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Ground-based survey methods both overestimate and underestimate the abundance of suitable tree-cavities for the endangered Swift Parrot

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Abstract. Most cavity-dependent species select tree-cavities with a narrow range of characteristics so that only a small subset of available cavities may be suitable for any species. Most surveys for tree-cavities are done from the ground using binoculars to reduce effort, but this technique is prone to error. These errors are likely to contribute to the loss of the cavity resource when used to inform conservation efforts for cavity-dependent species. The Swift Parrot (*Lathamus discolor*) is an endangered migratory bird threatened by ongoing removal of cavity-bearing trees by production forestry. We climbed trees with cavities used for nesting by Swift Parrots and determined that they prefer cavities with small entrances, deep chambers and wide floors. Such cavities are rare and occur in large trees that support higher than average numbers of tree-cavities. Importantly, cavities used by Swift Parrots were also likely to be both overestimated and underestimated using ground-based surveys, and without calibration by climbing, the size and direction of survey error could not be determined. We conclude that the most effective way to gain detailed information about the characteristics and abundance of tree-cavities is to climb a representative sample of trees to calibrate ground-based methods for a specific ecosystem.

Additional keywords: cavity availability, forestry, nest selection, survey error, tree-hollow.

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Introduction

Tree-cavities are used for nesting and shelter by a wide range of wildlife wherever trees occur (Brawn and Balda 1988; Newton 1994; Gibbons and Lindenmayer 2002; Gibbons *et al*. 2002; Heinsohn *et al*. 2003; Aitken and Martin 2007; Isaac *et al*. 2008; Goldingay 2009). Cavities are often a limiting resource (Brawn and Balda 1988; Lindenmayer *et al*. 1990; Newton 1994; Gibbons *et al*. 2002; Heinsohn *et al*. 2003; Cameron 2006) and their availability and suitability can drive population processes in the species that use them (Aitken and Martin 2008; Heinsohn *et al*. 2009). This is particularly pertinent for secondary cavity nesters, which are species that have no control over cavity availability and instead rely on primary cavity excavating species or natural decay to create cavities (Marsden and Pilgrim 2003; Martin *et al*. 2004; Aitken and Martin 2007, 2008; Murphy and Legge 2007). Cavity-dependent fauna are disproportionately threatened by the loss of cavity-bearing trees, both where primary cavity excavating fauna occur (Imbeau *et al*. 2001) and where these are absent (Gibbons and Lindenmayer 2002). Not all tree-cavities are suitable for the species that seek to use them, but the precise needs of individual species are poorly understood (Newton 1994; Lindenmayer *et al*. 2000; Martin *et al*. 2004; Aitken and Martin 2008; Goldingay 2009; Cockle *et al*. 2011). The range of specific requirements of secondary cavity nesters complicates the management of cavity-bearing trees in areas used for production forestry.

In undisturbed primary forests, tree-cavities can be common. For example, in a Polish forest never subjected to major anthropogenic disturbance, secondary cavity-nesting birds were not considered to be limited by cavity availability (Wesołowski 2007). Similar results have been found in undisturbed Mongolian forests (Bai *et al*. 2003). Agriculture and production forestry have been implicated in the depletion of tree-cavities globally (Cockle *et al*. 2008; Gibbons *et al*. 2010; Politi *et al*. 2010; Robles *et al*. 2011) and the loss of this resource is a threatening process for many species (Gibbons and Lindenmayer 2002).

Surveys for tree-cavities to inform management decisions in production forests are generally undertaken from the ground using binoculars, or by dissecting trees that have already been felled (Gibbons *et al*. 2002; Bai *et al*. 2003; Manning *et al*. 2004; Boyle *et al*. 2008; Koch 2008; Zheng *et al*. 2009; Cockle *et al*. 2011). A growing body of evidence suggests that ground-based surveys do not provide accurate estimates of the abundance of cavities in the canopy (Whitford 2002; Harper *et al*. 2004; Cockle *et al*. 2010; Rayner *et al*. 2011). For example, Cockle *et al*. (2010) found that of 86 cavities surveyed from the ground in Argentine Atlantic forest, only 19% were actually cavities that could be used by nesting birds. Such errors are inevitably incorporated into conservation management prescriptions when there is no understanding of the nature or size of the errors. Ground surveys for tree-cavities formed by natural decay provide little information about the characteristics of the cavity other than an estimate of entry diameter, which is a poor predictor of the internal dimensions (Gibbons *et al*. 2002). The reliability of ground surveys also varies between tree species and type of vegetation (Cockle *et al*. 2010; Rayner *et al*. 2011). Dissection surveys of felled trees provide a more accurate estimate of standing cavity abundance (Gibbons *et al*. 2002; Whitford 2002; Koch 2008) but this sampling methodology is destructive and fails to detect cavities destroyed or damaged by felling operations. In one study, 49.2% of cavities observed in pre-felling surveys could not be detected after felling (Koch 2008).

Climbing trees to survey cavities is rarely undertaken because it is regarded as expensive and impractical given the specialist skills and workplace safety conditions required to undertake such fieldwork. However, this method provides the best estimate of the number and characteristics of cavities available to wildlife in standing trees (Saunders 1979; Saunders *et al*. 1982; Heinsohn *et al*. 2003; Martin *et al*. 2004; Politi *et al*. 2010; Cockle *et al*. 2011; Rayner *et al*. 2011). Although generalised approaches to assessing the availability of cavities based on characteristics of trees (e.g. Lindenmayer *et al*. 2000) can provide a means for quickly estimating the abundance of cavities across large areas, we show here that such methods benefit from calibration with climbing surveys. We identify the specific cavity requirements of endangered Swift Parrots (*Lathamus discolor*) by climbing trees. We also compare the number of cavities recorded during climbing surveys to the number estimated from ground-based surveys. We show that suitable cavities are rare and that ground-based survey methods result in substantial detection errors.

Materials and methods

Study site

The study was undertaken across a broad area of south-eastern Tasmania, Australia. Sites were located in wet, dense and tall forest dominated by Stringybark (Messmate) (*Eucalyptus obliqua*)[A] in the Wielangta State Forest (42°44′S, 147°52′E), and dry forest and woodland dominated by White Peppermint (*E. pulchella*) on private properties on Bruny Island (43°09′S, 147°19′E), the Meehan Range (42°48′S, 147°24′E), Woodsdale (42°31′S, 147°39′E) and Nelson Tier (42°43′S, 147°40′E). Production forestry is the dominant land-use at Wielangta State Forest, Woodsdale and Nelson Tier.

Study species

The Swift Parrot is a medium-small (70–80 g), mostly nectarivorous, obligate cavity-nesting bird that breeds only in Tasmania, during the austral summer, and migrates to mainland south-eastern Australia during the austral winter (Brown 1989). It is listed as endangered in Tasmania (*Threatened Species Protection Act* 1995 (Tasmania), Schedule 3), nationally (*Environmental Protection and Biodiversity Conservation Act* 1999 (Commonwealth)) and internationally (BirdLife International 2012). Breeding Swift Parrots occur sympatrically with several other secondary cavity dependent species that are known to occupy cavities used by Swift Parrots (Koch *et al*. 2008). Much of the breeding range of Swift Parrots is within areas used for production forestry, and very little is included in the Tasmanian reserve system (Munks *et al*. 2004). Swift Parrots nest at low densities in forests and woodlands covering many thousands of hectares, and finding nests is labour- and time-intensive. We thus concentrated our search effort on: (1) areas where Swift Parrots had been known to breed in previous years; (2) areas identified by community volunteers as potential nesting habitat and (3) areas identified as possible nesting habitat during targeted nest searches conducted by the Tasmanian Department of Primary Industries, Parks, Water and Environment.

Identification of nest-trees

In the 2005 and 2010 breeding seasons, observers identified stands likely to contain nests by searching for behaviours indicative of breeding by Swift Parrots. These behaviours included: (1) adults perched quietly in the upper branches of a tree, before climbing or flying to a lower part of the canopy; (2) an adult male feeding a female near a tree-cavity; and (3) hearing the food-begging calls of either adult females or juveniles (Webb *et al*. 2012). These behaviours would initiate a more extensive search of the area by the observer who would closely follow birds, looking for pairs or individuals walking or flying from the upper canopy to a cavity, pairs or individual Parrots entering or leaving a cavity or juvenile Swift Parrots either heard or seen at the entrance to a cavity.

In the 2005 breeding season, we used the above method only to identify nest-trees, whereas in the 2010 season, we also climbed nest-trees using single-rope techniques to verify that the cavity was an active Swift Parrot nest. Nest-trees identified in the 2005 season were not climbed until 2010, but nest-trees discovered in 2010 were climbed several times as part of another study. Cavities used by Swift Parrots in 2005 were included in our analysis as nests (Webb *et al*. 2012) because other studies have shown that cavity morphology usually changes slowly over short time scales (e.g. Saunders 1979).

Characteristics of trees and cavities

To compare the characteristics of known Swift Parrot nest-trees to non-nesting trees, we randomly selected a paired tree of the same species for each known nest. We followed Manning *et al*. (2004) and selected a random tree using a bearing 30° more than the last

[A]The common name of *Eucalyptus obliqua*, Stringybark, is the preferred common name in Tasmania (see http://www.dpiw.tas.gov.au/inter.nsf/Publications/LJEM-6JL5QM?open).

random tree, in a clockwise direction around the compass. The random tree was selected as the first tree at least 30 m (maximum distance was 50 m) distant from the nest-tree that had a minimum size threshold of 50-cm diameter at breast height (DBH). We excluded trees with DBH <50 cm because cavities are less common in trees with smaller DBH (Gibbons and Lindenmayer 2002). For both the nest-tree and its random pair, we measured the DBH, the maximum crown diameter (MCD), height of the trees, tree-form and total number of cavities. We followed Manning *et al*. (2004) for measuring DBH and MCD and we used the categories outlined in Lindenmayer *et al*. (1991) for classifying tree-form in eucalyptus forests.

All trees were climbed to count the number of cavities in the standing tree and to measure the characteristics of the cavities. We defined a cavity as any cavity in the tree with a depth equal to or greater than the minimum dimension of the entrance. For each cavity, we recorded whether Swift Parrots had attempted to nest in it (yes or no), the maximum and minimum entrance diameter (cm), depth (cm), diameter of the floor (cm), position in tree (main trunk, snapped-off trunk top, branch mid, end of snapped off branch >1 m long, broken-off branch stub <1 m long, basal), height above ground (m), signs of use (also species using cavity when known), and signs of whether it had been flooded (e.g. a water mark or presence of standing water; yes or no). We used a small camera and a torch to investigate the contents of cavities.

We also estimated the potential number of tree-cavities in the standing crown of each tree from the ground as per the guidelines in the Tasmanian Forest Practices Code (Forest Practices Board 2000). These guidelines require an assessment of the occurrence of potential threatened species habitat, including 'habitat trees' that contain tree-cavities. For our ground-based surveys of cavity abundance, each tree was searched using binoculars from all angles on the ground for at least 2 min. All suspected cavities were defined, from the ground, as knotholes, broken-off branches and fissures. M. Webb conducted all ground-based surveys and D. Stojanovic undertook all climbing surveys to limit observer bias in each process.

Data analysis

To investigate the characteristics of trees that produce cavities suitable for a Swift Parrot, we compared the DBH, MCD, tree-height and the total number of cavities of each Swift Parrot nest-tree to its randomly selected paired tree using a paired *t*-test. Tree-form was described in categories, so we used a Chi-square test to compare the form of nest-trees to randomly selected trees. We used generalised linear mixed models to test whether cavity morphology affected the likelihood that Swift Parrots would use a cavity. Four cavity characteristics were tested in our model: (1) minimum dimension of the entrance, (2) depth, (3) floor diameter and (4) height above ground. We used the minimum entry dimension because we assumed this to be the functional dimension that excludes larger nest predators and competitors. We normalised the data for all four cavity characteristics using natural log-transformations. Most trees supported more than one cavity, so to avoid pseudoreplication by measuring more than one cavity from the same tree, we assigned the individual tree as a random factor.

To investigate the potential abundance of cavities that could be used by Swift Parrots, from our sample of unoccupied cavities, we calculated the number of cavities that fell within the range and one standard deviation of the mean for known Swift Parrot nests in all four characteristics outlined above.

We used generalised linear models to describe the accuracy of ground surveys of cavity abundance when the number of cavities in the standing canopy was determined by climbing ($n = 82$ trees). We examined the residuals of our regression model to confirm the data were normally distributed. We used predictions generated from the model to illustrate effect sizes, especially the discrepancy between ground-based estimates and the number of cavities as determined by climbing for different sizes of trees. We used four different sizes of trees (DBH of 50, 100, 150 and 200 cm) to illustrate the relationships between ground-based estimates and numbers of cavities determined by climbing, especially as size of tree is known to affect the accuracy of ground-based surveys (Rayner *et al*. 2011).

Results

Tree characteristics

Swift Parrot nest-trees had significantly larger DBH (mean = 102.43 cm ± 5.73 s.e.; range = 12.1–206 cm) than randomly selected trees (84.81 cm ± 3.35; 50.5–154 cm) ($t_{47} = 2.95$, $P = 0.005$). There was no significant difference between nest-trees and randomly selected trees in MCD ($t_{40} = 0.30$, $P = 0.762$) or tree-height ($t_{46} = -0.22$, $P = 0.830$). Nest-trees had significantly more cavities than randomly selected trees ($t_{46} = 9.1$, $P < 0.001$; Fig. 1*a*), and 80.1% of the cavities we measured co-occurred in the same tree as a Swift Parrot nest. Tree-form of nest-trees was not significantly different to that of randomly selected trees ($\chi^2 = 10.37$, d.f. = 47, $P = 0.5$).

Cavity characteristics

We measured 265 tree-cavities in 96 trees, including four trees that had two Swift Parrot nests. A total of 52 Swift Parrot nest-cavities were measured, 15 from 2010 and 37 from 2005. During our ground-based surveys for nesting Swift Parrots in 2010, we incorrectly identified 8.3% of tree-cavities as nests when they were not. Thus, of our sample of nests from 2005, approximately three would have been incorrectly identified as Swift Parrot nests when they were not, assuming that all other conditions during the detection of nests were equal. Three cavities used by Swift Parrots in 2005 were used again in 2010.

Use of cavities by Swift Parrots was significantly dependent on each of the four cavity characteristics measured (minimum entry dimension, cavity depth, floor diameter and height above ground). The only significant interactions between variables were between floor diameter and cavity depth and between height of the cavity above the ground and floor diameter (Table 1). Nesting cavities, compared with cavities not used as nests, had smaller minimum entry dimensions, were deeper, had wider floors, and were higher in the tree. Effect sizes of these significant variables are illustrated using log-transformed data in Fig. 1*b–e*. In our sample, Swift Parrots nested most frequently in cavities in the main trunk (38%) or in broken-off or mid-branches (26 and 24%).

In our sample of 213 cavities not used by Swift Parrots, we found that 34.3% fell within the range of all four characteristics

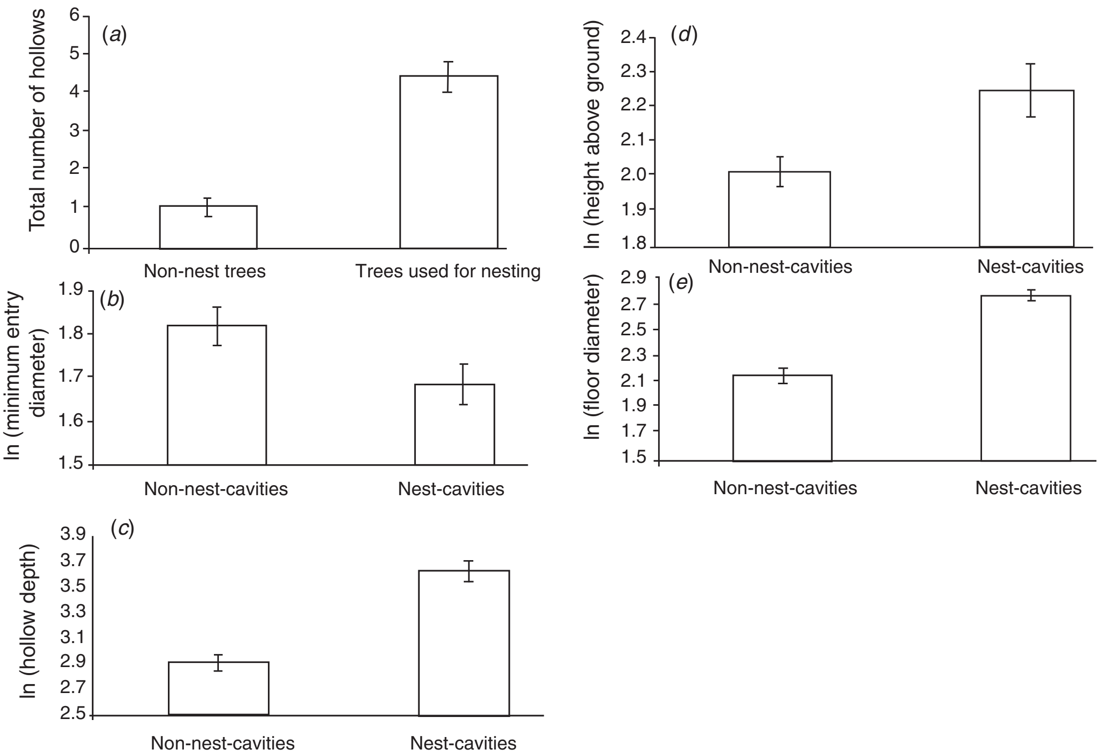

Fig. 1. (*a*) Mean number of cavities in non-nest trees ($n = 42$) and trees used for nesting by Swift Parrots ($n = 42$); (*b*) mean minimum entry dimension for non-nest-cavities ($n = 213$) and nest-cavities ($n = 52$); (*c*) mean depth of cavity for non-nest-cavities ($n = 213$) and nest-cavities ($n = 52$); (*d*) mean height above ground for non-nest-cavities ($n = 213$) and nest-cavities ($n = 52$); (*e*) mean floor diameter for non-nest-cavities ($n = 213$) and nest-cavities ($n = 52$). Means are shown ± standard error.

Table 1. Results of the Generalised Linear Mixed Model showing the importance of cavity characteristics for use of cavities by Swift Parrots
All characters were ln. Only significant interactions are shown; for all other interactions $0.066 < P < 0.793$. The effect of each variable is illustrated in Fig. 1

Fixed term	Wald statistic	d.f.	P
Minimum entry dimension (cm)	16.54	1	<0.001
Height of cavity above ground (m)	11.87	1	<0.001
Cavity floor diameter (cm)	13.23	1	<0.001
Internal depth of cavity (cm)	18.17	1	<0.001
Floor diameter × internal depth	21.05	1	<0.001
Height above ground × Floor diameter	4.59	1	0.033

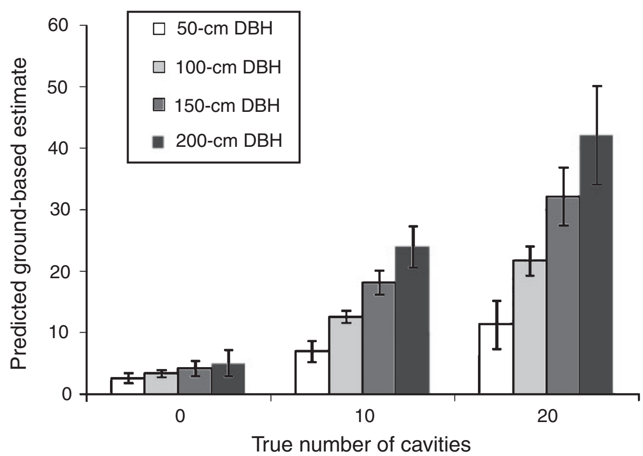

Fig. 2. The modelled relationship between the true number of cavities, as determined by climbing (*x*-axis) and the predicted number of cavities estimated from the ground (*y*-axis). Predictions (±standard error) from the generalised linear model are shown when there are 0, 10, and 20 true cavities across trees of four diameters at breast height (DBH): 50, 100, 150 and 200 cm.

measured in known nests, but only 5.2% fell within one standard deviation of the mean for all four cavity characteristics measured of known Swift Parrot nests.

Reuse of nest-trees by Swift Parrots and other species

We recorded reuse of tree-cavities by Swift Parrots for three cavities found in 2005. Several other species were detected using cavities of various sizes and dimensions in this study (the number of cavities in which each species was detected is given in parentheses): Tree Martins (*Cecropis nigricans*) (26), Green Rosellas (*Platycercus caledonicus*) (5), Common Brushtail Possums (*Trichosurus vulpecula*) (5), Striated Pardalotes (*Pardalotus striatus*) (3), Dusky Robins (*Melanodryas vittata*) (2), Sulphur-crested Cockatoo (*Cacatua galerita*) (1) and Musk Lorikeet (*Glosopsitta cocinna*) (1). We recorded Green Rosellas using old Swift Parrot nests twice and Tree Martins on 16 occasions. Twice we observed Tree Martins taking up cavities within 1–2 days of fledging of Swift Parrot nestlings.

Accuracy of ground-based surveys

The number of cavities identified in ground-based surveys increased when more cavities were actually present in the canopy ($F_{1,81} = 24.78$, $P = <0.001$) and with increasing tree DBH ($F_{1,81} = 42.01$, $P = <0.001$). Figure 2 illustrates this effect with predictions from the model. Ground-based surveys overestimated and underestimated the real number of cavities when DBH was 50 cm, but tended to overestimate the number when tree DBH increased (Fig. 2).

Discussion

There is a growing body of research internationally that the characteristics of cavities preferred by secondary cavity-nesting species are narrow in specification, and often rare in the landscape (Saunders *et al*. 1982; Newton 1994; Martin *et al*. 2004; Cornelius *et al*. 2008; Goldingay 2009). Our results show that like other secondary cavity-nesting birds, Swift Parrots only use a small subset of available cavities. Not all tree-cavities are suitable for all species, so determining the specific characteristics preferred by individual species is critical to managing this resource in production forests (Gibbons *et al*. 2002). The influence that the limited availability of suitable cavities can have on populations of secondary cavity nesters can be profound. For example, in Canada, exclusion from preferred tree-cavities led to a decline of local populations of European Starlings (*Sturnus vulgaris*), and those populations failed to recover when previous levels of cavity availability were restored (Aitken and Martin 2008). In this study, Swift Parrots strongly preferred cavities with small entrances (mean minimum entry dimension 5.7 cm), and that were deep with wide floors internally. These mostly occurred high in trees with a large DBH.

The characteristics of Swift Parrot nest-trees make them easily identifiable from the ground, but we found determining the number of nest-cavities is prone to underestimation and overestimation when assessed in this way. Moreover, the degree to which ground surveys overestimated the total number of cavities tended to increase with DBH of trees and number of cavities. Trees with a DBH similar to the average DBH of those used by nesting Swift Parrots (i.e. 100 cm) tended to have smaller errors than larger or smaller trees when surveyed from the ground. However, this result does not suggest that nest-trees are less likely to be subject to survey error than other cavity-bearing trees. We recorded only 27% of Swift Parrot nests in trees with a DBH within 10 cm of the mean Swift Parrot nest-tree, and all other nests are likely to be exposed to the full range of errors we report. Given that Swift Parrots nest in cavities with small entry dimensions, the observed errors in detection of cavities from the ground were expected. Koch (2008) found that small cavities are especially difficult to detect even when dissection surveys were used to calibrate ground-based surveys, and that both types of survey had a high error rate in detecting small cavities. We calculated that only 5.2% of all cavities fall within one standard deviation of the mean values for known Swift Parrot nests for minimum entry dimension, depth, floor diameter and height above ground. This scarcity of suitable cavities for Swift Parrots may result in poor conservation outcomes if forest management is based on a poorly performing index of cavity abundance derived from ground-based surveys. Swift Parrot cavities are rare and difficult to survey, so protecting known breeding habitat and encouraging the recruitment of new cavity-bearing trees should be a conservation priority for this species. We found evidence of reuse of cavities by Swift Parrots, with several nests identified in 2005 being reused by Swift Parrots in 2010.

Our results are similar to those reported by Manning *et al*. (2004), where trees that supported nests of Superb Parrots (*Polytelis swainsonii*) were larger and consequently produced more cavities than randomly selected trees. These results have a wider significance, because other endangered cavity-dependent species, such as the Masked Owl (*Tyto novaehollandiae castanops*) and Forty-spotted Pardalote (*Pardalotus quadragintus*), are sympatric with breeding Swift Parrots (Koch *et al*. 2008) and we detected several other secondary cavity-nesting species using cavities in this study. Internationally, cavity-dependent fauna face similar conservation issues to those we report here for Swift Parrots (Newton 1994; Cockle *et al*. 2008).

Typically, assessment of nesting habitat for Swift Parrots is undertaken from the ground or by using aerial photography (Stone 1998). Tree-cavities vary in their availability across the landscape in space and time in response to environmental factors like tree age, topography and climate (Gibbons and Lindenmayer 2002). At the landscape scale, this variability makes managing forests for tree-cavities difficult, but importance of tree-cavities as a resource for fauna makes managing them sensitively a priority (Gibbons *et al*. 2010). Although rapid ground-based surveys are the preferred and cheapest means of assessing tree-cavities in forestry operations, they fail to discern the differences in cavity morphology that can make an animal choose one cavity over another. Climbing trees to measure tree-cavities and calibrate ground-based methods provides a means to improve estimates of cavity abundance. Although the results of this study are based on a limited sampling effort of only one year, our results indicate that our approach will deliver a more sensitive and reliable planning tool for land managers who must balance the needs of production forestry with conservation. Given the perilous conservation status of many secondary cavity-nesting species, there is an urgent need to scrutinise the reliability of techniques used to assess the effect of production forestry on key resources needed by threatened species.

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