Early survival and canopy characteristics of retained habitat trees after timber harvesting and rough-heaped regeneration burning: implications for stand structural complexity in the karri forest

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ABSTRACT

Areas of karri (*Eucalyptus diversicolor* F Muell.) regrowth forest subject to timber harvesting (termed 'coupes') are thinned two to three times until the forest is predominantly mature, after which it is clearfelled. Forest structure in these karri coupes is characterised by even-aged regeneration that lacks a high degree of structural complexity, such as large mature and senescent trees. The Karri Silvicultural Guideline provides for some stand structural complexity in regenerating karri coupes by stipulating the retention of two immature (secondary) habitat trees per hectare. Mature and senescing (primary) habitat trees are not required by the guideline to be retained within karri clearfell coupes. However, a change in regeneration burning practices away from high intensity, broad-scale regeneration burns to milder, rough-heaped (i.e. piling up of non-commercial vegetation) regeneration burns offers greater scope to protect primary habitat trees if they were to be retained within clearfell coupes. In this study, 298 primary and secondary habitat trees (karri, marri, jarrah and blackbutt) were retained during clearfelling operations. Crown condition and survival of the retained trees were recorded before and 22 months after the regeneration burn. Most retained habitat trees (92%) survived the rough-heaping and regeneration burning. There was a significant decline in the canopy condition of karri ($p < 0.001$) and marri ($p = 0.017$) trees to a more intermediate crown senescence; increasing their probability (immediate or longer-term) of hollow occurrence. Assuming that these habitat trees will survive a typical karri harvest rotation (100 years), their presence will enhance the structural complexity of the regenerating stand and provide greater numbers of mature habitat elements, such as tree hollows. Research should continue to assess the survival of the retained habitat trees over a longer time period, and also their use by endemic fauna.

Keywords: clearfelling, eucalypt, habitat trees, retention, rough-heaping, structural complexity

INTRODUCTION

Unharvested forests are generally characterised by a complex and continuously changing mosaic of early, mid and late successional stands that generally contain a high level of structural complexity (Lindenmayer & Franklin 2002; Bradshaw & Rayner 1997a). Structural complexity refers to the number of different structural attributes that characterise a stand (e.g. canopy cover, tree height, tree species, understorey vegetation, etc.) and the relative abundance of each (McElhinny et al. 2005). A high level of stand and landscape structural complexity provides a variety of niches, providing habitat for a wider range of species than stands with low structural complexity, and subsequently corresponds with high levels of biodiversity (Lindenmayer & Franklin 2002; McElhinny et al. 2005; McElhinny et al. 2006). However, stands subject to clearfell harvesting are often characterised by a lack of structural complexity and have been found to be used less frequently by some species of fauna compared with areas of undisturbed stands containing a higher stand structural complexity (Lindenmayer et al. 2010; Stephens et al. 2012). Consequently, harvest planning and many silvicultural practices aim to provide for stand structural complexity through retaining mature forest features and creating a mosaic of stand ages in forests subject to clearfelling.

In karri (*Eucalyptus diversicolor* F Muell.) regrowth forest subject to timber harvesting, regenerated coupes (defined harvest area) are thinned two to three times until the forest is mature, after which it is clearfelled (approximately 100 year cycle; Department of Conservation and Land Management 2005). Regeneration is therefore predominantly even-aged at the local (operational) scale (Bradshaw & Rayner 1997a; Bradshaw & Rayner 1997b). Forest management practices aim to provide some structural complexity at the landscape scale by retaining harvested exclusion areas and structural diversity at the local scale by retaining mid- and over-storey habitat trees within harvest coupes (Conservation Commission of Western Australia 2004; Department of Conservation and Land Management 2005; Wardell-Johnson et al. 1991). Two types of habitat trees are recognised in native forests in south-west Western Australia: primary (mature) habitat trees, being habitat trees that have a moderate to high probability of bearing hollows; and secondary (immature or recruitment) habitat trees, being habitat trees that have a lower probability of bearing hollows at the time of harvesting, but provide for the sustained availability of hollows through time (Department of Conservation and Land Management 2005). Tree hollows are important habitat for many mammal and avian species in the karri forest (Christensen et al. 1985; Abbott & Whitford 2002), including the forest red-tailed black cockatoo (*Calyptorhynchus banksii naso*) and Baudin's cockatoo (*Calyptorhynchus baudinii*) that nest in large hollows in standing trees (Williams et al. 2001; Abbott 1998). Retaining mature habitat trees in clearfell coupes also ensures the perpetuation of coarse woody debris that is essential habitat for fungi and invertebrates and important for various ecosystem processes (Wardlaw et al. 2009; Grove & Forster 2011; Lindenmayer et al. 2002). Secondary habitat trees are retained within karri clearfell coupes at a rate of two trees per hectare (Department of Conservation and Land Management 2005). However, for reasons detailed below, primary habitat trees are not retained within karri clearfell coupes, although such trees usually occur in nearby formal and informal reserves and fauna habitat zones (Conservation Commission of Western Australia 2004; Department of Conservation and Land Management 2005; Wardell-Johnson et al. 1991).

Until recently, retention of primary habitat trees within karri clearfell coupes has been problematic for two main reasons. First, mature karri trees can suppress the growth of nearby regeneration, mostly by out-competing regenerating trees for water (Rotheram 1983). Second, the high intensity, broad-scale burns associated with karri regeneration, along with increased exposure after harvesting, have been observed to make mature trees more vulnerable to rapid crown deterioration and tree death via scorching and/or windthrow. Rapid crown deterioration and death not only results in the loss of trees possibly intended for future harvest but also the loss of a potential habitat tree for hollow-dependent fauna. Burning of harvested karri coupes is undertaken to provide a receptive mineral seedbed for eucalypt germination (Loneragan & Lindenmayer 1964). Additionally, the boles and crowns of retained karri trees are intentionally scorched to promote epicormic growth and increase the likelihood of future hollow formation (Department of Conservation and Land Management 2005). However, an alternative approach for managing structural complexity in karri stands, involving the retention of primary habitat trees within the karri coupe, may now be possible due to changes to regeneration burning practices (predominantly driven by environmental concerns and a growing viticulture industry). Karri coupes are now smaller and, once trees are harvested, residual vegetation (i.e. non-commercial vegetation matter) is now piled into rough heaps (see Appendix 1, Fig. A1) which are burnt in late autumn. These autumn regeneration burns are cooler than traditional summer, broad-scale burns and consequently they may offer a greater scope to retain and protect a greater proportion of mature habitat elements within karri coupes.

This study provides a sound foundation on which to develop and implement measures that maintain greater stand structural complexity, and potentially biological diversity, in karri clearfell coupes. The overall objective of the study was to assess the survival and changes to the canopy condition of mature trees (jarrah, marri, blackbutt and karri) before and after rough-heaped karri regeneration burns.

METHODS

Description of study site

The study site, Channybearup 3, was located in the Channybearup forest block within the Warren Region, approximately 10 km south-west of Manjimup, Western Australia (Fig. 1). The area harvested was 88.5 ha and consisted of a complex mixture of even-aged regrowth (harvested in 1933) and two-tiered karri forest (previously selectively harvested) standing at around 150 stems per hectare (spha). Middle-storey tree species in the study site included jarrah (*E. marginata* Sm.), marri (*Corymbia calophylla* [Lindl.] KD Hill & LAS Johnson) and blackbutt (*E. patens* Benth.). The species composition of the site varied with landform and soil type. Mixtures of karri and blackbutt dominate in the wetter valley floors, grading into mixtures of karri and marri upslope and transitioning to jarrah/marri mixtures on crests and ridges. Prior to harvest, the average height of karri in Channybearup 3 was approximately 42 m, jarrah 29 m, marri 32 m and blackbutt 33 m. Channybearup 3 consisted of seven harvest cells (Fig. 1) that were broken up by stream reserves, other informal reserves, and previously planted areas (2003). The majority of the harvested area faces south or west and ranges from 223 to 280 m in elevation. The soils in the study area consist of mainly yellow duplex soils or gravely duplex soils, formed on weathered mottled and pallid zone material (McArthur 2004). Harvesting occurred between April and November 2010.

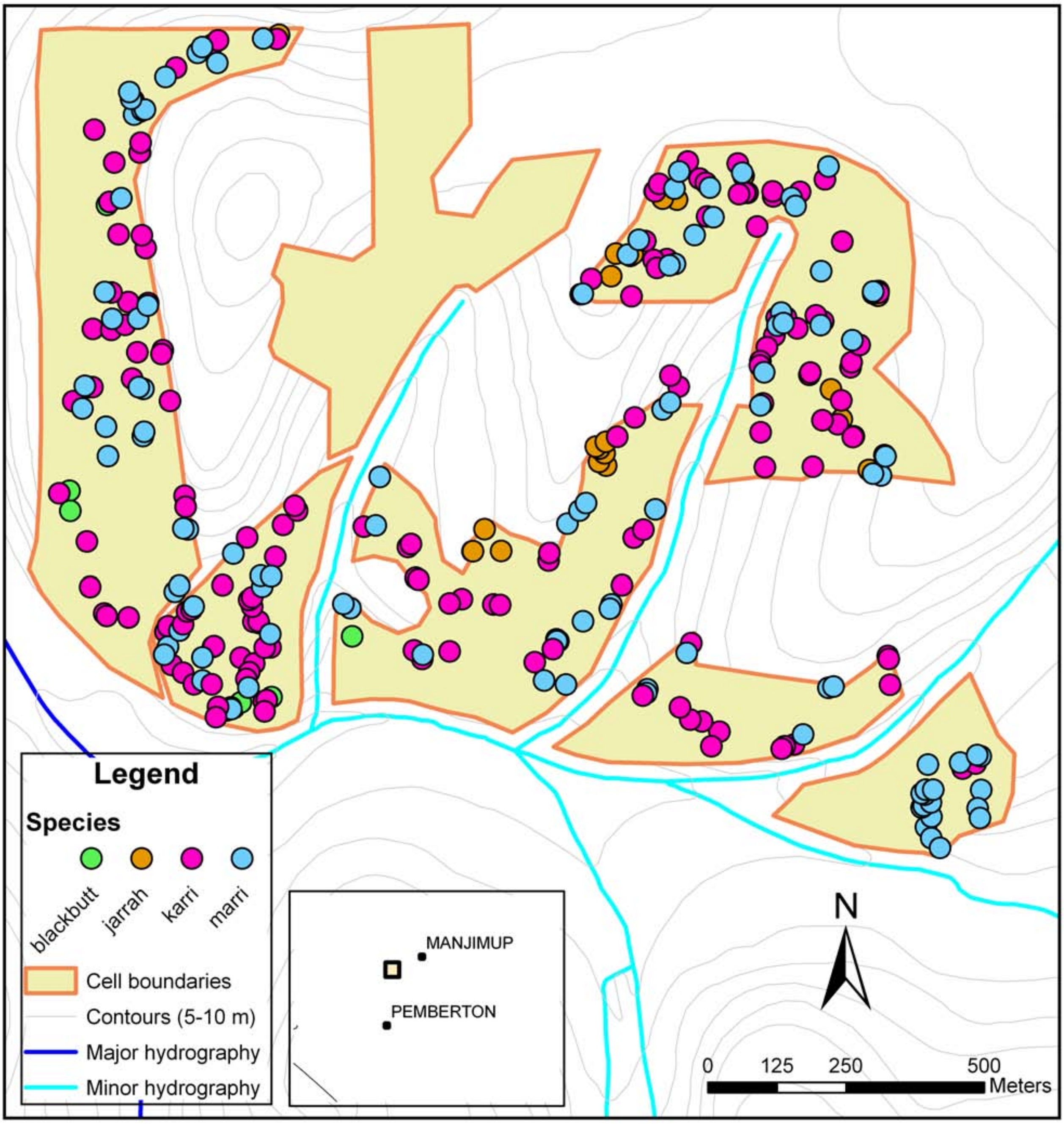

Figure. 1. Map of Channybearup 3 showing the location of the retained habitat trees within harvest areas. Tree crowns are not to scale. Additional habitat trees were contained in the mature forest buffering each stream (both major and minor hydrography); these stream zone buffers are not shown on the map.

Weather conditions

Channybearup 3 rough heaps were ignited on the 15 April 2011. The maximum temperature that day was 27 °C with a dew point of 7 °C (Bureau of Meteorology 2002). Maximum temperatures in the days leading up to the burn ranged from 20 to 25 °C (Bureau of Meteorology 2002). The soil dryness index on the day of the burn was 151, which is much lower than during traditional burning practices in the karri forest (Li et al. 2003).

Field procedures

In order to achieve a greater structural diversity in Channybearup 3 after harvesting, our intention was to retain primary and secondary habitat trees in lieu of the same number (≥ two trees per hectare) of secondary habitat trees normally retained under the Karri Silvicultural Guidelines (Department of Conservation and Land Management 2005). The inclusion of primary habitat trees allowed a more senescent canopy than what would

Figure. 2. Classes of crown senescence (SENES1 to SENES8) for eucalypt trees (from Whitford 2002). Assessment of crowns may be better (SENES0) or worse (SENES9 and SENES10) than those shown.

normally be marked. The crown senescence classes described in Whitford (2002) were used to achieve this (Fig. 2). Where safe to do so, marked trees were in a crown senescence class between SENES4 and SENES8 (Fig. 2), which allowed senescent trees that already contained hollows to be retained. Only living trees were marked as habitat trees. Tree marking was completed by Department of Parks and Wildlife (DPaW) and Forest Practices Commission (FPC) officers during felling operations. Although it is preferential to mark habitat trees before harvesting, the density of the understorey makes marking by tree markers difficult without the removal of at least some of the vegetation. Furthermore, it is difficult to assess the crown characteristics of karri trees in mature stands. Therefore, not every hectare contained trees in the higher senescence classes. Apart from changes to the regeneration burn and the senescence of retained trees, harvesting of Channybearup 3 was completed according to current Karri Silvicultural Guidelines (Department of Conservation and Land Management 2005).

For each tree marked to be retained, the following information was recorded: tree location, habitat tree species, tree diameter at breast height (DBH; cm), crown senescence class of the tree prior to rough-heaping and the regeneration burn, and clearfell gap size (ha). Rainfall (mm), dew point (°C), and temperature (°C) were recorded on the day of the regeneration burn as well as the days and months preceding the burn.

Six months after the regeneration burn, the retained trees were inspected to assess their survival and whether any limbs were lost. Trees that had died but were still standing were recorded. If any trees had fallen over, the

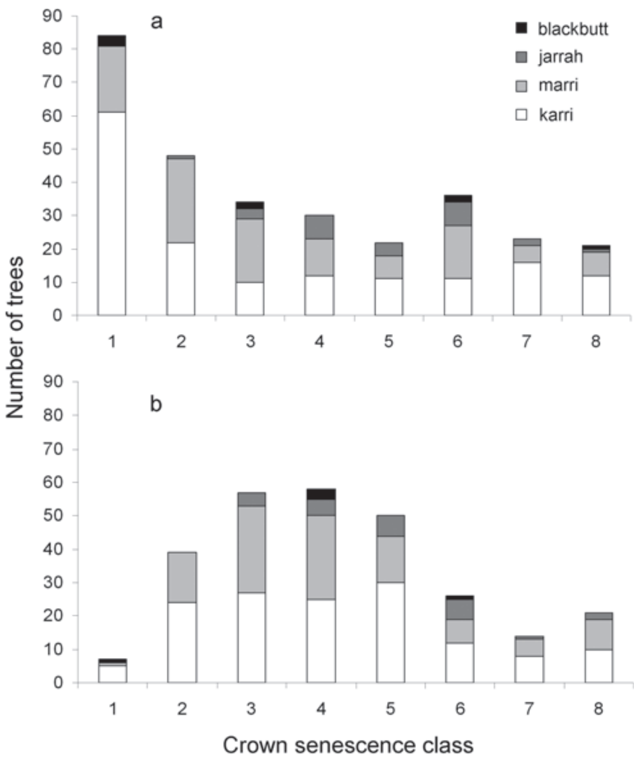

Figure. 3. The shift in crown senescence class distribution before (a) and after (b) regeneration burning in Channybearup 3 (22 months after the regeneration burn).

likely cause was recorded (i.e. fire, exposure). The survival and crown senescence of all remaining habitat trees was re-assessed 22 months after the regeneration burn.

Data analysis

Differences in the median rank of crown senescence for each species before and after the regeneration burn were assessed using Wilcoxon signed-rank tests (Quinn & Keough 2002). The null hypothesis was that the median difference between pairs of crown senescence observations (i.e. before and after burning) was zero. Wilcoxon signed-rank tests were used because this test allows the comparison of paired (same samples before and after an event) data on an interval scale and when the population cannot be assumed to be normally distributed (Quinn & Keough 2002). A comparison test for blackbutt habitat trees could not be undertaken because of the small sample size (n = 5). All statistical analyses were conducted in Microsoft Excel 2003 with a significance level of $p \leq 0.05$.

RESULTS

Characteristics of marked trees before harvesting and regeneration burning

In the trial area, 298 trees were retained as habitat trees (Fig. 3a). This corresponds with a retention rate of over three trees per hectare, exceeding the two trees per hectare required under the current Karri Silvicultural Guidelines (Department of Conservation & Land Management 2005). Retained trees were mostly karri (52%) or marri (37%), with a small proportion of jarrah (8%) and blackbutt (3%; Fig. 3a). Due to safety precautions, most of the marked karri trees were skewed towards crown senescence classes SENES1 (39%) and SENES2 (14%), but 32% were recorded within the target crown senescence classes of SENES5 to SENES8 (Fig. 3a). The other tree species had a more even distribution through all crown senescence classes (Fig. 3a). The diameter class distribution of all marked tree species was skewed towards the lower diameter classes (40 to 100 cm DBH; Fig. 4). Not surprisingly, however, karri trees dominated the higher diameter classes (>140 cm DBH; Fig. 4). The stand basal area of the retained trees was 3.1 m^2 ha^{-1} in total, comprising 1.8 m^2 ha^{-1} of karri, 1.0 m^2 ha^{-1} of marri, 0.22 m^2 ha^{-1} of jarrah, and 0.08 m^2 ha^{-1} of blackbutt.

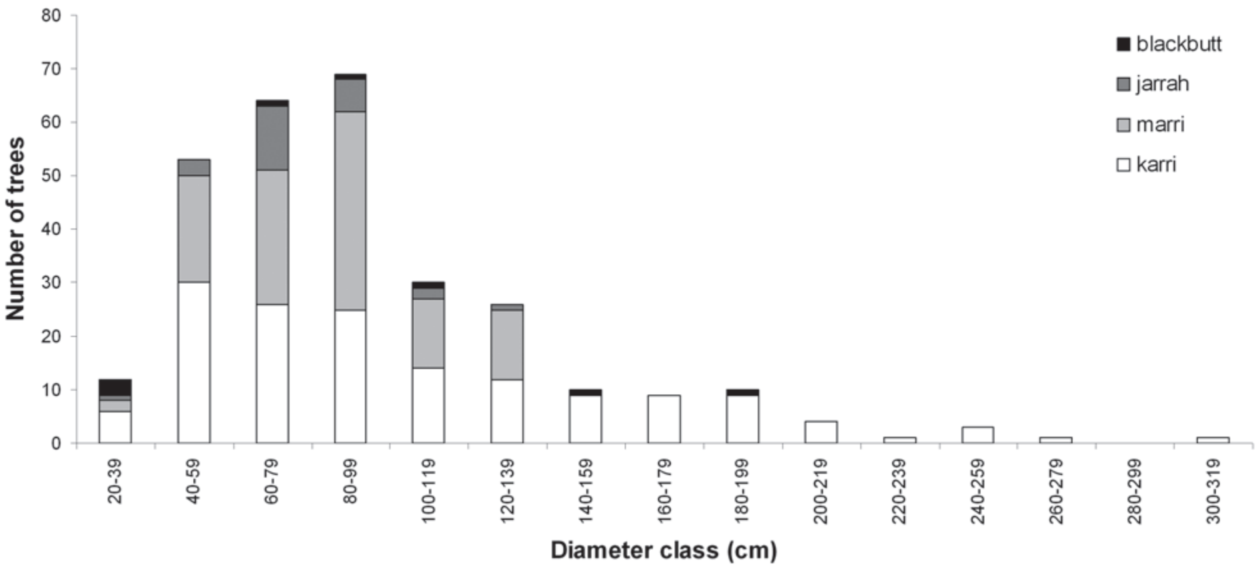

Figure 4. The number of karri, marri, jarrah and blackbutt habitat trees recorded in each diameter class at Channybearup 3.

Tree survival and characteristics

Six months after the regeneration burn

Approximately 94% (280 individuals) of the retained trees were still standing six months after the burning of Channybearup 3. Of the karri trees, 94% (145 individuals) were standing. Of the 18 trees that were no longer standing, three were felled (for safety reasons), nine were burnt down during the regeneration burn, five were knocked down during the rough-heaping of the post-harvesting debris (for safety reasons), and one tree was uprooted, presumably by strong winds. Most of these fallen habitat trees were karri (10 individuals), with five marri, two blackbutt and only one jarrah. Many retained trees were damaged, but not killed, during the harvesting and regeneration burn. This damage included loss of limbs and/or minimal to 100% crown and trunk scorching.

Twenty-two months after the regeneration burn

Twenty-two months after the regeneration burn a further seven habitat trees were no longer standing, presumably blown over due to strong winds (although the exact cause is not known). These fallen habitat trees included three karri, three marri, and one blackbutt. This brought the total number of fallen habitat trees to 25 individuals or 8% of the total number of marked habitat trees. The fallen karri trees were skewed (relative to pre-harvesting and burning data) towards the upper (SENES6 to SENES8) crown senescence and diameter classes but there was no obvious pattern in crown senescence for other species

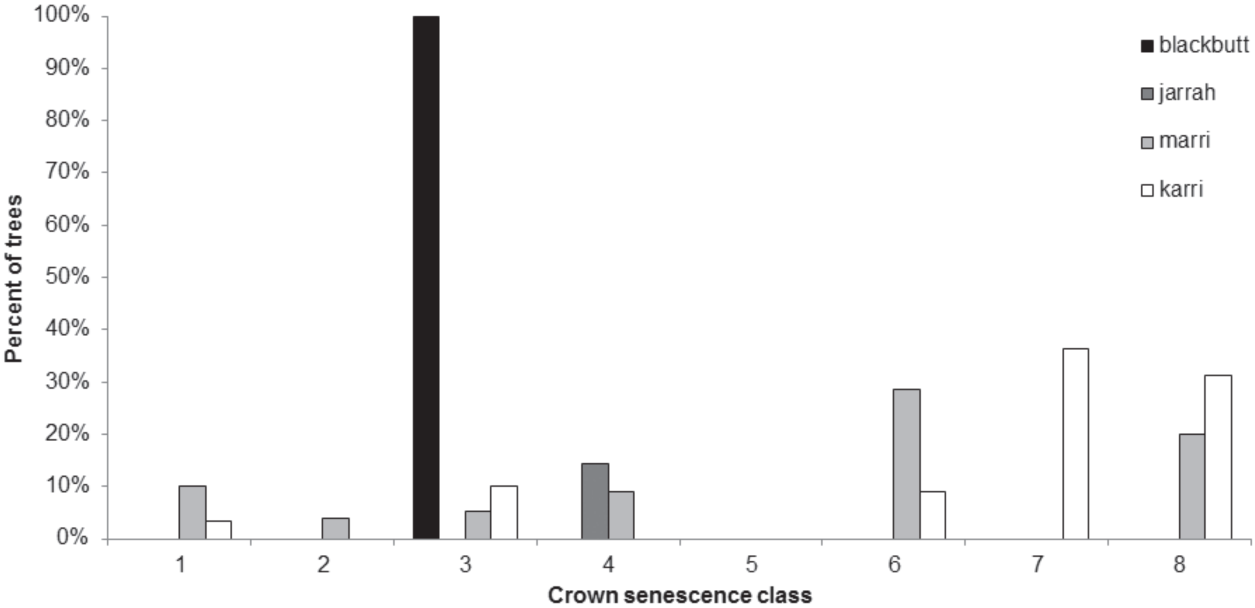

Figure 5. The pre-disturbance crown senescence class distribution of the karri, marri, jarrah and blackbutt trees that fell after the harvesting and regeneration burn within Channybearup 3, expressed as a percentage of all retained trees in each class for each species (note n = 8 for blackbutt).

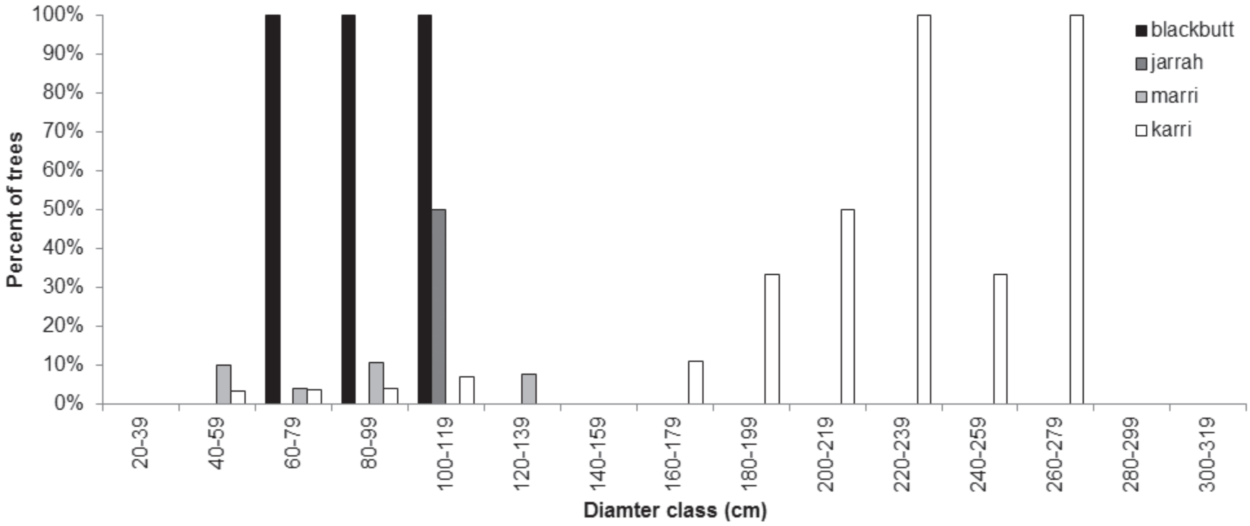

Figure 6. The pre-disturbance diameter class distribution of karri, marri, jarrah and blackbutt trees that fell after harvesting and regeneration burn within Channybearup 3 expressed as a percentage of all retained trees in each class for each species (note n = 8 for blackbutt).

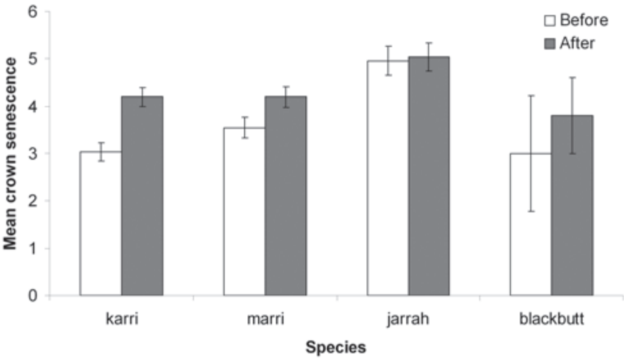

Figure 7. The mean crown senescence (± SE) for each habitat tree species before and after the regeneration burn at Channybearup 3.

(Figs. 5 and 6). Three karri and eight marri habitat trees were dead but still standing 22 months after the regeneration burn.

There was a significant deterioration (i.e. increase in crown senescence) in the crown structure of both karri ($p < 0.001$) and marri ($p = 0.017$) trees after the regeneration burn (Fig. 3b, Fig. 7). The deterioration in crown structure of six retained karri trees is evident in Fig. 8. However, there was no change in crown senescence for jarrah ($p = 0.9$) and no discernible change for blackbutt (Fig. 3b, Fig. 7).

DISCUSSION

Most retained habitat trees (92%) survived the clearfelling and burning of Channybearup 3 and persisted for a further 22 months, including a number of large karri trees with senescent crowns. These findings provide quantitative evidence that retained habitat trees from a variety of life stages, including senescent stages, can survive harvesting and rough-heaped regeneration burns and persist in the short-term. However, the most desirable habitat trees are the most vulnerable to damage from windthrow (Scott & Mitchell 2005). Assuming that these habitat trees will continue to survive, they will increase the structural diversity of the regenerating stand and allow for mature habitat elements, such as tree hollows, to be present. Without the retained primary habitat trees, mature habitat elements would not be present within the coupe until secondary (i.e. immature) habitat trees or karri regeneration reach maturity and begin to senesce (>120 years in age; Bradshaw & Rayner 1997a). For secondary habitat trees of 70 cm diameter this would be about 50 years from the time of regeneration (Bradshaw & Rayner 1997a). The persistence of retained habitat trees in Channybearup 3 should be monitored over a longer time period (>2 years). This will provide valuable information regarding the persistence of mature habitat trees in association with a regenerating karri stand. Many of the large, senescent karri trees are very exposed (Appendix 1, Fig. A2) and may be weakened and blown over during successive winter storms. In particular, the assessment of the condition of tree butts and boles should be incorporated into any future monitoring because their condition (i.e. fire scarring, extent of hollowing, evidence of decay and/or termites, etc.) will likely be related to tree fall (Everham & Brokaw 1996; Mitchell 2013).

While most habitat trees survived the regeneration burn, there was a significant increase in crown senescence of karri and marri trees from low crown senescence to a more intermediate senescence. Previous research found an increased probability of hollow occurrence for trees of intermediate crown senescence (Whitford 2002), raising the possibility of an increased hollow occurrence over time in the retained habitat trees in Channybearup. Although fire can create and extend hollows (Inions et al. 1989), any substantial increase in hollow occurrence will likely occur over a longer period of time, due to the promotion of decay on burnt limbs. The research by Whitford (2002) focused on jarrah and marri trees but similar relationships between crown senescence and hollow occurrence would likely be found in karri trees; however, research is required to confirm this.

The age of karri trees is likely to be an important factor for their survival during and after clearfelling. Many of the karri habitat trees that were killed by the regeneration burn (some still standing), and/or fell over in subsequent years, were large and observed to be in the later stages of crown senescence before harvesting (i.e. SENES6 to SENES8; Figs. 5 and 6). Observations following the regeneration burn revealed large hollow butts in many of the fallen karri trees, indicating a high degree of wood decay (Appendix 1, Fig. A3). This wood decay may have been caused by *Armillaria luteobubalina*, an endemic fungus that attacks the roots of susceptible karri trees causing root rot (Robinson et al. 2003), although this cannot be confirmed. Retaining habitat trees with hollow butts may reduce their longevity as habitat for arboreal species; however, once they fall they provide coarse woody debris that is essential habitat for terrestrial invertebrates and fungi (Grove and Forster 2011; Wardlaw et al. 2009). It must, however, be emphasised that many of the large karri trees in the later stages of crown senescence survived in the coupe up to 22 months after the regeneration burn. The cause of death of the remaining karri and other habitat tree species was mixed and included intentional felling due to safety reasons and also fire and/or wind damage. The damage of some habitat trees is inevitable but reduction of such deaths in the future can be made by (1) ensuring, where feasible, that rough heaps are not near marked habitat trees, or vice versa, and (2) that harvest contractors are more vigilant and aware of the presence of marked habitat trees.

Although rough-heap regeneration burns allow for a greater structural diversity in a regrowth karri stand, the potential ecological benefits need to be considered in the context of reduced growth and density of karri regeneration. Mature karri trees have been shown to suppress karri regrowth up to two crown radii around them (Rotheram 1983). Rotheram (1983) found that a 5% increase in mature karri canopy cover was associated

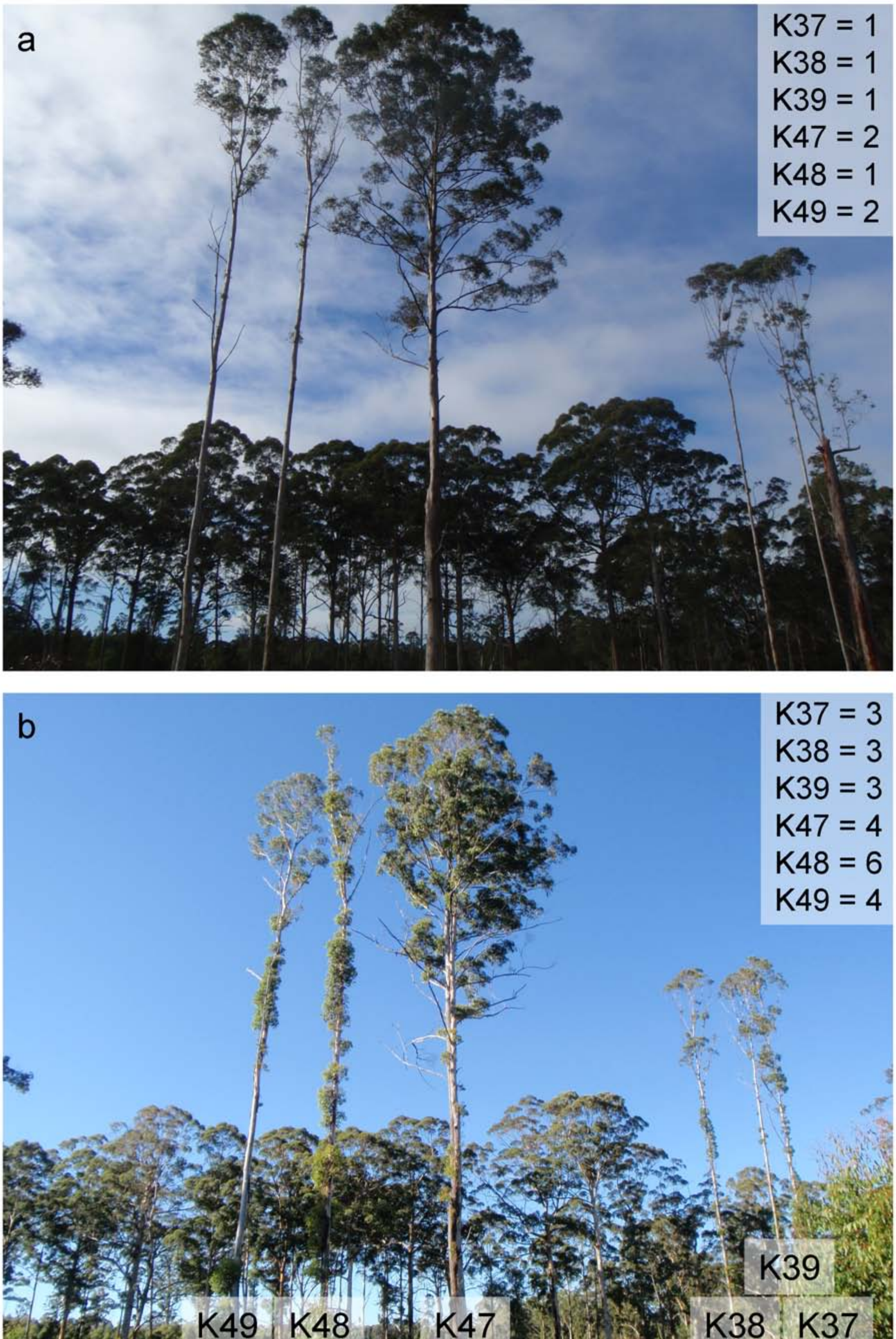

Figure 8. Photos of six retained karri trees (K37, K38, K39, K48 and K79): (a) before the regeneration burn and (b) 22 months after the regeneration burn. The crown senescence score for each retained karri tree is displayed in the top right hand corner in (a) and (b).

with a 10% reduction in regrowth stem volume and 15% understocking of karri regeneration. Root competition for moisture and nutrients, not shading from the canopy, was the likely cause for the suppression of regrowth (Rotheram, 1983). Therefore, the retention of large, mature habitat trees in karri clearfell coupes will likely lead to a reduction of merchantable regrowth volume. Additionally, because competition for moisture likely contributes to the suppression of karri regrowth, the sustained reduction in rainfall in the region (Bureau of Meteorology 2002; Department of Water 2009; Ruprecht & Rodgers 1999) may exacerbate this depressive effect.

Given the potential loss of merchantable regrowth it may be necessary to quantify the effectiveness of the increased stand structural complexity in maintaining the coupe's biological diversity relative to existing measures (Wardell-Johnson et al. 1991; Conservation Commission of Western Australia 2004; Department of Conservation and Land Management 2005). For instance, research could investigate biodiversity recovery in coupes with increased stand structural complexity compared with (1) biodiversity recovery in coupes harvested under current prescriptions (Department of Conservation and Land Management 2005), and (2) the biodiversity in existing formal and informal reserves and stream habitat zones. Research in Tasmania found that Tasmanian common brushtail possums (*Trichosurus vulpecula*) favoured hollow-bearing trees in surrounding mature, dry eucalypt forest compared with mature, hollow-bearing trees retained in recently harvested coupes (<10 years since harvest; Cawthen & Munks 2011). Importantly, the use of habitat trees by brushtail possums was greatest in the oldest regenerating coupe (17 years since harvest) assessed (Cawthen & Munks 2011). Time since disturbance is a key mechanism for species re-establishment in harvested stands (Baker et al. 2013), and it is important that any future research assesses the use of retained habitat trees by biota over the full rotation length between karri harvests (approximately 100 years). Research could also document the vertebrate and invertebrate species associated with each species of retained habitat tree through the senescence stages, giving a broad ecological understanding of the use of habitat trees in regenerating karri stands. Lastly, it is important that any research investigating the recovery of biodiversity in harvested stands compared with the surrounding unharvested forest account for other threats, such as predation from introduced species, as this can override or confound the findings (Wayne et al. 2011).

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APPENDIX 1

Figure A1. Photographs of (a) rough heaped piles at Channybearup 3 and (b) the burning of rough heaped piles.

Figure A2. Photographs of four large, exposed karri habitat trees in Channybearup 3.

Figure A3. A photo of a hollow butt on a large karri habitat tree that fell over after the regeneration burn.