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RESEARCH ARTICLE

Installing chainsaw-carved hollows in medium-sized live trees increases rates of visitation by hollow-dependent fauna

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Anthropogenic disturbance has resulted in a global reduction in the abundance of mature, hollow-bearing trees. Nest boxes have long been used to provide supplementary shelter sites in revegetated and regenerating landscapes, but limitations in their effectiveness when offsetting the loss of mature trees has led to increased interest in novel designs of artificial hollows. For example, mechanically excavating cavities into the trunk or branches of trees. However, the effectiveness of artificial hollows in attracting wildlife to visit small- or medium-sized, growing trees in human-disturbed landscapes has received little attention. In this study, we installed chainsaw hollows that were designed for small, hollow-dependent mammals and birds into the trunks of live medium-sized trees. We conducted a before-after control-impact experiment using passive camera traps to monitor changes in visitations by wildlife to (1) mature hollow-bearing trees, (2) developing trees without hollows (i.e. control trees), and (3) developing trees with newly installed chainsaw hollows. We found that, compared to large hollow-bearing trees and control trees, the developing trees that were selected for chainsaw hollow construction showed the greatest visitation rates by hollow-dependent wildlife (i.e. number of visits) during the "post-impact" surveys. Our results suggest that chainsaw hollows designed to replicate the external physical characteristics of natural tree hollows could be effective in attracting target hollow-dependent fauna to developing trees in regenerating and revegetated landscapes. Further studies are required to compare the effectiveness of natural hollows, chainsaw hollows, and nest boxes when deployed in a range of human-disturbed landscapes.

Key words: activity, artificial tree hollow, BACI, biodiversity offset, habitat restoration, nest box, supplementary shelter sites

Implications for Practice

- Retaining mature hollow-bearing trees should be a primary management objective for the conservation of hollow-dependent wildlife.
- Chainsaw hollows may facilitate improved outcomes of revegetation and restoration programs by reducing the amount of time it takes hollow-dependent wildlife to find newly installed supplementary hollows.
- Attraction of hollow-dependent fauna to developing trees after chainsaw hollow installation may result in reduced competition for the natural tree hollows that remain in human-disturbed landscapes.

Introduction

Anthropogenic disturbance has resulted in a global reduction in the abundance of mature hollow-bearing trees (McBride & Jacobs 1986; Lindenmayer & Laurance 2017; Liu et al. 2019). Countless invertebrate and vertebrate species worldwide are reliant upon the availability of tree hollows (Cockle et al. 2010; Hussain et al. 2013; Warakai et al. 2013; Carvalho et al. 2014; Quinto et al. 2014). Consequently, the conservation of mature trees is critical for the survival and ongoing viability of many hollow-dependent species within human-disturbed landscapes (Newton 1994; Lindenmayer et al. 2015). Despite wide-scale revegetation, the natural development of hollows within newly planted trees will not occur fast enough to offset the ongoing loss of mature trees caused by activities such as land clearing for agriculture, logging, and urban expansion (Manning et al. 2006; Munks et al. 2009; Fischer et al. 2010). Furthermore, the naturally occurring hollows that persist in urban landscapes are under continued pressure due to managed tree pruning and removal implemented by land managers to reduce risks of falling limbs harming people or property (Le Roux et al. 2014; Treby & Castley 2015). Significant time lags (e.g. at least

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100 years) are therefore likely to occur before revegetation programs implemented in disturbed landscapes can support viable populations of hollow-dependent faunal communities (Bennett et al. 1994; Vesk & Mac Nally 2006; Vesk et al. 2008).

Artificial hollows, such as nest boxes, are often used to provide supplementary shelter sites in revegetated and regenerating landscapes (Lambrechts et al. 2010; Mering & Chambers 2014; Goldingay et al. 2018). However, limited research has been undertaken to investigate the effectiveness of habitat supplementation techniques in attracting wildlife to visit small- or medium-sized, growing trees (hereafter, "developing trees") in human-disturbed landscapes. Le Roux et al. (2015) showed that visitation rates of hollow-dependent fauna to newly installed nest boxes can be affected by the size of the tree on which the boxes are attached, with boxes on small trees being less effective than those on large trees. Where nest boxes are deployed in revegetated or regenerating landscapes dominated by developing trees, such as urban and peri-urban parks and reserves, they may prove to have limited effectiveness in attracting hollow-dependent fauna, and ultimately in providing supplementary shelter sites (Le Roux et al. 2015, 2016; Griffiths et al. 2017). Further research is therefore required to investigate the efficacy of incorporating novel types of artificial hollows into conservation management and biodiversity offset programs (Rueegger 2017; Griffiths et al. 2017, 2017, 2018).

One habitat supplementation technique that is currently increasing in popularity across southeastern Australia involves the mechanical excavation of artificial cavities by cutting into the trunk or branches of trees with a chainsaw (hereafter "chainsaw hollows"; Griffiths et al. 2018). Few studies have tested the effectiveness of artificially excavated tree hollows, most of which have not reported initial responses in wildlife visitation rates after construction (see Table S1). Despite such methods proving to be an effective tool in conservation programs targeting threatened hollow-dependent wildlife, e.g. the red-cockaded woodpecker (*Leuconotopicus borealis*; Cox & McCormick 2016), they have not been widely adopted in landscape restoration or biodiversity offset programs (Griffiths et al. 2018).

Chainsaw hollows can be designed to closely mimic the physical characteristics of natural tree hollows that are used by target fauna, such as the size and shape of the entrance hole and the dimensions of the internal cavity (Saenz et al. 2001; Hurley & Harris 2014; Zapponi et al. 2014; Cox & McCormick 2016; Rueegger 2017; Griffiths et al. 2018). However, it is unclear whether installing artificial shelters designed to replicate the physical characteristics of natural tree hollows could result in increased tree visitations by hollow-dependent fauna. As the provision of chainsaw hollows as supplementary shelters is still in its relative infancy, particularly in the Southern Hemisphere, further empirical studies are needed to determine how fauna respond to the creation of chainsaw hollows.

Here, we investigate the behavioral response of hollow-dependent wildlife to the installation of chainsaw hollows into the trunks of live, developing trees located in urban and peri-urban parks and reserves across Greater Melbourne, Victoria, southeastern Australia. We created chainsaw hollows that were designed for small marsupial gliders (e.g. *Petaurus* spp.) or small hollow-nesting birds (e.g. Musk Lorikeet *Glossopsitta concinna*, Little Lorikeet *Parvipsitta pusilla*). However, minor variations to the entrance size and internal dimensions could make these supplementary shelters suitable for a range of other hollow-dependent arboreal mammals, tree-roosting insectivorous bats and secondary cavity-nesting passerines (Newton 1994; Kunz & Lumsden 2003; Goldingay et al. 2015). In this study, we posed the question: can the introduction of chainsaw hollows increase the visitation by hollow-dependent fauna to developing trees? We hypothesized that the addition of chainsaw hollows to developing trees would increase the activity of hollow-dependent fauna (measured as daily rates of visitation to trees), particularly immediately after hollow creation, as animals investigate these novel habitat structures as possible shelter sites (Lumsden et al. 2016). To test this hypothesis, we conducted a before-after control-impact (BACI) chainsaw hollow addition experiment and used passive camera traps to monitor changes in visitations by hollow-dependent wildlife to (1) mature hollow-bearing trees, (2) developing trees without hollows (i.e. control trees), and (3) developing trees with newly installed chainsaw hollows. This study provides a preliminary insight into the potential for chainsaw hollows to augment the habitat value that developing trees could provide for hollow-dependent fauna in human-disturbed landscapes. Our study was designed for specific relevance to managers of urban and peri-urban parks and reserves, which are increasingly being targeted for restoration and revegetation activities (Shanahan et al. 2011; Archibald et al. 2017).

Methods

Study Site

The response of hollow-dependent fauna to the installation of chainsaw hollows in live *Eucalyptus* trees was examined at five public reserves located across Greater Melbourne, in southeastern Australia: Burke Road Billabong Reserve, The Briars, Woods Bushland Reserve, Warringine Creek, and Warringine Park (Fig. 1). Reserve selection was based on support from land managers (e.g. local councils), the known or likely presence of target hollow-dependent fauna, and the availability of medium-sized, developing *Eucalyptus* trees capable of supporting chainsaw hollows. The five reserves varied in size and dominant vegetation type (Table 1).

The Greater Melbourne region experiences a Mediterranean climate: temperatures range from a mean monthly maximum of 26.9°C in February to a mean monthly minimum of 5.6°C in July, but can exceed 40°C during summer and occasionally falls below 0°C during winter (Australian Bureau of Meteorology 2020).

Tree Selection and Chainsaw-Hollow Installation

Mechanically excavating cavities into live trees can reduce the structural integrity of trunks and branches, potentially resulting in tree failures, that is stem breakages occurring at the location where an artificial cavity has been excavated (Carey &

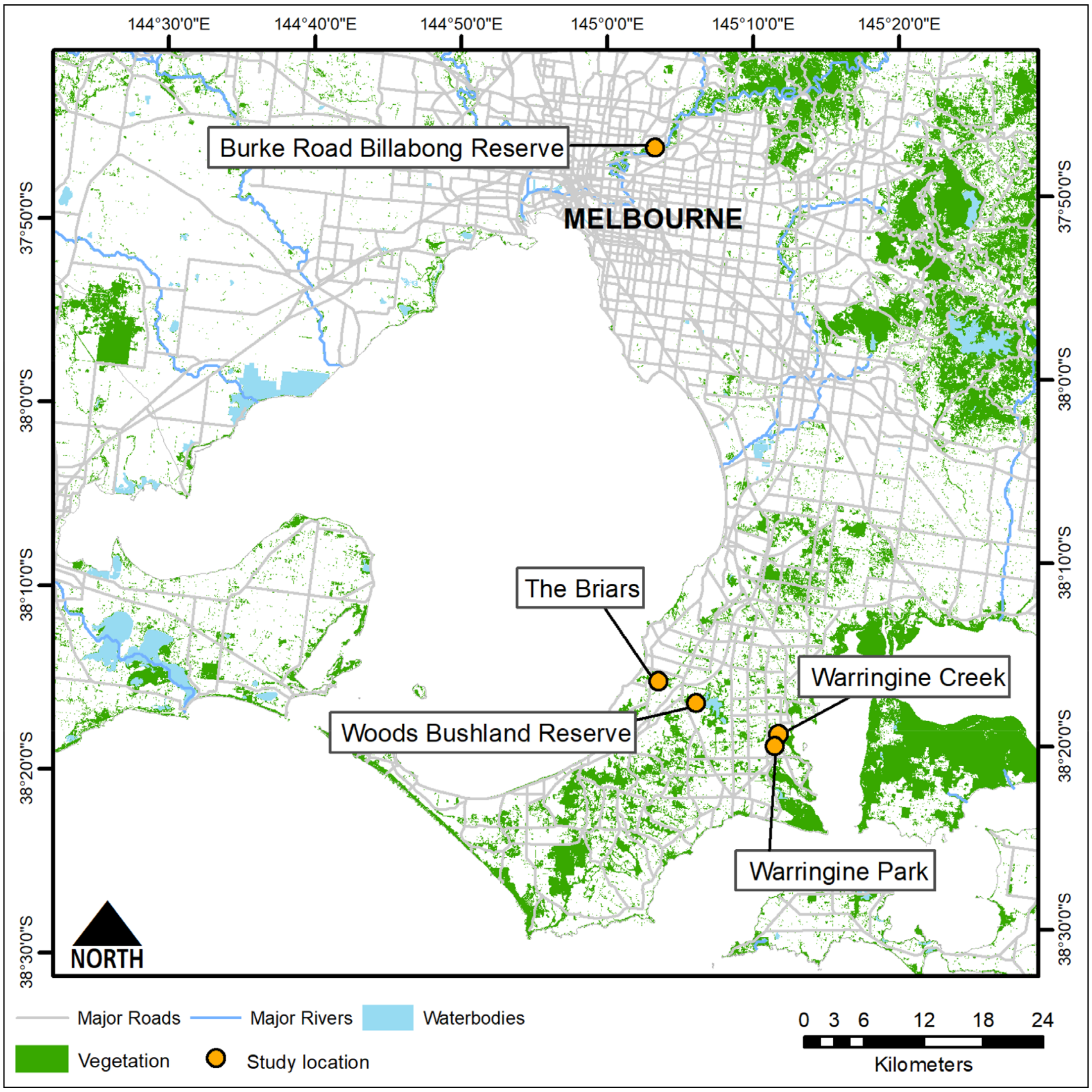

Figure 1 Location of the five reserves across Greater Melbourne, Victoria, south-eastern Australia, where chainsaw-carved hollows were installed in the trunks of live, developing *Eucalyptus* trees.

Table 1 Details of the five reserves. Ecological vegetation classes (EVCs) at each reserve include: floodplain riparian woodland (FRP), swampy riparian woodland (SRW), grassy woodland (GW), and lowland forest (LF) (Brereton et al. 2004).

Reserve	*Size (ha)*	*EVCs*	*Dominant* Eucalyptus *spp.*
Burke Road Billabong	10	FRP	River red gum *E. camaldulensis*
The Briars	89	SRW, GW	Manna gum *E. viminalis*; messmate *E. obliqua*; peppermint gum *E. radiata*
Warringine Creek	25	SRW, GW	Manna gum; swamp gum *E. ovata*
Warringine Park	15	LF	Messmate; peppermint gum; swamp gum
Woods Bushland Reserve	56	SRW, GW, LF	Messmate; peppermint gum; swamp gum

Sanderson 1981; Carey & Gill 1983; Gano & Mosher 1983; Hooper et al. 2004; Lumsden et al. 2016). To reduce the probability of this occurring we employed a two-stage systematic risk assessment procedure (Griffiths et al. 2018). First, we consulted specialized arborists and the managers of the five study sites to select live, healthy trees that were located in areas within the reserves that, in the event of failures, posed a negligible risk to the public (Griffiths et al. 2018). Second, we used an empirical strength loss formula (described below) to calculate the minimum stem diameter required to safely accommodate chainsaw hollows (with pre-determined dimensions) into the trunks of live trees (Griffiths et al. 2018).

In this study, we focused on *Eucalyptus* trees, because they occur widely throughout the Australian continent, and many species compartmentalize damage caused by natural processes (e.g. fire scaring, branch abscission, and slow decay caused by fungal attack and termites) resulting in the gradual formation of hollows (Gibbons & Lindenmayer 2002). Our intention was to create cavities that would remain as structural features of medium-sized trees, which had not already developed natural hollows, for the standing life of the trees.

Trees allocated for chainsaw hollow installation were selected based on their ability to support an internal cavity with a diameter of approximately 20 cm and a circular entrance hole with a diameter of 35 mm. These dimensions were designed to replicate the characteristics of artificial hollows previously used by small marsupial gliders (e.g. Sugar glider *Petaurus breviceps*; Beyer & Goldingay 2006). However, small adjustments to the diameter of the entrance hole and internal cavity dimensions would likely enable use by a range of hollow-dependent mammals and birds (Kunz & Lumsden 2003; Goldingay 2009, 2011). Using the percentage strength-loss (%SL) formula from Smiley and Fraedrich (1992), we calculated that a minimum stem diameter of 30 cm (at the point of chainsaw hollow excavation) was required to reduce the likelihood of stem failures to within an acceptable risk level (i.e. predicted %SL of <30%). To further reduce the risk of tree failures we cut hollows in trees with a trunk diameter ≥40 cm (Griffiths et al. 2018). The trees we selected for chainsaw hollow installation had a mean (± SD) diameter at breast height (DBH) of 63.4 ± 10.3 cm (range 45–76 cm; Fig. S1), including bark, and a mean stem diameter at the location where the cavity was carved (4–5 m above the ground) of 52.3 ± 10.9 cm (range 40–72 cm), which resulted in a mean predicted %SL of 15.3 ± 6.6 (range 6.6–28.3; Table 2).

The %SL formula used in this study was developed based on decay that forms in tree stems over many years (Smiley & Fraedrich 1992), as opposed to the manual excavation of tissue from the cambium and heart wood that takes approximately 1 hour when a chainsaw hollow is created. No studies have empirically tested the maximum cavity sizes that can be carved into tree trunks or branches without compromising structural integrity and causing stem failure. Consequently, caution should be taken when using these formulae to assess the risk of a mechanically created hollow causing a stem failure (Kane et al. 2001; Bond 2006; Griffiths et al. 2018). At the time of publication (approximately 4 years post-installation), no failures had occurred in any of the tree trunks in which we carved chainsaw hollows.

Experimental Design

We used a BACI study design (Underwood 1994) to compare changes in activity of free-ranging animals at each site pre- and post-cutting, although these analyses required a pseudo-BACI design due to data constraints (see below). Prior to cutting chainsaw hollows, several sites with a radius of approximately 60 m were selected within each reserve. At each site, three live *Eucalyptus* trees were selected for fauna activity monitoring: one mature tree containing natural hollows and two medium-sized, developing trees without natural hollows. The presence or absence of tree hollows was determined via ground-based surveys; we acknowledge that observers using this method may have missed some hollows (Harper et al. 2004). The candidate tree selection process produced a total of 60 trees across all sites and reserves: 24 messmate (*Eucalyptus obliqua*), 16 manna gum (*Eucalyptus viminalis*), 12 river red gum (*Eucalyptus camaldulensis*), 5 peppermint gum (*Eucalyptus radiata*), and 3 swamp gum (*Eucalyptus ovata*). We had no a priori expectation of different visitation responses between the eucalypt species included within this study, nor did we design this experiment to test these differences; therefore we pooled data across tree species for the analysis. Of the 60 trees included in this study, 13 were used for chainsaw hollows (Table 2), 21 had natural hollows, and 26 were control trees. Trees with natural hollows were necessarily larger than control and

Table 2 Details of the 13 medium-sized, developing *Eucalyptus* trees that were selected for chainsaw hollow installation. Diameter at breast height (DBH) was measured at a height of approximately 1.5 m above the ground. "Trunk diameter" refers to the stem diameter at the location where the chainsaw hollows were installed (4–5 m above the ground). Predicted percentage strength loss (%SL) was calculated for each candidate tree using the formula from Smiley and Fraedrich (1992), which predicts that failure is likely to occur when the amount of wood removed from a stem results in a predicted %SL that is above 30%.

Species	*DBH (cm)*	*Trunk Diameter (cm)*	*Internal Cavity Dimensions (width × height × depth) (cm)*	*Predicted %SL*
E. ovata	68	44	16 × 26 × 17	19.7
E. obliqua	74	49	17 × 25 × 19	17.3
E. obliqua	57	46	22 × 23 × 21	28.3
E. camaldulensis	66	51	19 × 24 × 16	11.9
E. camaldulensis	51	40	15 × 25 × 18	18.7
E. camaldulensis	54	44	19 × 23 × 20	18.1
E. obliqua	45	48	17 × 24 × 20	20.3
E. obliqua	76	72	18 × 20 × 19	6.9
E. obliqua	73	63	19 × 25 × 18	9.2
E. ovata	59	51	19 × 24 × 18	14.1
E. viminalis	74	65	18 × 23 × 17	6.6
E. radiata	56	40	16 × 24 × 19	20.7
E. viminalis	73	68	21 × 20 × 18	7.4

chainsaw hollow trees, but control and chainsaw hollow trees had equivalent DBH (see Fig. S1).

Three surveys were undertaken using camera traps to monitor fauna activity. Survey 1 was undertaken from November 2015 to March 2016 to identify fauna activity prior to the introduction of chainsaw hollows. Following Survey 1, at each site, one of the two medium-sized, developing trees that did not have natural hollows was randomly selected and a chainsaw hollow was cut into the trunk (Fig. 2). The remaining developing tree without natural hollows was retained as a control tree. Surveys 2 and 3 were then conducted during October–November 2016 and December–January 2017, respectively, to identify fauna activity 4 and 7 months after chainsaw hollows were installed. The chainsaw hollows created during this project are part of a larger, ongoing study investigating temporal patterns in wildlife use of the different types of natural and artificial hollows, along with documenting changes in tree health and any required maintenance, the findings of which will be presented in a subsequent study.

Camera Trap Surveys

During each survey, we used passive infrared motion-sensing camera traps (ScoutGuard SG550V8-HD and Reconyx HC600 HyperFire) to record the activity of wildlife on each tree treatment at each site continuously for a period of approximately 3 weeks. We programmed camera traps to record during both the day and night, as we expected that the chainsaw hollows would attract diurnal birds and nocturnal mammals (Gregory et al. 2014; Cotsell & Vernes 2016). Cameras were secured to L-shaped metal brackets that were attached to tree trunks at a height of 5–6 m above the ground (approximately 1 m above the location where a chainsaw hollow was installed), angled to point down the trunk toward (1) the location where chainsaw hollows were installed in treatment trees and (2) the equivalent location on the trunk of hollow-bearing and control trees (i.e. tree treatments without chainsaw hollows; Fig. 2). A series of three photographs were taken per trigger and a 1 minute delay was set between trigger events. Data collected from camera traps were used to quantify changes in activity and allowed us to observe the behavioral response of fauna to chainsaw hollows being installed. Wildlife activity was quantified as daily visitation rates, with a visit defined as a photograph of an animal interacting with the tree trunk at the location of the chainsaw hollow, or the equivalent location on the trunk of hollow-bearing and control trees (see Figs. 2–4). ScoutGuard SG550V8-HD cameras were used for all trees in Survey 1 but produced excessive false triggers. Consequently, for Surveys 2 and 3, Reconyx HyperFire HC600 cameras were used.

Data Analyses

Visitation rate data were collated for two target species groups, hollow-dependent mammals and birds, as well as for the most frequently recorded species: Sugar gliders, Common brushtail possums, Common ringtail possums, and eastern rosellas.

Figure 2 (A) Chainsaw hollows were created by an arborist making angled plunge cuts into the trunk of the tree from a rectangular opening (8 cm wide × 20 cm high), the internal cavity was approximately 20 cm in diameter across the interior wall. (B) A faceplate made from kiln-dried hardwood was then used to block the opening (Carey & Gill 1983), with a small gap (35 mm in diameter) left above the hollow to allow animals to enter and exit. (C) Passive infrared motion-sensing camera traps were secured to an "L-shaped" bracket that was attached to the tree trunk approximately 1 m above the chainsaw hollow (5–6 m above the ground), with the camera facing down the trunk toward the ground.

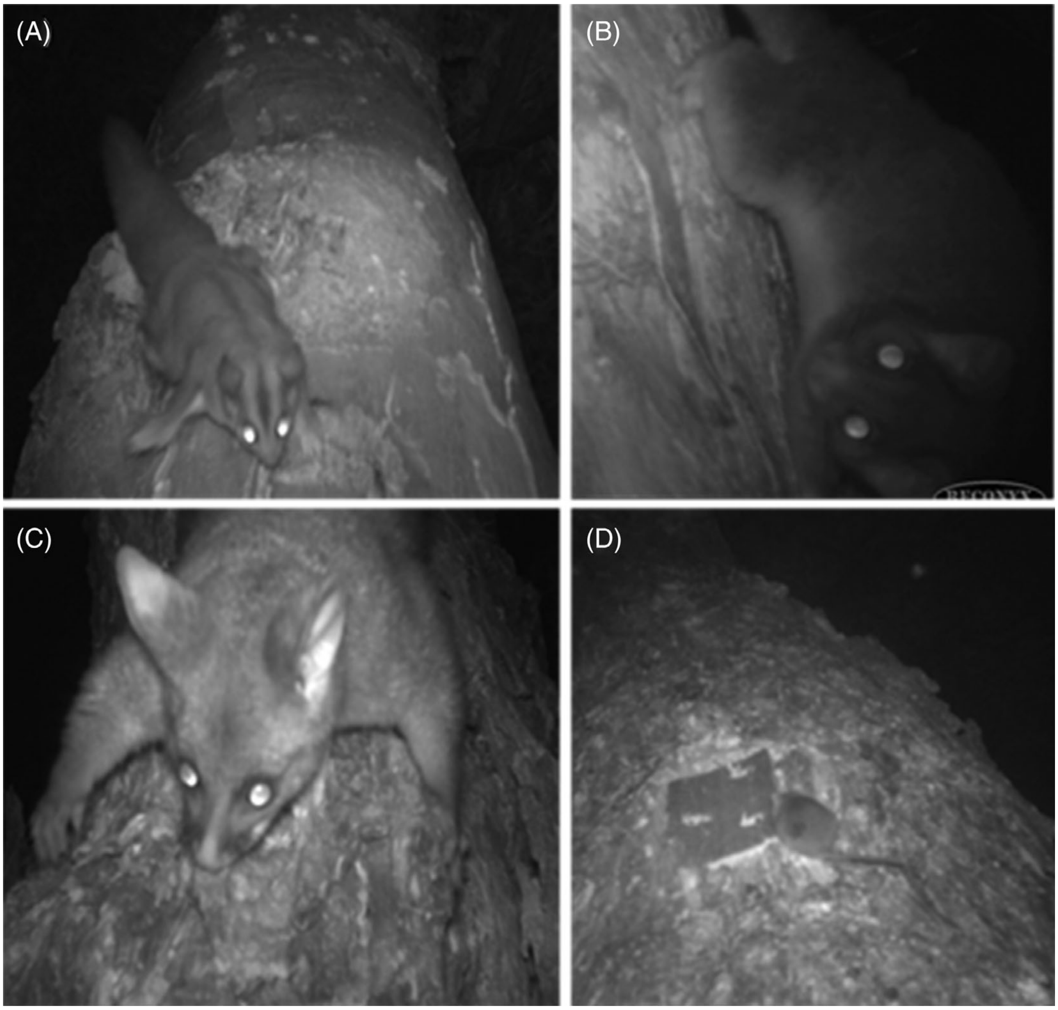

Figure 3 Hollow-dependent arboreal mammal species visiting and inspecting chainsaw hollows carved into developing trees: (A) Sugar glider, (B) Common ringtail possum, (c) Common brushtail possum, and (d) Agile antechinus. All chainsaw hollows were installed at a height of 4 m above the ground. Photographs were taken by passive infrared motion-sensing camera traps that were secured to a bracket that was attached to the tree trunk 1 m above chainsaw hollows (approximate camera height was 5 m above the ground). Camera traps were positioned perpendicular to the tree trunk, facing downwards toward the ground (see Fig. 2C).

Concurrent visits that occurred less than 15 minutes apart were considered likely to be repeat observations of the same individual during the same visit. Statistical analysis was therefore performed on an aggregated dataset where visits occurring within 15 minutes of each other were represented as a single visitation event and the number of visitation events equated to the visitation rate. Statistical analysis was conducted to calculate the effect of treatments on tree visitation rates. Models were constructed only on grouped hollow-dependent mammals because of the high number of zeros (no visit) for single species or birds that prevented comparisons between treatments. All data compilation and analyses were conducted using R version 3.6.0 (R Core Team 2019) through R-Studio (RStudio Team 2015).

A generalized additive mixed model (GAMM) with a negative binomial family specification was used to evaluate the effect of treatments on visitation rates. Given the different camera trap outputs between the before (Survey 1) and after (Survey 2 and 3) surveys, direct comparisons between before and after surveys were not conducted. The base rate (visitation rate in Survey 1) was instead included as a predictor variable within the GAMM to account for differences prior to treatment. This variable was included as the log of visits in Survey 1 plus one. Survey period and tree treatment (and their interaction) were included as fixed factors, while tree identity and site location were included as random effects. To account for the small variation in the number of days sampled during each survey, visitation data were input to the models as summed visits per survey with log of days in survey included as an offset using the *offset* function in the "stats" package. We ran the model using the *gam* function in the "mgcv" package (Wood 2011).

Post hoc contrasts between treatment factors were conducted on the GAMM using the *emmeans* function in the "emmeans" package (Lenth 2019), with significance level of 0.05. The exponentiated coefficient estimates (minus one) provided the

Figure 4 Hollow-nesting bird species visiting and inspecting chainsaw hollows carved into developing trees: (A) Eastern Rosella, (B) Crimson Rosellas, (C) Laughing Kookaburra, (D) Galah, (E) Rainbow Lorikeets, (F) Wood Duck, and (G) Spotted Pardalote.

Table 3 Summary of total visits (images of a species or species group recorded >15 minutes apart) by all hollow-dependent mammals and birds to each tree treatment during the three survey periods: 1, November 2015 to March 2016; 2, October–November 2016; 3, December–January 2017.

Tree treatment	*Survey*	*Mammals*	*Birds*
Chainsaw hollow	1	14	1
Chainsaw hollow	2	114	121
Chainsaw hollow	3	128	46
Control	1	10	0
Control	2	53	2
Control	3	74	0
Natural hollow	1	31	0
Natural hollow	2	90	13
Natural hollow	3	114	3

proportional increase in the response for that treatment compared to the control, which was then converted to a percentage. Confidence intervals (95%) were calculated as the exponentiated lower and upper bounds—estimated as the coefficient ± two times standard error.

Results

Over 3,951 camera-trap nights, we recorded 836 tree visitations by fauna, 814 of which were by hollow-dependent taxa: 251 at natural hollow trees, 139 at control trees, and 424 at chainsaw hollow trees (Table 3). Of these, 628 visitations were identified to four species of nocturnal mammals (233 Common brushtail possum *Trichosurus vulpecula*, 216 Sugar glider *P. breviceps*, 157 Common ringtail possum *Pseudocheirus peregrinus*, and 22 Agile antechinus *Antechinus agilis*) (Fig. 3); while 186 visitations were identified to seven species of diurnal hollow-nesting birds (34 Crimson Rosella *Platycercus elegans*, 128 Eastern Rosella *Platycercus eximius*, 9 Rainbow Lorikeet *Trichoglossus moluccanus*, 8 Galah *Eolophus roseicapilla*, 3 Spotted Pardalote *Pardalotus punctatus*, 2 Laughing Kookaburra *Dacelo novaeguineae*, and 2 Wood Duck *Chenonetta jubata*) (Fig. 4). All species recorded visiting trees were generalist species. A full list of species recorded and total visits is provided in Table S2.

Natural hollow, control, and chainsaw hollow trees were all visited and inspected by the same four species of native hollow-dependent arboreal mammals. All seven native hollow-nesting birds visited and inspected chainsaw hollows, compared to four species at natural hollows (Crimson Rosella, Eastern Rosella, Rainbow Lorikeet, Wood Duck) and one species at control trees (Eastern Rosella). Despite introduced hollow-nesting birds being observed at all five reserves during this study (e.g. Common Myna *Acridotheres tristis* and Common Starling *Sturnus vulgaris*), there was no evidence of any exotic hollow-dependent taxa visiting trees.

Across all sites, hollow-dependent mammals had greater visitation rates after treatment (Surveys 2 and 3) for all tree treatment types (Fig. 5). There was a non-significant increase in visitation rate for mammals between Surveys 2 and 3 (mean = 11%, range: −25 to 166, $p = 0.58$) when accounting for variation among reserves and trees. Post hoc contrasts between treatments indicated a significantly higher visitation rate for trees with chainsaw hollows compared to control trees (mean = 139%, range: 33–329, degrees of freedom [*df*] = 83.8, $p = 0.011$). These contrasts also indicated non-significant higher rates for natural hollow trees compared to control trees (mean = 24%, range: −27 to 113, $df = 83.8$, $p = 0.70$) and chainsaw hollow trees compared to natural hollow trees (mean = 92%, range: 8 to 242, $df = 83.8$, $p = 0.67$). Hollow-dependent birds had a substantially greater visitation rate on chainsaw hollow trees post-treatment compared to other tree treatments, but the variation in rates among trees was high (Fig. 5). Bird visitation rates on control and natural hollow trees were low across all surveys.

These trends were similar for the most frequently recorded species. However, Sugar gliders appeared to have a greater positive response to chainsaw hollow trees than Common brushtail or Common ringtail possums (Fig. 6). Hollow-dependent bird responses were dominated by Eastern Rosellas, which were much more likely to visit chainsaw hollow trees after treatment than any other trees (Fig. 6). When observing all species collectively, chainsaw hollow trees had a 100% likelihood of post-treatment visitation by hollow-dependent fauna.

Discussion

Mechanically carving artificial cavities into trees with chainsaws is a method gaining popularity in habitat restoration and conservation programs targeting hollow-dependent fauna (Hurley & Stark 2014; Zapponi et al. 2015; Cox & McCormick 2016; Lumsden et al. 2016; Rueegger 2017; Griffiths et al. 2018; Stojanovic et al. 2018). However, little attention has been paid to investigating the initial response of hollow-dependent wildlife to the installation of chainsaw hollows, specifically in terms of the rates at which animals visit trees before and after hollow creation. In our study, we predicted that the addition of chainsaw hollows to live, medium-sized trees would lead to increased visitations by hollow-dependent wildlife. We found that, compared to large hollow-bearing trees and control trees, the medium-sized trees that were selected for chainsaw hollow construction showed the greatest visitation rates by hollow-dependent wildlife (i.e. number of visitations) during the "post-impact" surveys. The high visitation rates to chainsaw hollow trees were species-specific, including greater effects for birds and Sugar gliders. This observed increase in activity could have been caused by repeated visits by individual animals, or by increased activity by multiple individuals (Fiske & Chandler 2011). Visitation rates by hollow-dependent mammals remained high across the second and third surveys that were conducted 4 and 7 months after chainsaw hollows were installed, respectively. This suggests that animals may have been repeatedly returning to chainsaw hollow trees to assess the suitability of these artificial shelter sites as potential nest or den sites (Clement & Castleberry 2013), beyond initial exploratory behavior out of curiosity at a novel feature being introduced into their habitat (Threlfall et al. 2013).

Chainsaw hollows can be designed to more effectively replicate the external physical characteristics of natural hollows than

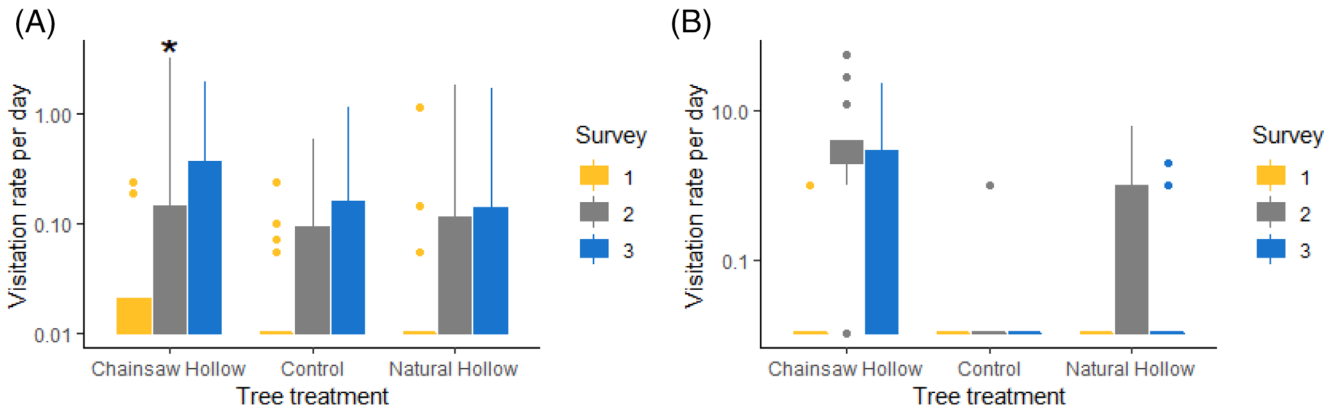

Figure 5 Visitation rate per day (log 10 scaled) for: (A) hollow-dependent mammals, and (B) hollow-nesting birds. Asterisk indicates significant effect ($p < 0.05$) compared to control. For each boxplot, the box indicates the range between the first and third quartiles of the data, the whiskers extend up to 1.5× the inter-quartile range, and outliers occur as points beyond those limits.

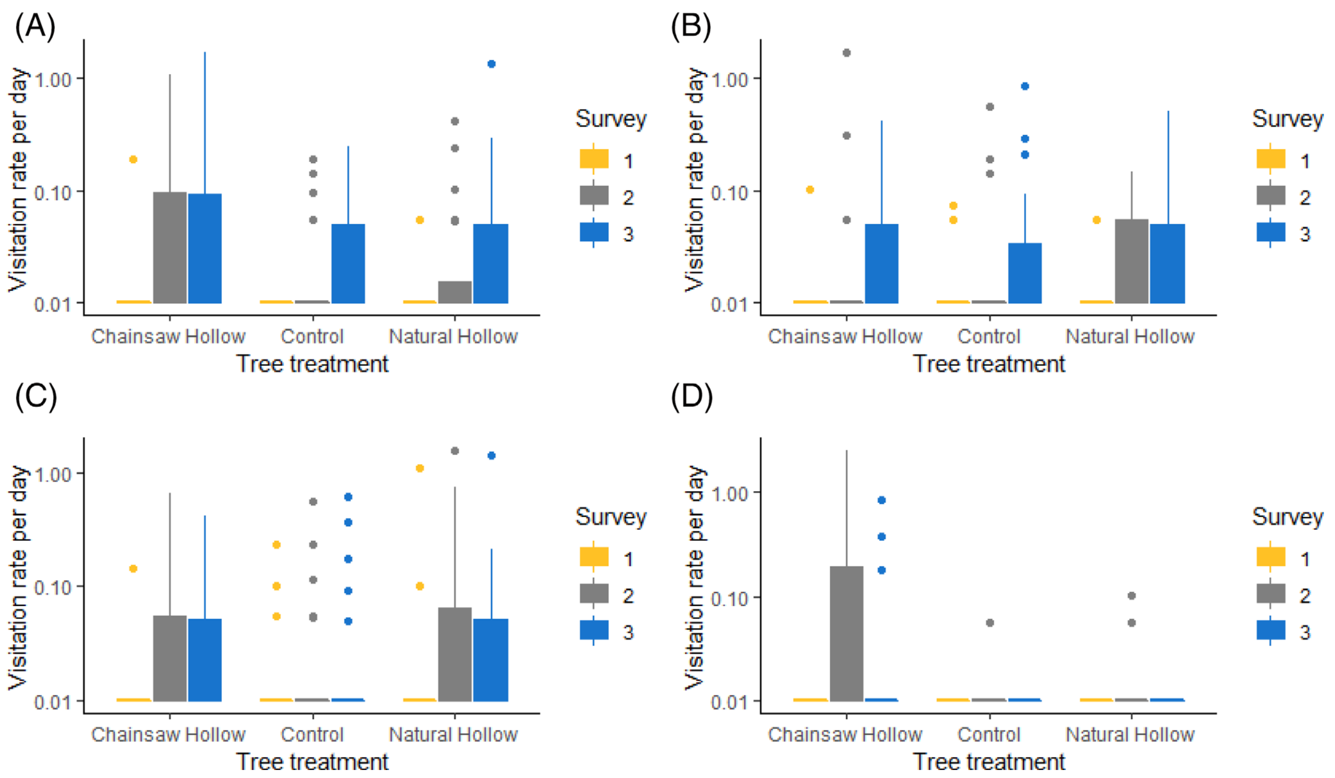

Figure 6 Visitation rate per day (log 10 scaled) for: (A) Sugar glider, (B) Ringtail possum, (C) Brushtail possum, and (D) Eastern Rosella. For each boxplot, the box indicates the range between the first and third quartiles of the data, the whiskers extend up to 1.5× the inter-quartile range, and outliers occur as points beyond those limits.

nest boxes (Griffiths et al. 2018). If chainsaw hollows fit a "search image" criteria that hollow-dependent animals use when looking for new tree hollows, then this may reduce the time it takes them to recognize and subsequently use these supplementary shelter sites. The behavioral methods and environmental cues used by hollow-dependent mammals and birds when searching for tree hollows, and investigating them as potential new shelter sites, are largely unknown. There is some evidence that tree-roosting insectivorous bats use a combination of olfaction, visual cues, and auditory signals produced by conspecifics when searching for and selecting tree roosts (Ruczyński et al. 2007; Furmankiewicz et al. 2011; Ruczyński & Barton 2012). While we do not have any information on how the species observed in this study go about searching for new tree hollows, our results clearly show that a range of hollow-dependent arboreal mammals and birds quickly found and inspected newly installed chainsaw hollows. The mechanism underlying these behaviors is an understudied area that warrants further investigation.

All of the animals that visited and inspected chainsaw hollows during this study were native hollow-dependent species. No introduced pest species that are known to use natural and artificial hollows in human-disturbed landscapes (e.g. Common Myna *A. tristis*, Black rat *Rattus rattus*; Harper et al. 2005; Lindenmayer et al. 2009; Grarock et al. 2013) were recorded visiting chainsaw hollows. These results are consistent with other studies undertaken within timber production forest landscapes in southeastern Australia, where endemic hollow-dependent mammals and birds have been observed to use chainsaw hollows, while no exotic species were recorded (Rueegger 2017; Lumsden et al. 2016). Together, these findings suggest that chainsaw hollows designed to replicate the external physical characteristics of natural hollows could be effective in attracting target fauna to developing trees in regenerating and revegetated landscapes. However, further studies are required that compare the use of natural hollows, chainsaw hollows, and nest boxes installed in a range of human-disturbed landscapes to empirically test the effectiveness of different habitat supplementation techniques in attracting target endemic species versus exotic pests (Griffiths et al. 2018).

Despite the dimensions of chainsaw hollows used in this study being designed for small marsupial gliders, various species of endemic hollow-nesting birds visited and attempted to access the chainsaw hollows (e.g. Crimson Rosella, Eastern Rosella, Rainbow Lorikeet, Striated Pardalote, Wood Duck, and Laughing Kookaburra). These findings contrast with those of Le Roux et al. (2015), where the addition of nest boxes to small- and medium-sized trees did not result in increased activity of hollow-nesting birds at the tree. Furthermore, despite being unable to fit through the 35 mm entrance holes used in this study, Crimson Rosellas, Eastern Rosellas, and Rainbow Lorikeets all made repeated efforts to widen the entrance to gain access to the chainsaw hollows. Therefore, hollow-nesting bird species that investigated the chainsaw hollows during this study may have occupied them if they were not restricted by the entrance size.

In this study, we have provided evidence that chainsaw hollows added to developing trees that previously did not provide shelter sites increased visitations by hollow-dependent mammals and birds. Further long-term field studies are required to test the effectiveness of this novel habitat supplementation technique in providing suitable shelter sites for hollow-dependent wildlife in a range of human-disturbed landscapes (e.g. agricultural or timber production forests). Of particular interest would be studies comparing temporal patterns in wildlife use of natural tree hollows, nest boxes, and chainsaw hollows, and testing whether occupancy of these different shelter structures results in variation in the fitness of hollow-dependent fauna (see Goldingay 2017; Norris et al. 2018). However, where possible, the retention of mature, hollow-bearing trees, and further recruitment of new trees should be the primary objective of conservation and management programs targeting hollow-dependent wildlife in disturbed landscapes (Manning et al. 2006; Lindenmayer 2017).

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Summary of studies investigating mechanically excavated tree hollows.
Table S2. Summary of total visitations by all species to all tree treatments.
Figure S1. Diameter at breast height (DBH) of all trees in each treatment category.

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