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Validation of a landscape-scale planning tool for cavity-dependent wildlife

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Abstract Tree cavities provide important habitat for wildlife. Effective landscape-scale management of cavity-dependent wildlife requires an understanding of where cavities occur, but tree cavities can be cryptic and difficult to survey. We assessed whether a landscape-scale map of mature forest habitat availability, derived from aerial photographs, reflected the relative availability of mature trees and tree cavities. We assessed cavities for their suitability for use by wildlife, and whether the map reflected the availability of such cavities. There were significant differences between map categories in several characteristics of mature trees that can be used to predict cavity abundance (i.e. tree form and diameter at breast height). There were significant differences between map categories in the number of potential cavity bearing trees and potential cavities per tree. However, the index of cavity abundance based on observations made from the ground provided an overestimate of true cavity availability. By climbing a sample of mature trees we showed that only 5.1% of potential tree cavities detected from the ground were suitable for wildlife, and these were found in only 12.5% of the trees sampled. We conclude that management tools developed from remotely sensed data can be useful to guide decision-making in the conservation management of tree cavities but stress that the errors inherent in these data limit the scale at which such tools can be applied. The rarity of tree cavities suitable for wildlife in our study highlights the need to conserve the tree cavity resource across the landscape, but also the importance of increasing the accuracy of management tools for decision-making at different scales. Mapping mature forest habitat availability at the landscape scale is a useful first step in managing habitat for cavity-dependent wildlife, but the potential for overestimating actual cavity abundance in a particular area highlights the need for complementary on-ground surveys.

Key words: cavity-dependent wildlife, forest, landscape-scale management, remote sensing, tree cavity.

INTRODUCTION

Mature forests are important hot spots for biodiversity around the world (Myers *et al.* 2000). Despite their biodiversity values, mature forests are often exploited for timber, or cleared for agricultural, urban and industrial expansion (Brooks *et al.* 2002; Schmitt *et al.* 2009). Global demand for timber has a major impact on forests around the world, and is unlikely to abate in the short term (Echeverria *et al.* 2006; Gaveau *et al.* 2007; Hart & Chen 2008). Individual logging operations often only affect relatively small areas, but incrementally, their cumulative impacts on forested landscapes can seriously affect processes that regulate populations of forest dependent species (Mac Nally & Horrocks 2000; Nunes & Galetti 2007; Malt & Lank 2009). Failure to manage the cumulative impacts of multiple individual logging operations can seriously impact biodiversity decline (Butchart *et al.* 2010; Gibson *et al.* 2011; Lindenmayer *et al.* 2012). Given the parlous conservation status of forest dependent species, managing anthropogenic habitat loss at the landscape scale is a top priority (Castelletta *et al.* 2005; Peh *et al.* 2005; Ernst *et al.* 2006).

Among the most important habitat resources for wildlife in mature forests are tree cavities that form by decay or tree damage (Newton 1994; Heinsohn *et al.* 2003). They develop slowly and are most abundant in old trees (Whitford 2002; Gibbons *et al.* 2010), but are continually created and lost in mature forests (Murphy & Legge 2007; Edworthy *et al.* 2012; Wesolowski 2012). Specialised habitat requirements make cavity-dependent wildlife particularly vulnerable to anthropogenic habitat loss, and as a functional group, they are of serious conservation concern (Gibbons & Lindenmayer 2002). Cavity-dependent wildlife have species-specific preferences for cavity

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characteristics, and not all tree cavities are suitable (Goldingay 2009; Cockle *et al.* 2010). In undisturbed forests, cavities are abundant and vary in their morphology, hence they support diverse assemblages of dependent wildlife (Gibbons & Lindenmayer 2002; Wesołowski 2007). Loss of mature trees (as happens in logging operations) directly reduces cavity abundance (Eyre *et al.* 2010), which can negatively impact populations of dependent wildlife (Cockle *et al.* 2010; Politi *et al.* 2010). Loss of tree cavities can lead to the decline (e.g. Lindenmayer *et al.* 1990) and local extinction of cavity-dependent species (e.g. Aitken & Martin 2008). Minimising loss of cavities for wildlife is critical to achieving sustainable forest management in logged forests (Gibbons *et al.* 2010).

There is a growing international effort to balance the production objectives of logging with conservation of mature forest elements and associated species (Whitford & Williams 2002; Butchart *et al.* 2010; Gibson *et al.* 2011; Lindenmayer *et al.* 2012), but progress can be hampered by inadequate conservation prescriptions (Gibbons & Lindenmayer 1997; Everett & Otter 2004; Hutto 2006). To effectively conserve cavity-dependent wildlife, managers should aim to perpetuate cavities at multiple spatial scales (Gibbons *et al.* 2010). But data that could inform sustainable management of forests at these scales remain scarce (Loehle *et al.* 2002). Forests are challenging environments to undertake extensive field surveys, so identifying where cavities occur is difficult. Consequently, most detailed studies on cavity availability are conducted at the stand scale, or use ground based survey data from a limited spatial sample to extrapolate cavity availability over larger areas (e.g. Munks *et al.* 2007; Fox *et al.* 2009).

Remote sensing products can provide relatively low cost mapping of habitat at broader spatial scales than intensive field surveys (Stone 1998; Foody 2008). However, tree cavities are cryptic and difficult to survey (Harper *et al.* 2004; Koch 2008; Rayner *et al.* 2011). Cryptic habitat features can be estimated using surrogate measures (e.g. Spanhove *et al.* 2012). Koch and Baker (2011) assessed the relationship between cavity-bearing trees and aerial photo-interpreted data (Stone 1998) in Tasmania, Australia, and found that spatial layers of tree maturity and senescence could be used to reflect relative cavity availability across the landscape. As a result of this study, a map of mature forest habitat availability was developed across Tasmania (hereafter, 'map'), to guide landscape-scale management of tree cavities in forested areas utilised for wood production (Forest Practices Authority 2011b).

It is important to examine the efficacy of habitat models before they are used for on-ground conservation management. Model validation is particularly important for habitat features (like tree cavities) that cannot be surveyed directly using remotely sensed data. In this study, we tested the ability of the map to predict the relative abundance of potential cavity-bearing trees and potential cavities suitable for wildlife in dry forest. We tested whether surrogate measures of cavity abundance (i.e. mature tree density) provide realistic estimates of the true abundance of tree cavities suitable for wildlife at a fine spatial scale. We used our findings to evaluate the general utility of habitat models as tools for guiding management of habitat for cavity-using species at multiple spatial scales.

METHODS

Background to the mature habitat availability map

The map was produced using existing data on the density of mature eucalypt crowns and tree senescence in Tasmania (Commonweath of Australia: State of Tasmania 1996; Stone 1998; Koch & Baker 2011). These data were collected using aerial photo interpretation, have a minimum resolution of 3 ha, and vary in accuracy and completeness across the state (e.g. the data are oldest on private land) (Stone 1998). Based on the relationship between the availability of potential tree cavities and tree maturity/senescence (Koch & Baker 2011), the map estimates and categorizes the relative availability of tree cavities across Tasmania for areas presumed to have been covered by a eucalypt-dominated vegetation type prior to European colonization (Forest Practices Authority 2011b). Categories were defined as: (i) High: ≥40% mature eucalypt crown cover, with no/unknown senescence; (ii) Medium: 20–40% mature eucalypt crown cover, with no/unknown senescence; (iii) Low: 5–20% mature eucalypt crown cover and areas of higher density mature crowns where senescence was 'nil'; (iv) Negligible: areas with <5% cover of mature eucalypt crowns, for example, agricultural areas or regrowth forest (Forest Practices Authority 2011b). All areas presumed to be covered by non-eucalypt dominated vegetation prior to European settlement were classified as 'not suitable' (Forest Practices Authority 2011b).

Study area

We accounted for potential differences in the availability of cavities between forest types by constraining our field sampling to white peppermint (*Eucalyptus pulchella*) dry forests and grassy woodlands (hereafter, white peppermint forest) in south-eastern Tasmania (Fig. 1). White peppermint forest is a widespread vegetation community across eastern Tasmania and has been impacted across its range by agriculture, logging, urban development and wildfire (Forest Practices Authority 2011a). White peppermint forests are utilised by three endangered secondary cavity-nesting birds (swift parrots *Lathamus discolor*, forty-spotted pardalotes *Pardalotus quadragintus* and Tasmanian masked owls *Tyto novaehollandiae castanops*), and several other cavity-dependent species (Koch *et al.* 2008; Stojanovic *et al.* 2012; Webb *et al.* 2012).

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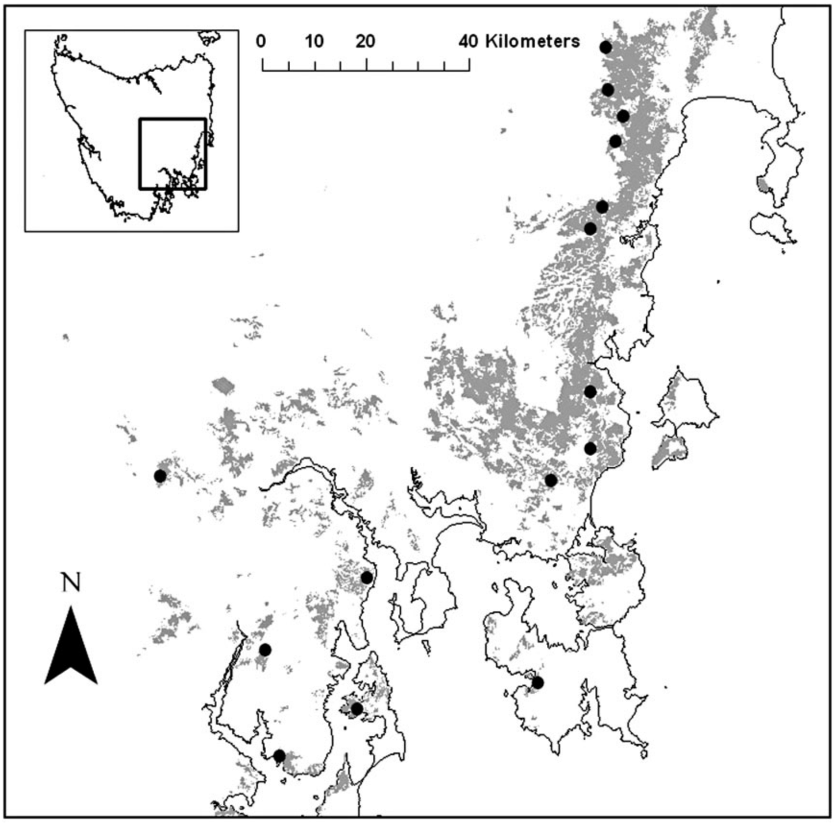

Fig. 1. The study area in southeastern Tasmania, Australia. The points show the location of individual study blocks ($n = 15$) and the grey shading indicates the distribution of white peppermint forest across the area.

We used the map to categorise the availability of mature habitat in white peppermint forests. We only considered areas mapped as 'high', 'medium' or 'low', excluding 'negligible' and 'not suitable' because anecdotal evidence suggests that the availability of mature trees is extremely low in these areas. We excluded privately owned land or areas further than 1 km from a road or track. We accounted for unmeasured local abiotic and biotic variation by using a blocked study design. From our potential study area, we randomly selected 15 locations (blocks), where all three mapped categories were within 900 m of one another. Each block was situated at least 4 km away from its nearest neighbour (Fig. 1).

Field surveys

At each block we established three transects, one in each map category. Transects were 100 m long, 10 m wide, oriented along topographic contours and their starting point was randomly selected using GIS. We surveyed all trees with a diameter at breast height (DBH) ≥ 10 cm whose trunk occurred wholly or partly within transects. We recorded tree species, DBH (cm), tree form and number of potential tree cavities (counted from the ground using binoculars, as in Stojanovic *et al.* 2012). We scored tree form using an ordinal categorical scale where: (1) was a young regrowth tree, (2) a mature (i.e. rounded) crown, (3) a mature crown with some dead limbs, (4) a senescing mature crown dominated by dead or dying limbs, and (5) a dead but standing mature tree. Cavity counts and tree form assessments were only undertaken by DS to account for observer bias.

Characteristics of cavities

To assess the availability of cavities suitable for wildlife, we aimed to climb three mature trees in each transect. We only chose trees ≥ 80 cm DBH to improve the likelihood of encountering cavities suitable for wildlife (80 cm was chosen based on the results of Stojanovic *et al.* 2012; Webb *et al.* 2012). However, at many transects, there were not enough trees suitable for climbing, so sample sizes among map categories were unbalanced. We randomly selected suitable trees within 50 m of each transect and recorded species, DBH, form and number of potential cavities (using the ground count method described above). Each tree was then climbed using single rope techniques to count and measure all accessible tree cavities. We defined a cavity as any hole where the internal depth was equal to or greater than the minimum entrance diameter. Only three potential cavities observed in ground surveys were not accessible by climbing and in each case we assumed they were not a true cavity (as in Stojanovic *et al.* 2012). At each cavity, we recorded minimum diameter of the entrance (cm), depth (cm), floor diameter (cm), height above the ground (m) and signs of use by wildlife. Where signs of use by wildlife were observed, we recorded the species based on either direct observation or detection of traces (like feathers, fur, scratch marks and nests). We were able to positively identify to species all instances where signs of use by wildlife were encountered at cavities.

Data analysis

To check whether the map accurately predicted relative cavity abundance, we used generalised linear mixed models (GLMM), fitted using restricted maximum likelihood (REML) to compare five different response variables between the three categories: (1) number of trees per transect, (2) number of trees per transect with a potential cavity (estimated from the ground), (3) tree DBH, (4), total number of cavities per tree (estimated from the ground) and (5) tree form. We assumed tree form was linear in our analysis because it is an ordinal categorical score. To account for variation between sites, we assigned individual blocks as a random factor in models 1 and 2, and both block and transect as random factors in models 3–5. We used an identity link function for model 3, and a logarithm link for all other models. We examined the residuals of our models for normality and generated predictions (± standard error) for each variable based on the three map categories (i.e. high, medium and low).

We pooled data for all climbing surveys across map categories due to the small sample size of trees from the medium and low categories. Before doing so, we tested for differences in the characteristics of trees from different categories using GLMM. To do this the characteristics of the trees (i.e. form, DBH, height, number of cavities counted from the ground and by climbing) from each category were used as the response variables, map category as the fixed effect, and block and transect were included as random factors. We then used the pooled data to test whether cavity morphology affected the likelihood that they would be used by wildlife (binary response, 1 = yes, 0 = no) using GLMM with a logit link function. Most trees supported more than one cavity, so tree ID was used as the random factor in our model. All analyses were performed in Genstat, 15th edition (VSN International 2012).

RESULTS

Map accuracy

We found no significant difference in the number of trees per map category (Wald statistic = 0.55, d.f. = 2, $P = 0.76$), but there was a significant difference in the number of potentially cavity-bearing trees per transect among the categories (Wald statistic = 147.61, d.f. = 2, $P < 0.001$). Predicted values suggested that the 'high' and 'medium' categories were more similar to one another than they were to the 'low' category in the number of potentially cavity bearing trees per transect (Fig. 2). There were significant differences among map categories in tree DBH (Wald statistic = 8.55,

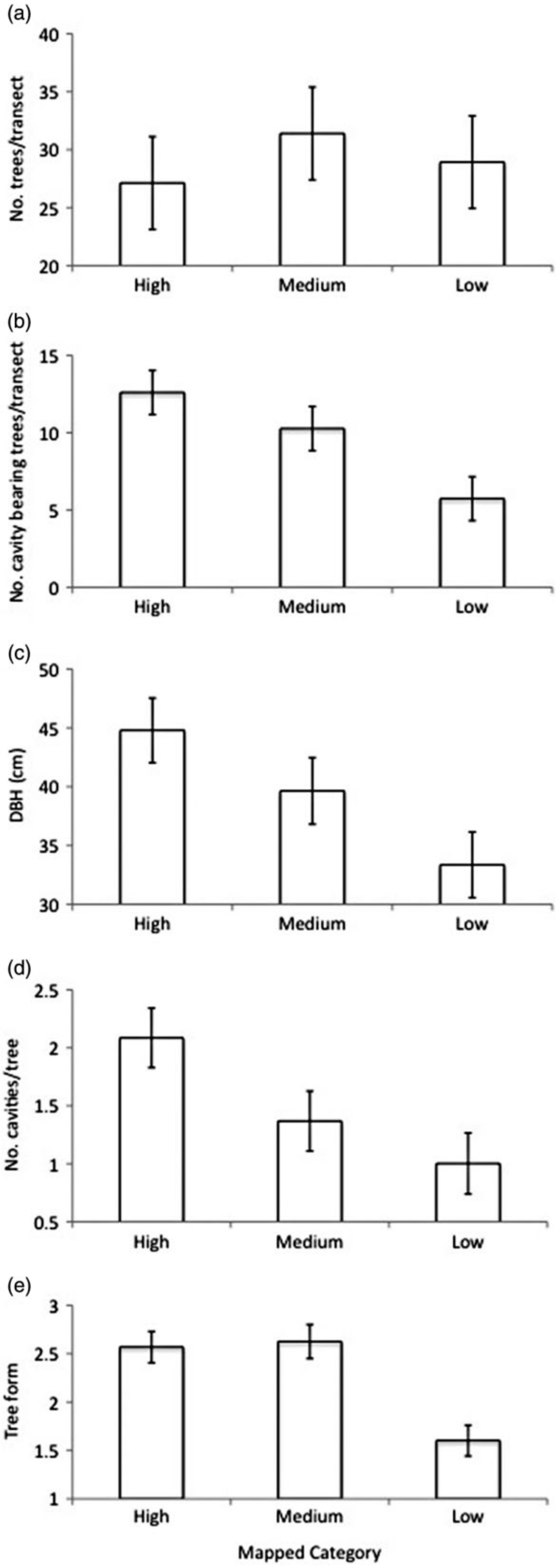

Fig. 2. Predictions (± standard error) among mapped categories (high/medium/low) from the models for: (a) number of trees per transect, (b) number of potentially cavity bearing trees per transect, (c) diameter at breast height (cm), (d) number of potential cavities per tree, and (e) tree form.

d.f. = 2, $P = 0.016$), number of potential cavities per tree (Wald statistic = 9.03, d.f. = 2, $P = 0.013$) and tree form (Wald statistic = 24.94, d.f. = 2, $P < 0.001$). The three map categories appeared to differ in predicted tree DBH and number of potential cavities per tree, but for tree form, the 'high' and 'medium' categories were more similar to one another than to the 'low' category (Fig. 2).

Characteristics of cavities

We sampled 64 trees in our climbing survey. Trees suitable for climbing were more abundant in the 'high' ($n = 45$) than in the 'medium' ($n = 11$) and 'low' ($n = 8$) categories. Most trees in our climbing surveys were white peppermint ($n = 37$), however we also sampled stringybark/messmate (*E. obliqua*, $n = 14$), Tasmanian blue gum (*E. globulus*, $n = 11$), mountain gum (*E. dalrympleana*, $n = 1$) and white/manna gum (*E. viminalis*, $n = 1$). The average tree sampled in our climbing survey had a DBH of 100 cm (±0.53 SE), form 2.84 (±0.10 SE), and height 17 m (±0.28 SE). Ground counts of these trees recorded mean 7.13 (±0.23 SE) potential cavities per tree, but climbing counts found there were only 2.83 (±0.18 SE) true cavities per tree. There was no significant difference among trees in our climbing surveys originating from different mapped categories (see Table 1), so we pooled data for tree cavity morphology.

Of the 158 tree cavities we measured, only 8 (5.1%) showed signs of use by wildlife. Cavities were used by: brush-tailed possums (*Trichosurus vulpecula*, $n = 3$), green rosellas (*Platycercus caledonicus*, $n = 2$), sugar gliders (*Petaurus breviceps*, $n = 1$), tree martins (*Petrochelidon nigricans*, $n = 1$) and yellow-tailed black-cockatoos (*Calyptorhynchus funereus*, $n = 1$). Used cavities were significantly deeper, with larger entrance diameters, wider floors, and were slightly lower in the tree than unoccupied cavities (Table 2, Fig. 3). Used cavities were most common in areas mapped as 'high' ($n = 4$), but also occurred in the 'medium' ($n = 2$) and 'low' ($n = 2$) categories.

Table 1. Test statistics showing that the characteristics of individual mature trees in our climbing survey did not differ significantly among mapped categories

Fixed term	Wald statistic	d.f.	P
Tree DBH (cm)	2.08	2	0.378
Tree height (m)	4.69	2	0.137
Number of potential cavities	1.92	2	0.422
True number of cavities	0.81	2	0.677

Potential cavities were counted from the ground, whereas the true number refers to counts derived from climbing.

DISCUSSION

The map of mature habitat availability that we tested may be a useful tool in managing the availability of tree cavities at the landscape scale. Our results indicated that for the broad spatial scale for which its use is currently recommended (Forest Practices Authority 2011b), the map performed well at differentiating the relative availability of potential cavity-bearing trees and potential cavities. Cavity abundance has been correlated with both tree DBH and form in several studies (e.g. Lindenmayer *et al.* 2000) and both of these variables increased with map category. However, the model predicted that tree form had greater similarities between the 'high' and 'medium' categories than the other variables we tested (Fig. 2). This could be attributed to known limitations in the availability of data describing the density and distribution of mature trees across Tasmania (Forest Practices Authority 2011b). Alternatively, this result may be explained by the rapid attainment of mature crown form by trees in dry forests (Koch & Baker 2011), which does not necessarily correspond to development of potential tree cavities in young trees (Gibbons & Lindenmayer 2002).

Although we found significant differences among categories in the proportion of potentially cavity bearing trees and number of potential cavities, climbing surveys demonstrated that tree cavities suitable for use by fauna were actually extremely uncommon. Even though we biased our climbing surveys to trees most likely to support tree cavities (i.e. mature trees with a large DBH), ground surveys over-estimated the total abundance of true tree cavities by more than double. Indexes of tree cavity abundance are useful for assessing relative abundance (Lindenmayer *et al.* 2000), but our study shows they can be misleadingly high. To reduce error, assessments of cavity availability should be conducted at multiple spatial scales. The map is accurate enough to provide a coarse assessment of cavity availability at the landscape scale, but if detailed, fine scale information about habitat availability is required, additional field surveys (e.g.

Table 2. Test statistics showing how cavity morphology impacted the likelihood a cavity would be used by wildlife

Fixed term	Wald statistic	d.f.	P
Minimum entrance diameter (cm)	18.58	1	<0.001
Internal depth (cm)	39.95	1	<0.001
Floor diameter (cm)	34.38	1	<0.001
Height of cavity above ground (m)	8.32	1	0.004

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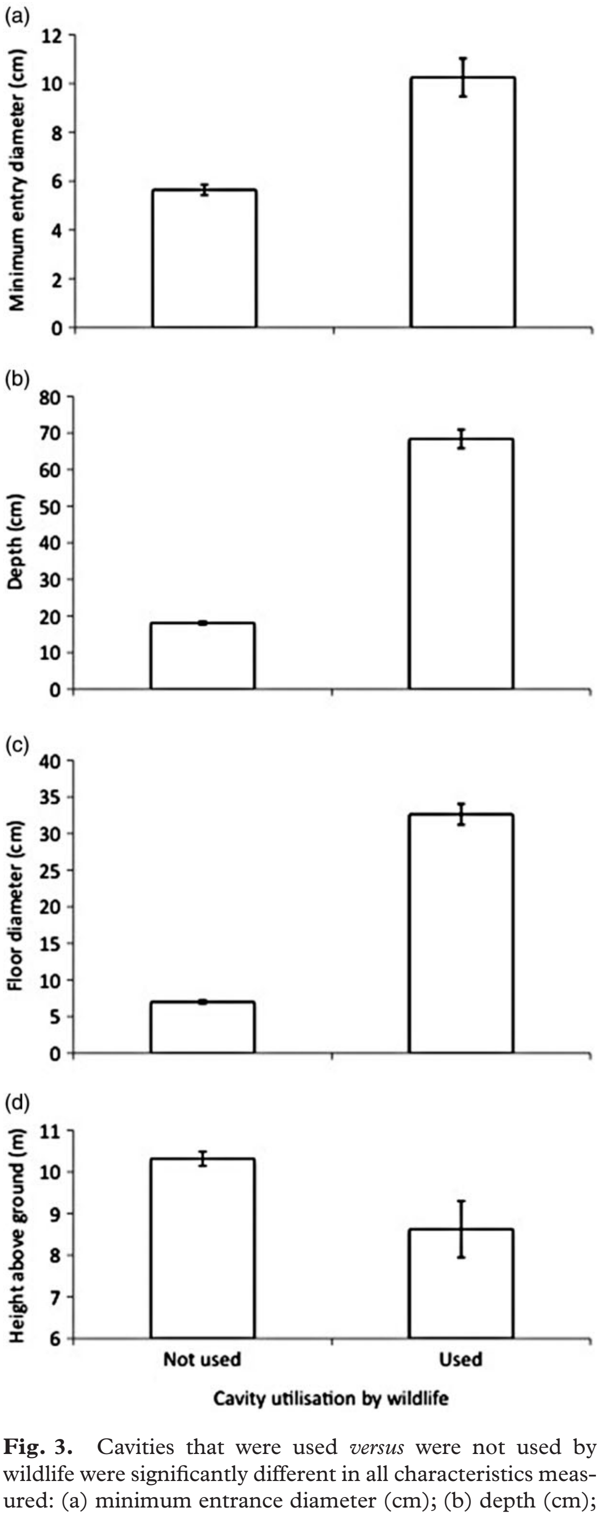

Fig. 3. Cavities that were used *versus* were not used by wildlife were significantly different in all characteristics measured: (a) minimum entrance diameter (cm); (b) depth (cm); (c) floor diameter (cm) and; (d) height above the ground (m). The figures are calculated from the raw data, and show the mean value ± standard error. Note that the sample size of used cavities was very small ($n = 8$) compared with unused cavities ($n = 158$), but these results are similar to those of several other studies of cavity-dependent species.

tree climbing) must also be undertaken. Fine scale surveys are particularly important in areas where threatened species occur.

Our data show that potentially cavity bearing trees and potential tree cavities were more abundant in the 'medium' and 'high' categories than the 'low' category. However, not every tree in an area categorized as 'high' or 'medium' is likely to support a cavity suitable for wildlife. Cavities used by wildlife in our study were sparsely distributed, and only one cavity was used by wildlife for every eight mature trees climbed. These results indicate that some trees have a disproportionate importance for fauna. For instance, at the fine scale, individual mature trees in the 'low' category may support the only available tree cavities in predominantly regrowth stands. Individual mature trees are important focal points for cavity-dependent wildlife and should be conserved as a priority when cavity-poor areas predominate in the surrounding landscape (Lindenmayer *et al.* 2006).

Wildlife utilised only a small subset of the cavities available to them in our study. We encountered 158 cavities during climbing surveys, but only 5.1% ($n = 8$) were used by wildlife. Cavities used by wildlife had significantly larger minimum entrance diameters, deeper chambers, wider floors and were slightly lower in the tree than cavities that were not used (Fig. 3). Although most used cavities occurred in the 'high' category ($n = 4$), they also occurred in both other categories ($n = 2$ each for 'medium' and 'low'). Our results are similar to those of several other studies that highlight the importance of cavity morphology for wildlife occupancy both in Tasmania (Koch *et al.* 2008; Stojanovic *et al.* 2012) and elsewhere (Gibbons *et al.* 2002; Martin *et al.* 2004; Cockle *et al.* 2008). Our study points to the scarcity of cavities suitable for wildlife in some forests. Given the inflated estimates of total cavity abundance, our results highlight that cavities suitable for wildlife represent only a small fraction of an already rare resource in our study area.

Effective landscape-scale management of tree cavities for wildlife depends on reliable data. Our study shows that remote sensing techniques can be used to model the relative availability of mature forest at the landscape scale. However, we caution that indices of cryptic habitat features must be interpreted carefully, and applied as part of a multi-faceted approach to estimating wildlife habitat availability. Cross checking model performance with complementary on-ground surveys is critical to ensure that conservation management is informed by the best available data.

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