent species are maintained across their range'. The need to take into account current theory and to be clear, practical, measurable and agreed to by all stakeholders were all considered in the development of this objective. If stakeholders are not consulted and the social, economic and logistical constraints associated with management of forests in off-reserve areas are not taken into account, then there is a high likelihood that such an objective will not be met by on-ground practice.

Although it has been agreed that the primary objective should be to maintain and ensure the persistence of the hollow resource at a range of spatial scales to cater for species that depend on this habitat, its translation into something that is practical and measurable has proved difficult. Two difficulties encountered are the lack of information on current and past hollow availability across landscapes, and hollow demand by the range of fauna that depend on this habitat. Some recent work has begun to assess hollow availability in a range of forest types in Tasmania (Munks et al., 2007; Koch et al., 2008b). The intention is to develop remote methods that can be used to assess availability of the hollow resource as has been done elsewhere (Fan et al., 2003), but a functional technique has yet to be established in Tasmania. An assessment of hollow demand is hampered by a lack of reliable data on the distribution and abundance of many hollow-using fauna. Until such information is available decisions on the priority for conservation of the hollow resource at the landscape scale may be based on the proportion of different vegetation types (being a surrogate of ecological diversity) that are either reserved or within areas not available for harvesting.

5. Strategy 3: stand level measures in off-reserve areas

Management strategies identified as important for biodiversity conservation at the stand level include structural retention at the time of harvest, management of regenerated and existing stands to create specific structural conditions in a landscape context, and harvest rotation length (Lindenmayer and Franklin, 2002). Clear, measurable and agreed objectives are also required as they help set silvicultural objectives and standards.

Many of the prescriptions outlined in current operational planning tools used in the Tasmanian forest practices system are provided on the assumption that there will be successful native vegetation regeneration postharvest and subsequent recovery of species and their habitats. Although not clearly stated as being such, the current wording of the Tasmanian *Forest Practices Code* implies that the objective of hollow conservation management at the stand level is '. . .to assist the maintenance of habitat required by hollow dependent fauna and enhance recolonisation of areas following harvest' (Forest Practices Board, 2000). While this statement does provide some direction, it is lacking in detail and so does not facilitate the construction of quantitative prescriptions. More information is required about the desired outcome with respect to the species, and the outcome needs to be measurable. A more useful objective might be, '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'.

Although some hollow-bearing trees may be retained by the silvicultural practices currently implemented in Tasmania, the main method for their retention within the harvesting unit is by prescribed\retention of about 50 m × 20 m patches of trees known as wildlife habitat clumps (Fig. 4, Taylor, 1991a). These patches are described as "an area containing habitat trees set aside in a harvesting coupe to aid in the maintenance of fauna habitat

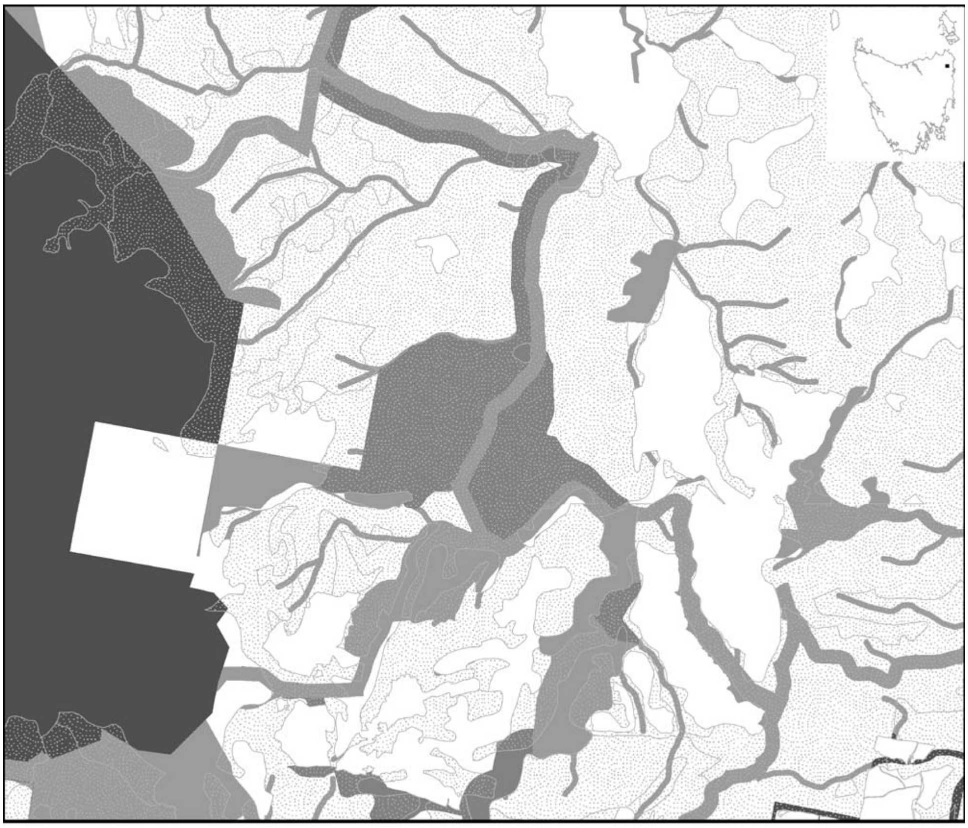

Fig. 3. Landscape level retention of habitat. A map of a forest block indicating formal CAR reserves, informal CAR reserves, and areas established as part of management prescriptions delivered via the Tasmanian *Forest Practices Code* (Forest Practices Board, 2000).

diversity'' (Forest Practices Board, 2000). The current requirement in areas subject to no or low intensity regeneration burning is that approximately one clump, containing at least 2–3 hollow-bearing trees, should be retained every 5 ha. In areas exposed to clearfelling and high intensity regeneration burning habitat clumps are to be retained every 200 m along the harvest boundary (Forest Practices Board, 2000). These clumps are expected to contain a number of younger 'recruitment' trees that are important to retain as a source of hollows into the future (Gibbons and Lindenmayer, 1996; Ball et al., 1999).

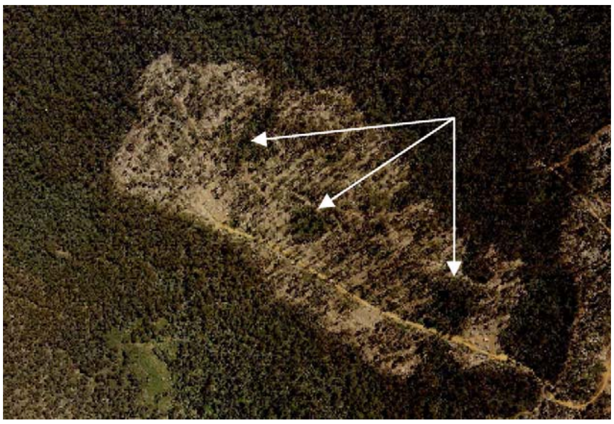

Fig. 4. Stand level retention measures (wildlife habitat clumps) in a selectively harvested area in *Eucalyptus delegatensis* forest in Tasmania (*source*: Forestry Tasmania).

There are a number of advantages with using these clumps to retain hollow-bearing trees. The mortality rate of retained trees can be influenced by the amount of protection they receive from surrounding trees (Gibbons and Lindenmayer, 1996; Gibbons et al., 2000); mortality rate is expected to be lower for trees in clumps than isolated trees (Gibbons et al., 2008). These clumps provide understorey habitat as well as tree hollows. They are versatile in that they can be placed in a range of areas to incorporate multiple values, e.g. rocky outcrops, and are easily monitored to determine whether the retention rate is complying with specified requirements. A disadvantage is that a clump of 2–3 hollow-bearing trees retained every 5 ha is not beneficial to fauna that use multiple hollows across a smaller home range or fauna that are territorial (Gibbons and Lindenmayer, 1997). In our experience, however, the number, type and location of trees retained in practice varies from the prescription according to whether the fauna species potentially present is threatened or not, age and structure of the forest within the logged area, and local variations in how clumps are interpreted by forest managers. Clumps are often amalgamated in a harvest unit as a result of the local availability of hollow-bearing trees and harvest or regeneration burning boundary constraints. There is a need for the current management prescriptions to recognise such flexibility provided the objective for conservation of the hollow resource at the stand level is met.

6. Strategy 4: monitoring and adaptive management

Two types of monitoring are required to determine whether conservation management strategies are working (Lindenmayer and Franklin, 2002). Implementation or compliance monitoring determines whether prescribed management is actually conducted. Effectiveness monitoring determines whether the management specified has achieved its objective and whether the outcome was actually a consequence of management. A general lack of resources in combination with a lack of clear measurable objectives at both the landscape and stand level has made it difficult to design a monitoring program that thoroughly assesses the adequacy of the current hollow management strategy in Tasmania.

Information that has been gathered on implementation and effectiveness of the stand level measures, highlights some of the issues associated with the current approach for the conservation of the hollow resource within harvest areas. The annual monitoring of compliance, involving an examination of approximately 15% of all harvesting plans, found that implementation of wildlife habitat clumps is consistently 'above sound' (Forest Practices Authority, 2007a). A study of clump implementation and survival at ten harvest sites on State forest found that, in general, the current area and tree requirements were being met (Duhig et al., 2000). In contrast a study that examined retention of habitat for the threatened swift parrot on private land found that implementation of wildlife habitat clumps was poor (Munks et al., 2004). Although advice by scientists was generally incorporated into harvesting plans, only 16% of the retained clumps contained hollow-bearing trees as per the prescription. This was in part due to the sparse distribution of suitable trees but also to a lack of clear direction for those implementing the prescribed action, in particular the type of trees to be targeted (Munks et al., 2004). This breakdown in communication was seen as a significant weakness in the planning process because those who prepare timber harvesting plans are generally not directly involved in their implementation. Duhig et al. (2000) found that the way in which clumps of trees were marked out prior to harvest affected their quality (size, composition and level of damage) and hence their capacity to provide suitable habitat for hollow-using fauna. The best results were generally achieved when the clumps were identified and marked by a trained forester (Duhig et al., 2000). This emphasises the importance of appropriate training for foresters and contractors in identification of habitat to ensure adequate interpretation of specialist advice and implementation of prescribed actions. The lack of consistency in the overall results reported in these 'implementation monitoring' studies also illustrates the importance of a continual and diverse monitoring program so that good results in some areas do not lead to complacency.

An informal survey of implementation of the stand level measures by forestry workers has led to discussions on how prescriptive retention measures should be (Koch, unpublished data). The wording for clump retention, as it stands, is interpreted literally by some forest planners and contractors and more loosely by others. Having flexible guidelines would allow the forest workers to move the placement of the clumps, as required. This would potentially increase not only the efficiency of the harvest operation, but also the quality of the habitat that the clumps provide and the level of protection they receive from the surrounding landscape. On the other hand, clear guidance is required to ensure that the right habitat is indeed being retained, that the spatial arrangement of retained areas is being considered, and to ensure that the measures being implemented remain clear enough to allow monitoring. Therefore, not only is the method of retaining habitat important to consider with hollow management, but also how the retention measures are communicated to ensure maximum compliance and efficiency.

Some small-scale studies have explored specific questions relating to the effectiveness of actions to meet the current implied stand level objective—'...to assist the maintenance of habitat required by hollow dependent fauna and enhance recolonisation of areas following harvest at the stand level' (Wapstra and Taylor, 1998; MacDonald et al., 2005; Cawthen, 2007). The results suggest that the value to fauna of hollow-bearing trees retained at the stand level depends on the species present, the age of the regenerating forest within the harvested area and the availability of hollow-bearing trees in the surrounding area. However, although the retained trees assist in the maintenance of habitat, stand level measures on their own do not ensure that hollow-using fauna remain present within a harvest unit at all times. The authors of all of these studies acknowledged the potential limitations of more widely applying the results because of lack of spatial and temporal replication. Nevertheless the studies collectively contribute much information to assist with developing practical guidelines for retention of hollow-bearing trees at the stand level.

The overall effectiveness of a management strategy in meeting objectives for the conservation of hollow-using fauna should not be assessed by looking at stand level measures alone; measures applied at other spatial scales also need to be considered (Whitford and Stoneman, 2004). A recent detailed study in two major production forest types provides information that can be used to assess the effectiveness of the current approach in Tasmania at both the landscape and stand scales (Koch, 2007; Koch et al., 2008a, b). This work found that old trees >100 cm dbh with dead wood in the canopy and at least one large hollow or six small hollows visible from the ground were the most likely to be used by fauna. Trees currently recommended to forest planners for retention may not be the best ones for fauna conservation.

The current minimum rate of retention required within partial harvest areas (one wildlife habitat clump every 5 ha) was based on the number of hollow-bearing trees found to be occupied by four species of birds in a dry sclerophyll forest in north-eastern Tasmania (Taylor and Haseler, 1993). To estimate demand by the full complement of hollow-using fauna, information is needed on species distribution and their requirements, a task that requires considerable resources which are currently unavailable. In other areas of Australia, the rate at which trees are used and/or need to be retained has been determined according to the density of species and estimated hollow requirements (e.g. Smith, 1993; Smith and Lees, 1998), by comparing species occurrence with the density of hollow-bearing trees (Mackowski, 1984), by using nest boxes (Menkhorst, 1984) or examining felled trees (Gibbons et al., 2002). Using the last approach to estimate the use of hollows by fauna in Tasmania, Koch et al., 2008a found that the estimated rate at which trees were used was substantially different to the current rate of tree retention, suggesting that prescribed rates may not be adequate. However, how rate of use relates to rate required is unknown. The array of forest types found in Tasmania and the degree to which reserves and other areas excluded from harvest contribute to hollow availability, increases the complexity of determining the retention levels required.

The Tasmanian forest practices system is centred on the concepts of sustainable forest management in the context of an adaptive management framework based on best practice with continual improvement (Wilkinson, 2006). Refinement of technical manuals and note sheets, simplification of prescriptions and intensive training for forest planners in the identification of the hollow resource have been implemented in response to outcomes from some of the above studies (Duhig et al., 2000; Munks et al., 2004). These changes were relatively easy to achieve since they did not conflict with wood production goals. Little strategic adaptive management in relation to conservation of the hollow resource has occurred since the initial introduction of the provisions into the *Forest Practices Code* in 1993. This has been, in part, because of the absence of clear objectives, and the lack of a system for monitoring strategic effectiveness and an agreed process to ensure that the outcomes of research and monitoring are used to inform continual improvement. Strategies that would lead to effective adaptive management include agreement by all stakeholders to allow some structured variation in practice so that comparisons can be made between different approaches. This should include a monitoring effort that ensures all data are collected consistently and stored centrally so that they can be used to advance management actions.

7. Discussion

The theoretical approach for forest biodiversity conservation provided by Lindenmayer and Franklin (2002) has provided a useful framework for the current review of hollow management in Tasmania. In general, the approach that has evolved since around the mid-1980s has elements that fit the four main strategies Lindenmayer and Franklin (2002) propose to meet the guiding principles of maintaining connectivity, maintaining landscape heterogeneity, maintaining stand structural complexity and adopting 'risk-spreading' measures. The strengths and weaknesses of the current approach in Tasmania, however, illustrate the difficulties that arise when trying to apply a theoretical 'risk-spreading' approach to on-ground practice.

While reserve systems obviously play an important part in meeting objectives of sustainable forest management, with respect to biodiversity, conservation management in the areas outside of reserve systems is essential. This is illustrated in our experience with the management of the hollow resource in Tasmania where the on-going emphasis on traditional 'set-asides' has reduced the area available for production forestry. This has resulted in an intensification of harvesting practices in areas outside of the reserve system (Lindenmayer and Franklin, 2002), which has in turn resulted in increasing challenges for those involved in managing such areas for biodiversity conservation.

The major impediments that need to be addressed when trying to apply a theoretical approach to off-reserve management at both the landscape and stand level include a lack of clear and measurable objectives, lack of information about the particular habitat, and difficulties involved in effectively communicating desired outcomes to those involved in implementing actions. We need to be clear about what it is that we really want to achieve in off-reserve areas with respect to conservation of a particular value. This is often difficult due to a lack of relevant information. In our experience, the separation of wood production goals from conservation goals also creates unnecessary challenges, particularly at the stand level. A silvicultural system has been defined in Tasmania as

> "A regime of operations applied to a forest to produce or enhance forest values such as wood production, water yield, wildlife habitat, soil conservation and landscape aesthetics. In wood production forests a silvicultural system normally comprises a harvesting operation in conjunction with a regeneration treatment" (Forestry Commission, 1994).

Innovative silvicultural methods are required that address both wood production requirements and conservation of wildlife habitat, such as tree hollows for fauna. This outcome will only be achieved by silviculturalists and economists working closely with biologists to reach an agreed position for all objectives (e.g. Polasky et al., 2005).

Tree-hollow management in Tasmania needs empirical data to enable development of management actions for a particular habitat. There are dangers in using information from a particular site and attempting to extrapolate to other areas where availability of habitat and demand by fauna may be different (Gibbons and Lindenmayer, 1997). Wildlife habitat clumps clearly have value as a practical stand level measure that can be implemented by forest workers to retain hollow-bearing trees in off-reserve areas. However, the adequacy of a 'one-size-fits-all' stand level measure in assisting the maintenance of hollow-using fauna in off-reserve areas remains unclear. Local research and monitoring, combined with a broader understanding of the issues from other regional studies suggest that a variety of clear and practical measures may be required.

Assessing the effectiveness of a forest practices system in relation to a particular element of biodiversity is an extremely difficult task (Kimmins et al., 2007) and made more difficult by the lack of measurable objectives or desired outcomes. Unfortunately the piece-meal nature of many of the monitoring studies and their lack of a contextual framework e.g. reporting against defined objectives, has lessened their usefulness for developing a management system.

Effective communication of desired outcomes and training for those involved in implementing actions need to be part of the management of the hollow resource. Clear but flexible guidelines ensure translation to on-ground practice and reduce conflict between harvesting goals and conservation. The desired type and spatial arrangement of habitat to be retained should include flexibility for a particular harvest area to increase the likelihood that the appropriate habitat is retained and not disturbed.

The theoretical approach and guiding principles advanced by Lindenmayer and Franklin (2002) are useful in ensuring a multi-scaled approach and a range of strategies for managing habitat for forest biodiversity, as well as identifying shortcomings of existing approaches. However, the present review has shown that there needs to be more emphasis on practical guidance to assist with implementation. Current management of the hollow resource in the wood production forests of Tasmania has identified the following practical considerations that may assist others trying to achieve successful management of habitat for biodiversity in off-reserve areas:

- well-defined and objectively measurable goals set within the confines of a legislative framework;
- development of a set of clear and practical guidelines to complement the defined goals;
- a means for practitioners to adopt and implement guidelines in a flexible and practical manner;
- integration of stand level measures with silvicultural practice;
- long-term replicated studies that have practical outcomes;
- ongoing training and education of all stakeholders, particularly those involved in implementation;
- monitoring implementation and effectiveness at both landscape level and stand level;
- formal reporting of research, monitoring, compliance and effectiveness in a public forum to allow feedback into a adaptive management system;
- timely adaptive management including acceptance that 'goal posts' may change;
- adequate resourcing for the effort required;
- stakeholder involvement in the development of planning tools.

As has been pointed out by many authors (e.g. Caughley and Gunn, 1996; Lindenmayer and Franklin, 2002; Lindenmayer and Burgmann, 2005) there are significant social and political hurdles to overcome to achieve effective off-reserve conservation and most decisions, particularly on private land are driven by economics. Practitioners involved in taking the theory and trying to turn it into on-ground practice should be encouraged to report on their experience as we have done here so that successes and failures can be debated. Finding a balance between environmental and wood production goals can be complex, but a cooperative and flexible approach, involving all stakeholders, combined with a commitment to long-term monitoring and reporting should lead to significant improvements.

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