CSIRO PUBLISHING

SHORT COMMUNICATION
https://doi.org/10.1071/ZO21012

AUSTRALIAN JOURNAL OF ZOOLOGY

Choice of monitoring method can influence estimates of usage of artificial hollows by vertebrate fauna

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Handling Editor:
Paul Cooper

Received: 29 April 2021
Accepted: 13 October 2021
Published: 23 November 2021

Cite this:
Honey R *et al.* (2021)
Australian Journal of Zoology
doi:10.1071/ZO21012

ABSTRACT

The loss of hollow-bearing trees is a key threat for many hollow-dependent taxa. Nesting boxes have been widely used to offset tree hollow loss, but they have high rates of attrition, and, often, low rates of usage by target species. To counter these problems, chainsaw carved hollows (artificial cavities cut into trees) have become a popular alternative, yet little research has been published on their effectiveness. We examined the usage of 150 chainsaw carved hollows by cavity-dependent fauna in the central west of New South Wales using observations from traditional inspection methods and remote cameras. Between October 2017 and April 2019, we detected 21 species of vertebrates (two reptile, one amphibian, 10 bird, and eight mammal species) inside chainsaw carved hollows, but the number of species detected was dependent on the chosen monitoring method. We detected six species inside hollows during physical inspections, whereas remote cameras detected 21 species entering hollows. Cameras detected eight species using hollows as breeding sites, whereas physical inspections detected just four species. Cameras detected two threatened mammals (squirrel glider (*Petaurus norfolcensis*) and greater glider (*Petauroides volans*)) raising young inside hollows, yet we failed to detect these species during physical inspections. For birds, the two methods yielded equivalent results for detection of breeding events. Overall, our study showed that few cavity-dependent species used chainsaw carved hollows as breeding sites. This highlights how artificial hollows are not a substitute for retaining naturally occurring hollows in large trees and revegetation programs.

Keywords: biodiversity, camera trap, chainsaw carved hollow, habitat loss, habitat use, threatened species.

Introduction

Large trees are critical keystone structures that provide many important resources, including the provision of hollows that many animals require for nesting and shelter (Tews *et al.* 2004; Remm and Lõhmus 2011; Stagoll *et al.* 2012; Lindenmayer *et al.* 2014). Since European settlement, over 40% of Australia's native forests have been cleared for agriculture, urban development, and forestry projects (Bradshaw 2012; Evans 2016), which has caused a significant decline in large hollow-bearing trees across the continent (Walker *et al.* 1993; Ozolins *et al.* 2001). Within Australian forests, rates of hollow production are slow, and in many tree species it can take 120 years for hollows suitable for parrots to form (Stoneman *et al.* 1997; Koch *et al.* 2008), and 200 years for the creation of larger hollows (Mackowski 1984; Wormington and Lamb 1999; Gibbons and Lindenmayer 2002). Consequently, once hollows are lost, recruitment of new hollows is slow, which can affect the abundance and occupancy of hollow-dependent fauna (Smith and Lindenmayer 1988; Wormington *et al.* 2002; McLean *et al.* 2018; Lindenmayer *et al.* 2021). Nearly 300 species (or 15%) of Australia's vertebrate fauna use tree hollows (Gibbons and Lindenmayer 2002; Kavanagh *et al.* 2004), and in NSW loss of tree hollows has been listed as a key threatening process under Schedule 4 of the *Biodiversity Conservation Act 2016* No 63 (https://legislation.nsw.gov.au/view/html/inforce/current/act-2016-063#sch.4).

In an effort to maintain hollows within timber production landscapes, guidelines have been developed to retain hollow-bearing trees, along with younger 'hollow recruitment trees' that have the potential to develop hollows later in life (Gibbons and Lindenmayer 2002; Environment Protection Authority 2014; McLean *et al.* 2015). However, in forests and woodlands that are already devoid of hollows, the introduction of artificial hollows has been proposed as a conservation measure (Norman and Riggert 1977). This has been done through the installation of artificial hollows, primarily wooden nesting boxes (Gibbons and Lindenmayer 2002; Beyer and Goldingay 2006). Studies on the utility of nest boxes have produced mixed results. In some studies, usage of nest boxes by target species was high (Goldingay *et al.* 2015; Terry *et al.* 2021), whereas in other studies, usage by target species was low (Le Roux *et al.* 2016*a*; Lindenmayer *et al.* 2017). Use of nest boxes by invasive species (e.g. honeybees) or non-target native species can reduce their occupancy by target fauna (Menkhorst 1984; Pell and Tidemann 1997; Harper *et al.* 2005; Beyer and Goldingay 2006) and may render nest boxes useless until researchers have cleared them (Suckling and Goldstraw 1989; Lindenmayer *et al.* 2003). Furthermore, nest boxes have high attrition rates and require regular maintenance and/or replacement if they are to offset the slow natural formation of hollows (Lindenmayer *et al.* 2009, 2017; Goldingay *et al.* 2015; Goldingay *et al.* 2018). Regular, ongoing maintenance and replacement of nest boxes can make them financially unviable (Lindenmayer *et al.* 2003, 2017; Harper *et al.* 2005).

To tackle these problems, chainsaw carved hollows have been proposed as an alternative to wooden nesting boxes (Carey and Gill 1983; Gano and Mosher 1983). The general method involves slicing a faceplate from a tree trunk, carving a cavity into the trunk, and screwing the faceplate containing the entrance hole back onto the cavity (Rueegger 2017); in some cases arborists cut the entrance hole into the limb or trunk rather than through the faceplate. In the last decade, researchers, councils, ecologists and community groups have installed several hundred chainsaw carved hollows across Australia (Rueegger 2017; Griffiths *et al.* 2020). Despite this work, there is limited published research on usage of chainsaw carved hollows by native wildlife (Griffiths *et al.* 2020). Most projects have involved low numbers of chainsaw carved hollows, with promising results. For example, Rueegger (2017) created 16 chainsaw carved hollows and monitored them with remote cameras, and recorded four mammal species (feathertail glider (*Acrobates pygmaeus*), sugar glider (*Petaurus breviceps*), brown antechinus (*Antechinus stuartii*), and Gould's wattled bat (*Chalinolobus gouldii*)) and one bird species (white-throated treecreeper (*Cormobates leucophaea*)) using the hollows over a 15 month period. In another study, researchers created 45 chainsaw carved hollows and reported high rates of usage by brush-tailed phascogales (*Phascogale tapoatafa*) and sugar gliders over 2.5 years (Terry *et al.* 2021). Researchers have also used different methods to monitor artificial hollows. Physical inspections, whereby researchers climb trees and look inside hollows, or use a pole camera to inspect hollows, are widely used (Goldingay *et al.* 2018; Terry *et al.* 2021). Inspections provide point data on when species use hollows, and provide indirect evidence of past usage by species from nests, feathers, fur, eggs, and faeces and record a single point in time (Lindenmayer *et al.* 2016). Researchers have also used camera traps to monitor hollows and nesting boxes (O'Connell *et al.* 2011; Goldingay *et al.* 2012; Meek *et al.* 2015; Rueegger 2017; Griffiths *et al.* 2020). The primary advantage with using camera traps is that fewer climbing trips are needed to detect species, and long-term data can be collected on the frequency of visitations to hollows by target and non-target species, and predators (McComb *et al.* 2019).

The aim of this study was to identify and quantify the diversity of fauna using artificial tree hollows in the central west of NSW, and to determine if the species recorded via camera traps differed from those recorded by physical inspection. We predicted that the majority of arboreal hollow-dependent vertebrate fauna from the region would use or at least inspect the artificial hollows, and that we would detect more species from the camera traps than from physical inspections due to the greater number of sampling days associated with the cameras.

Methods

Study area

We conducted the study at 11 sites across the central west of NSW (Fig. 1). Much of the habitat in this area has been altered, mainly through dryland agriculture and plantations, leading to the depletion of large hollow-bearing trees (Dillon *et al.* 2011). We selected nine study sites through consultation with landholder councils; these were located in current and predicted future breeding areas of the threatened superb parrot (*Polytelis swainsonii*) (Garnett *et al.* 2010; Baker-Gabb 2011). This threatened species was of particular interest to local community groups and land care groups. Vegetation communities varied between sites, and consisted predominantly of western slopes grassy woodlands (dominated by white box (*Eucalyptus albens*), kurrajong (*Brachychiton populneus*), white cypress pine (*Callitris glaucophylla*) and yellow box (*Eucalyptus blakelyi* and *Eucalyptus melliodora*)); southern tableland grassy woodland (dominated by *E. blakelyi*, apple box (*Eucalyptus bridgesiana*), bundy (*E. goniocalyx*) and red stringybark (*E. macrorhyncha*)); western slopes dry sclerophyll forest (dominated by tumbledown red gum (*E. dealbata*) and mugga (*E. sideroxylon*)); and floodplain transition woodlands of grey box (*E. microcarpa*) and yellow box (*E. melliodora*) (Keith 2006).

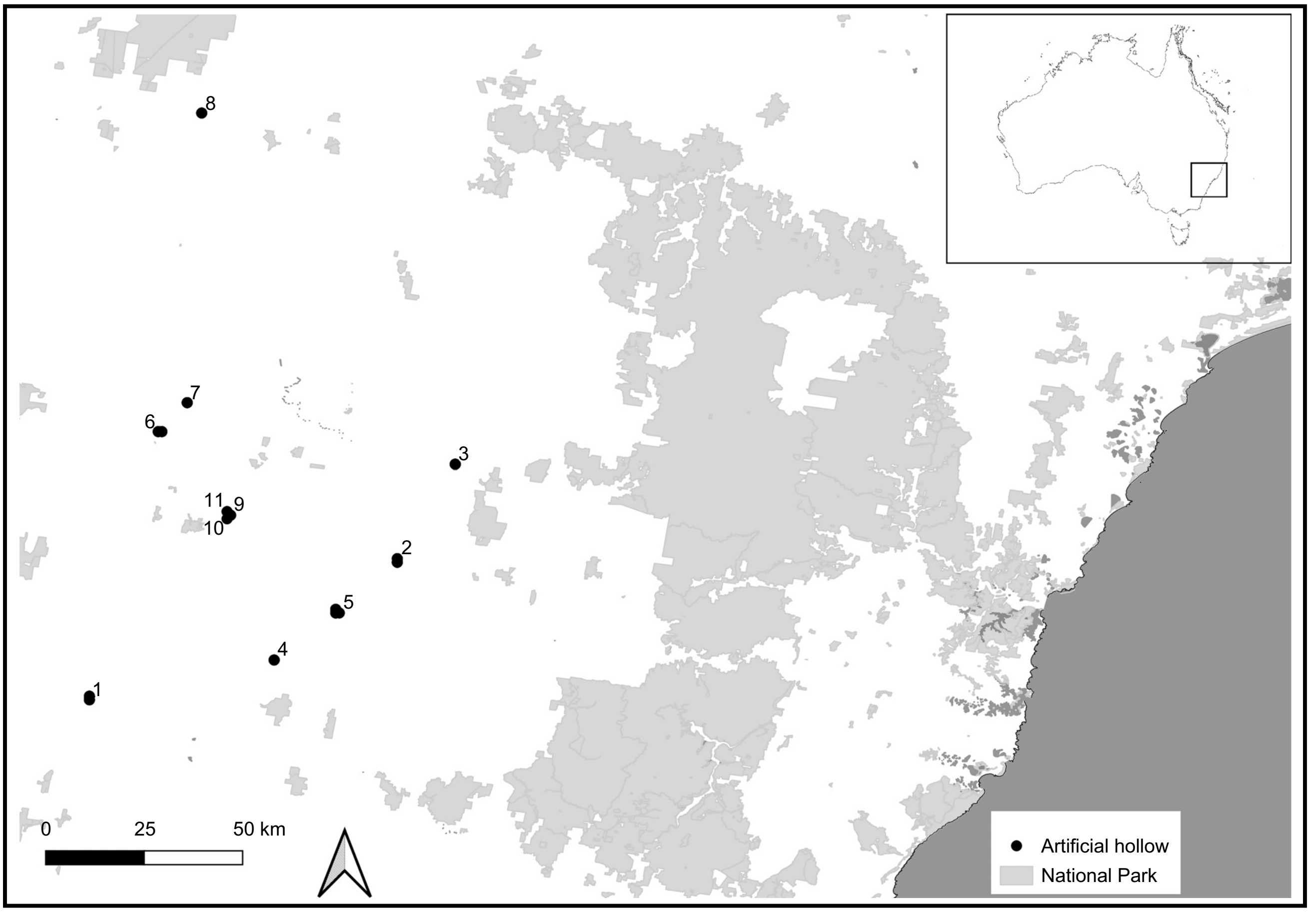

Fig. 1. The location of study sites where we created artificial hollows in the central west of NSW.

Hollow creation

During 2017 and 2018, a team of qualified arborists installed 187 artificial hollows across the 11 sites (Fig. 1). Arborists created hollows in dead trees devoid of hollows or in live trees large enough to house an artificial hollow. Hollows were constructed in live trees of *E. bridgesiana*, *Eucalyptus viminalis*, *E. melliodora*, *E. blakelyi*, and *E. albens* that had a wall thickness that was at least 30% of the trunk radius, in accordance with Mattheck's t/R tree threshold (Mattheck *et al.* 1993). We used this criterion because previous studies have suggested that tree failure is more likely to occur if residual wall thickness surrounding a natural hollow is <30% of the stem thickness (Rueegger 2017). The internal dimensions of the hollows were 250–700 mm high and 120–400 mm wide. All hollows were placed at heights of 7–20 m above the ground, and were created by an arborist working from an elevated work platform.

Arborists created each hollow with a chainsaw and other tools following the steps outlined by Rueegger (2017). Briefly, this involved removing a 20–50 mm thick faceplate from the tree (Fig. 2*a*), and creating plunge cuts to produce a grid (Fig. 2*c*) that was removed through manual force. To provide drainage in the event of water ingress into the hollow, the arborist angled the bottom cut upward. An entrance hole, with size of 40 or 100 mm, was then cut into the hollow (Fig. 2*d*), before the faceplate was reattached to the tree with 120 mm galvanised screws (Fig. 2*e*).

Hollow monitoring

We compared hollow use by fauna through physical inspection and remote camera traps. Physical inspections of 150 hollows were carried out four times between October 2017 and April 2019 with approximately 6-month intervals between checks. For these inspections, we climbed trees and used a snake eye camera with a 1.5 m long camera tube to inspect inside hollows. Any vertebrates inside hollows were recorded, as was indirect evidence of usage such as wear around the hollow entry, fur or feathers, nesting materials, eggshells, or faeces.

We deployed 80 remote cameras (Moultrie M40i, USA) between October 2017 and April 2019. We mounted the cameras directly above or opposite the hollow, approximately 0.5–1 m away from the hollow. We programmed each camera to take a single photograph, with a trigger time of 0.3 s, which produced operating times of up to six months. Where possible, we moved some cameras to new

Fig. 2. Photographs showing the steps involved in the construction of an artificial hollow in a live tree. The key steps involve removing the faceplate (*a*), creating plunge cuts (*b*), removing grid to create a hollow (*c*), cutting an entrance hole in the back of the hollow (*d*) and attaching the faceplate with metal screws (*e*).

hollows to increase our sample size, which allowed us to monitor 115 different hollows with cameras.

We downloaded images to a computer, and a trained ecologist painstakingly sorted the images manually. Images containing fauna were tagged according to whether the animal was observed (1) inspecting the hollow entrance, but not entering the hollow; (2) entering the hollow on at least one occasion; and (3) breeding inside the hollow, as evidenced by photographs of both adults and young entering and exiting the hollow. We also recorded interactions between species, and noted if there was any evidence of predation.

Results

Two of the 187 chainsaw carved hollows failed (due to the tree collapsing) over the two-year monitoring period. Of 150 hollows that we physically inspected, 85% had evidence of visitation by fauna, and all 115 hollows monitored with camera traps were visited by fauna. Using camera traps, we detected 21 species entering hollows, but we detected only six species by means of physical inspections (Table 1).

Cameras detected 13 species of birds either inspecting, entering or breeding in the hollows (Table 1). Individuals of 10 species entered chainsaw carved hollows, and 17 individuals of three species (eastern rosella (*Platycercus eximius*), crimson rosella (*Platycercus elegans*), common starlings (*Sturnus vulgaris*)) raised offspring (Table 1). By contrast, physical inspections found just three species entering hollows, and eight individuals of three species breeding (two eastern rosellas, one crimson rosella and five common starlings).

Cameras detected eight species of mammals entering hollows, of which 20 individuals of five species raised offspring (Table 1). These included four Krefft's gliders, one greater glider, five squirrel gliders, two ringtail possums and

Table 1. Number of individuals of each species that inspected, entered, or bred inside the artificial chainsaw carved hollows, as determined from camera traps and physical inspections of hollows.

	Camera traps			Physical inspections		
	Inspected	Entered	Bred	Inspected	Entered	Bred
Mammals						
Acrobates pygmaeus (feathertail glider)	2	2	0	0	0	0
Petaurus notatus (Krefft's glider)	4	4	4	3	3	1
Petaurus norfolcensis (squirrel glider)	5	5	5	0	0	0
Petauroides volans (greater glider)	1	1	1	0	0	0
Pseudocheirus peregrinus (ringtail possum)	2	2	2	0	0	0
Trichosurus vulpecula (brushtail possum)	8	8	8	2	2	0
Antechinus sp.	2	2	0	0	0	0
Microbat sp.	2	2	0	1	1	0
Birds						
Alisterus scapularis (king parrot)	3	0	0	0	0	0
Eolophus roseicapilla (galah)	5	3	0	0	0	0
Platycercus eximius (eastern rosella)	8	8	6	2	1	1
Platycercus elegans (crimson rosella)	7	7	6	2	2	2
Polytelis swainsonii (superb parrot)	1	0	0	0	0	0
Psephotus haematonotus (red-rumped parrot)	2	2	0	0	0	0
Pardalotus striatus (striated pardalote)	2	2	0	0	0	0
Cormobates leucophaea (white-throated treecreeper)	3	3	0	0	0	0
Todiramphus sanctus (sacred kingfisher)	4	2	0	0	0	0
Dacelo novaeguineae (laughing kookaburra)	5	2	0	0	0	0
Eurystomus orientalis (dollarbird)	1	1	0	0	0	0
Chenonetta jubata (Australian wood duck)	1	0	0	0	0	0
Sturnus vulgaris (common starling)	7	7	5	5	5	5
Reptiles and amphibians						
Varanus varius (lace monitor)	1	1	0	0	0	0
Litoria sp.	1	1	0	0	0	0
Unidentified skink	2	2	0	0	0	0

eight brushtail possums. Cameras also detected microbats and antechinus that we could not identify to species. By contrast, physical inspections detected just three species: the common brushtail possum, Krefft's glider and a microbat. A Krefft's glider was the only mammal we recorded breeding from physical inspections (Table 1). We did not detect any reptiles or frogs in hollows during physical inspections. However, cameras detected a lace monitor (*Varanus varius*), a tree frog (*Litoria* sp.) and two unidentified skinks entering and exiting hollows (Table 1).

Discussion

Our study produced several interesting findings. First, the method we used to monitor artificial hollows strongly influenced our interpretation of hollow usage by wildlife. Cameras detected 21 species of vertebrates entering the chainsaw carved hollows, whereas physical inspections found only six species inside hollows. In addition, cameras detected eight species using hollows as breeding sites, whereas physical inspections found just four species. For birds, the two methods yielded equivalent results for detection of breeding events. These results suggest that studies that rely solely on physical inspections of artificial hollows may underestimate patterns of cavity usage by non-avian fauna, particularly if inspections are infrequent.

Of the 21 species recorded entering hollows, eight were mammals, representing 80% of the hollow-using mammals recorded in the region (Menkhorst and Knight 2011). Importantly, we detected the threatened greater glider (*Petauroides volans*) and squirrel glider (*Petaurus norfolcensis*) raising young inside hollows. Had we relied solely on physical inspections, we would not have detected these species breeding inside artificial hollows. Through land clearing and forestry practices, much of this region of NSW has become devoid of hollows (Ozolins *et al.* 2001; Parnaby *et al.* 2011), which may have contributed to the declines of gliders across the region (Kerle 2004; Paull and Kerle 2004). Increasing hollow densities through creation of chainsaw carved hollows across central west NSW could be useful for supporting populations of possums and gliders in the region. An increase in the populations of these species could provide flow-on effects for owls, as possums and gliders make up a large portion of their diets (Barnes *et al.* 2005; Cooke *et al.* 2006; Stanton 2011).

For birds, physical inspections and cameras yielded similar data for breeding events. Only two common rosella species, and invasive starlings, bred inside artificial hollows. Cameras showed that seven native species entered hollows, but did not use them as breeding sites. The low rate of usage of hollows by birds likely reflects the fact that the hollows, or the trees that harboured the hollows, did not match species preferences. For example, larger cockatoos, such as galahs, prefer hollows with larger diameter entrances than those used in this study (Saunders *et al.* 1982). The superb parrot (one of which inspected a hollow), shows a preference for nesting in trees that have multiple cavities. Superb parrots also select for specific cavities that are wider, deeper, and have wider entrances than randomly available cavities (Stojanovic *et al.* 2021*a*). Thus, it seems likely that the artificial hollows used in this study were unsuitable for this vulnerable species. No owls used chainsaw carved hollows. This is likely due to owls preferring to use larger nest hollows than the ones that we created, and which are located higher than 15 m above ground level (Kavanagh 1996; Kavanagh 1997; McNabb and Greenwood 2011). As with previous studies on hollows and nest boxes, we detected invasive starlings breeding inside hollows (Le Roux *et al.* 2016*a*; Rogers *et al.* 2020). Starlings may prevent native species from using artificial hollows, and may therefore limit their effectiveness as a conservation tool (Stojanovic *et al.* 2021*b*).

We were unable to identify *Antechinus* spp. or microbats to species from camera images. At least four species of *Antechinus* and 16 species of microbat occur in the region (Menkhorst and Knight 2011). To understand whether microbats use chainsaw carved hollows, future research could radio-track hollow-dependent microbats to determine their roost preferences in these areas or undertake stag watching, assisted with an ultrasonic bat detector at dusk to determine which species emerge. Identifying which species of hollow-dependent microbats use hollows is a priority, as several species, such as the greater long-eared bat (*Nyctophilus corbeni*), are at risk of extinction (Law *et al.* 2016). Previous studies have found that microbats are selective in their roost preferences (Mering and Chambers 2014; Rueegger 2017), so it is likely that the chainsaw carved hollows did not match the bats' preferences.

We recorded a lace monitor, a skink, and a tree frog, with the use of remote cameras. Compared to the literature on mammals and birds, there are few published studies on tree hollow usage by herpetofauna in Australia (Webb and Shine 1997). Although several studies have used camera traps to monitor hollows and nest boxes, remote cameras rely on passive infrared sensors to detect a thermal differential between the subject and the background, and so they often fail to detect small reptiles. In addition, the long focal length of most cameras makes it difficult to identify small species from photographs. Recent innovations, such as setting focal lengths to shorter distances, placing cork tiles in the field of view to create a thermal differential between the reptile and substrate, and programming cameras to record time-lapse photographs, can overcome these problems (Welbourne *et al.* 2019), and would help to improve detection rates for reptiles in future studies.

In summary, our study found that two native bird species and five mammal species used chainsaw carved hollows as nest sites across sites in the central west of NSW. Although artificial hollows clearly have some utility, they should not be used in biodiversity offset programs, as few species used them as breeding sites. In addition, several important questions remain unanswered. For example, it is not clear whether we can scale up production of artificial hollows to provide tangible benefits to vulnerable species, such as the superb parrot, which are often the focus of community conservation projects. Future research to elucidate landscape level features (e.g. patch size) and other factors that influence usage of artificial hollows by target species would be useful in this context. Finally, monitoring methods should match the aims of the project; if the aim is to detect breeding birds, then physical inspections with pole cameras may well be adequate, and will involve lower costs (both in time and money) than deployment and retrieval of remote cameras.

Finally, we reiterate that artificial hollows should not replace the retention of large hollow-bearing trees, which provide additional resources for wildlife besides hollows (Le Roux *et al.* 2016*b*; Lindenmayer and Laurance 2017). To prevent future declines of hollow-dependent taxa, community groups and councils should place a high priority on protecting old trees, revegetating open habitats, and creating suitable corridors for wildlife (Lindenmayer and Laurance 2017). To enhance the success of such programs, they should involve a high degree of community ownership and participation, and include long-term monitoring to evaluate their effectiveness.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

Conflicts of interest. The authors declare no conflicts of interest.

Declaration of funding. The project was supported financially by grants from Central Tablelands Local Land Services through funding from Catchment Action NSW, and the Wettenhall Environment Trust.

Acknowledgements. We thank the Central West Councils Environment and Waterways Alliance for initiating the production of the chainsaw carved hollows, providing funding and other logistical support. We thank two anonymous reviewers for providing constructive comments and suggestions that helped to improve the manuscript. We thank all of the volunteers who helped with the research. This work was completed under NSW National Parks and Wildlife Service scientific licence number SL101905 and UTS Animal Care and Ethics approval number ETH17-1361.

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