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Outcomes of decades long installation of nest boxes for arboreal mammals in southern Australia

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Summary Nest boxes are commonly installed to support hollow-using species where the abundance of hollow-bearing trees is deficient. Recent studies have provided equivocal evidence about the effectiveness of nest box projects and have highlighted significant management costs associated with some projects. We document the functionality of 303 nest boxes installed across five different community-led projects in southern Australia for periods of 10–25 years. As expected, we found that nest boxes lost functionality over time. However, 60% remained functional to support the Brush-tailed Phascogale (*Phascogale tapoatafa*) and the Sugar Glider (*Petaurus breviceps*) after almost 20 years. Years installed, method of nest box attachment and tree species influenced whether boxes remained functional. Nest box construction material changed over time so could not be assessed specifically. When inspected in a single year, the Brush-tailed Phascogale occupied 9% of functional boxes and another 48% contained their nests. The Sugar Glider occupied 15% of functional boxes and another 22% contained their nests. These values suggest the nest box installations were highly effective for these species, although more detailed study is needed to understand what contribution these installations have made to support the local populations. Maintenance of most nest boxes occurred twice a year in the first five years after installation, but many received no maintenance for periods of three years, and some 10–15 years, before our census. Our findings suggest that infrequent maintenance by community groups can sustain nest box projects over periods of several decades. Research into employing nest boxes as a management tool in Australia is still in its infancy. Further studies are needed to resolve factors that limit their effectiveness.

Key words: *artificial cavity, nest box attrition, nest box maintenance.*

Introduction

Many species of birds and mammals are completely dependent on tree cavities or hollows for survival (Newton 1994; Gibbons & Lindenmayer 2002; Goldingay 2009). The depletion of this habitat feature due to human activities has led to a decline in the abundance of many of these species, either locally or broadly (e.g. Newton 1994; Lindenmayer *et al.* 2013; Kiss *et al.* 2017). Tree hollow depletion presents a serious challenge to land managers because tree hollows typically require at least 100 years to be produced by natural processes (Saunders *et al.* 2014). A potential short-term solution is the installation of nest boxes which may provide shelter sites for some species throughout the year or provide seasonal breeding sites for others. Nest box installation is intended as a habitat restoration tool and not as a justification for tree cavity depletion. For nest box programmes to be effective, nest boxes need to be used at a frequency that is comparable to the frequency of use of natural tree hollows. If intended for population support, they need to support the local population of the target species over time. Furthermore, the ongoing maintenance of the nest boxes must be sustained for long periods of time to maintain that frequency of use.

The use of nest boxes as a management tool in Australia has remained contentious due to low rates of use by many species and the high cost forecast to maintain large numbers of nest boxes (Lindenmayer *et al.* 2017). Maintenance may be required to manage insect infestations, as well as deterioration of boxes caused by decay or damage from nontarget species. However, some studies have documented high rates of use (>30%) and have found insect infestations to be inconsequential (Goldingay *et al.* 2007, 2015; Rueegger *et al.* 2012). Nest box programmes may also be undermined due to boxes falling from trees due to attachment failure or after being struck by falling branches (Lindenmayer *et al.* 2009, 2017). Attrition of nest boxes can be substantial over a 10-year period (Lindenmayer *et al.* 2009) and sometimes high within the first few years (Lindenmayer *et al.* 2017). However, there is also evidence that nest boxes can be maintained with limited effort over periods of at least 10 years (Goldingay *et al.* 2015; Smith *et al.* 2015).

Nest box programmes for birds have been in place for decades around the world. Some, involving 80–150 nest boxes, have been monitored for 41–64 years in Sweden, North America and England (Schölin & Källander 2011; Shutler *et al.* 2012; Burgess 2014), while others involving >200 boxes have been monitored for 15–30 years in Canada, England, Sweden and France (Robertson & Rendell 2001;

Goodenough *et al.* 2008; Corrigan *et al.* 2011; Hipkiss *et al.* 2013; Lambrechts *et al.* 2016). Some long-term studies involving nonflying mammals have included 90–200 boxes monitored over 18–25 years (Adamík & Král 2008; Williams *et al.* 2013). Most long-term studies provide scant detail of the management that may have been applied to the nest boxes. Nest boxes 'were replaced successively as needed' (Schölin & Källander 2011), were 'repaired, replaced' if required (Hipkiss *et al.* 2013) or were maintained by volunteers (Goodenough *et al.* 2008; Corrigan *et al.* 2011; Lambrechts *et al.* 2016). Some stated that old nests were removed from each box at the conclusion of the breeding season (Robertson & Rendell 2001; Hipkiss *et al.* 2013). All studies included repeated monitoring of occupants during the bird breeding season which presumably provided opportunity to maintain boxes.

The variable rates of nest box use and attrition in Australia may be due to some local environmental conditions that do not favour long-term nest box programmes. Further studies are required at different locations to increase our ability to generalise from the findings. In this study, we document the fate of nest boxes installed for arboreal mammals in southern Australia for periods of 10–25 years. The Brush-tailed Phascogale (*Phascogale tapoatafa*), listed as threatened in Victoria, was the main target of the nest box installations (see Soderquist *et al.* 1996). Long-term monitoring of this species in Victoria suggests it is in decline (Holland *et al.* 2012). The Sugar Glider (*Petaurus breviceps*) was also present in the study landscape and was expected to use these nest boxes due to a similar nest box entrance size requirement. The nest boxes were installed and maintained by community volunteers but had not been visited for at least three years when we assessed their condition for this study. We address the following questions: What was the fate of the nest boxes after differing periods of installation; did nest box material or tree attachment influence their fate; have nontarget species prevented use by target species; and was the frequency of use by target species at a level that could support local populations?

Methods

Study area

The study was conducted in sections of the Greater Bendigo National Park (One Tree Hill and Mandurang Blocks) and Bendigo Regional Park (Diamond Hill/Kangaroo Gully Sections), which are located south of Bendigo, Victoria. The nest boxes (Fig. 1) were spread across an area of approximately 4000 ha. The habitat of the study area was dominated by Box-ironbark Forest and Heathy Dry Forest. The original forest was subject to clear-felling so the area is now dominated by regrowth of approximately 80 years of age. Soderquist (1999) found that the Bendigo district had tree canopy hollow densities of <1 per ha (hollows were ≥10 cm deep, >2 cm minimum entrance diameter) and had the lowest density of tree hollows of any he surveyed in box–ironbark forests in Victoria. We recorded two hollows per ha (canopy and basal) suitable for the Brush-tailed Phascogale or Sugar Glider (≥15 cm deep, entrance diameter 2.5–6 cm) within 23 circles of 20-m radius across our study sites.

Nest box designs and inspection

Nest boxes were installed by different groups of people in five different projects in response to recommendations later published in Soderquist *et al.* (1996). The boxes were established individually or in small clusters of 2–5 boxes, with a spacing of 50–125 m, 30–100 m from forest roads, or along a riparian zone at one location, leading to a wide variation in nest box density, from 0.2 per ha in one area up to 7 per ha in another area. The intention of the original projects was to use the nest boxes as a survey tool for the Brush-tailed Phascogale (Soderquist *et al.* 1996) but to also provide some local population support in areas somewhat devoid of hollows. They were installed in different years commencing in 1990 and were inspected in this study during 2016. Thus, they represent installations covering periods of approximately 10 (n = 31), 11 (n = 48), 18 (n = 114) and 25 years (n = 110). The maintenance applied to the nest boxes varied among projects. Mostly it consisted of visits to remove Feral Honeybees (*Apis mellifera*) which were viewed as detrimental to use by mammals. The 25-year-old boxes were visited 1–2 times per year in the first 10 years but not again in the last 15 years. The 18-year-old boxes were visited annually but not for two years in the middle or in the final three years. The 10- to 11-year-old boxes appear to have received no maintenance.

The nest boxes were relocated from written records. We had original maps or locations for most of the sites we visited and we were guided by those who installed the boxes originally. The number of boxes located and checked on any day varied but was generally about 3–5 boxes per day. The whole census was conducted over a 9-month period. We recorded the condition of each box as follows: off tree (missing from nails on tree or on-ground), partially detached (Fig. 2a), panels split (Fig. 2b), inspection panel damaged, lid chewed with hole and entrance enlarged

Figure 1. Different nest box designs installed for use by the Brush-tailed Phascogale and the Sugar Glider. (a) A side-entry design. (b) A repaired box with reinforced lid and front entrance, and tilting front inspection panel. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 2. (a) A dysfunctional 25-year-old box which has come adrift from its backing board and the lid dislodged. (b) A dysfunctional 25-year-old box in which the backing board and vertical panels have fractured with the lid askew. (c) A dysfunctional 18-year-old box in which the entrance has been enlarged to 10 cm in width. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 3. A nest box inspection taking place with a pole camera through the entrance hole. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 4. Contents of a nest box showing feathers and strips of bark which are characteristic of the nest of a Brush-tailed Phascogale. [Colour figure can be viewed at wileyonlinelibrary.com]

(Fig. 2c) by chewing (>65 mm diameter; 78% were 100 mm). If any of these attributes occurred we scored boxes as non-functional for occupation by the target mammals. Although our target species may occasionally use nest boxes with entrance holes >65 mm diameter (Menkhorst 1984), large competing species often displace smaller species (Traill & Lill 1997; Goldingay *et al.* 2007, 2015). Breeding female Brush-tailed Phascogales, in particular, favour nest sites with narrow (≤55 mm diameter) entrances (Soderquist 1993; Traill & Coates 1993). Box entrance size is fundamental to enable the targeting of species (Goldingay *et al.* 2007, 2015). The contents of the nest boxes were inspected using a pole camera (Brite Star Model 22R – 61), either through the entrance hole (Fig. 3), through the lid or sometimes using a ladder and observing directly through the inspection panel. From this, we recorded the presence of animals and the users of the boxes based on the presence of any nesting material. Different types of nesting material such as green or dead leaves, strips of bark, twigs, feathers (Fig. 4) and scats enable users of nest boxes to be confidently identified (Soderquist *et al.* 1996; Beyer & Goldingay 2006).

The nest boxes varied with respect to some but not all attributes. Most (98%) were of a similar volume measuring 19–25 cm × 15–25 × 30–40 cm. All nest boxes had entrance holes of 35–45 mm diameter, positioned either on the front (84%) or side of the box (Fig. 1). Boxes were attached to trees at heights of 4–6.5 m above ground. Most (90%) of the boxes were positioned on the eastern side of a tree. Most (94%) were orientated in a vertical position rather than horizontally. Preliminary analysis of these variables showed they did not influence our response variables.

The nest boxes were constructed from hardwood, pine or plywood. The panel that enabled inspection of the contents of a nest box varied, with many having a hinged lid or a tilting front panel but some had a lid that slid in a groove. The boxes were attached to different tree species and differed in their mode of attachment which was of three types: the nest box was attached to a narrow vertical backing board that itself was nailed directly to a tree or for several boxes it was an extension of the back panel that was nailed; the backing board was hung on a large nail hammered into the tree; or the box itself was hung on a large nail.

Data analysis

Three separate logistic regression analyses (Tabachnick & Fidell 2013) were conducted. One examined nest box attributes that may have influenced whether the boxes were scored as functional at the time of our census. The other two examined individually whether any nest box attributes influenced use by our two target species (Brush-tailed Phascogale and Sugar Glider). The analysis was implemented within IBM SPSS Statistics 24 (IBM, Armonk, NY, USA). Logistic regression allowed us to assess how well our independent or explanatory variables (nest box attributes) explain or influence each dependent variable. The overall model is assessed via a chi-square test which compares the full model with all explanatory variables against the intercept-only model (Tabachnick & Fidell 2013). Each independent variable is assessed via a Wald statistic which is compared to a chi-square distribution. A measure of the strength of the influence of each independent variable is the odds ratio. An odds ratio >1 indicates an increase in the odds of that event when the predictor (independent variable) increases by one unit, whereas an odds ratio of <1 indicates a decrease in the odds of that event when the predictor increases by one unit (Tabachnick & Fidell 2013).

In the first analysis the response variable was whether a box was functional (1) or not (0). The explanatory variables considered for inclusion in the analysis were as follows: box construction material (hardwood, pine or ply), type of inspection panel (hinged lid, tilting panel or sliding panel), tree species (Red Ironbark (*Eucalyptus tricarpa*), yellow box (*E. melliodora*), grey box (*E. microcarpa*) or other), tree DBH (diameter at breast height) (Ln transformed), mode of attachment (nailed backing board, backing board hung on nail, box hung on nail) and years installed (10–11 or 18–25). We checked whether any explanatory variables showed collinearity. Years installed was highly correlated ($r > 0.60$) with tree DBH, material and inspection panel so only years installed was included in this analysis. Goodness of fit was assessed by a Hosmer and Lemeshow test which revealed no significant lack of model fit ($\chi^2 = 1.92$, $df = 6$, $P = 0.93$).

The other analysis examined nest box attributes that may influence use by different species. Only those boxes scored as functional were used in this analysis. The response variable was whether a species used a box (1) or not (0). We ran separate analyses for the Brush-tailed Phascogale and sugar glider. There was some ambiguity in boxes used by the Brush-tailed Phascogale and Sugar Glider because the nesting material of one could sometimes be found over the top of the other. We assigned a box to a single species record to avoid ambiguity so the most recent use was the only use recorded. This related to 22 boxes of which 59% were scored as used by Brush-tailed Phascogales. The explanatory variables used in the analysis included the following: tree species, tree DBH and type of inspection panel. Tree DBH was used in this analysis because it had more ecological relevance than years installed. There was no significant lack of model fit in either the Brush-tailed Phascogale analysis ($\chi^2 = 7.11$, $df = 8$, $P = 0.53$) or the Sugar Glider analysis ($\chi^2 = 9.88$, $df = 8$, $P = 0.27$).

Results

Factors influencing whether a nest box was functional

We located 303 nest boxes or the trees they were installed on. We scored 165 of these nest boxes as functional. For differing periods since installation, we found that 84% of boxes were functional at 10–11 years, 60% at 18 years and 28% at 25 years. Some attribute data were missing which reduced the sample size in the analysis of box functionality to 291 nest boxes. Whether a nest box was functional was significantly influenced by the explanatory variables ($\chi^2 = 103.71$, $df = 6$, $P = 0.001$). All variables individually contributed significantly to the model: years installed (Wald = 33.43, $df = 1$, $P = 0.001$), attachment method (Wald = 29.59, $df = 2$, $P = 0.001$) and tree species (Wald = 18.26, $df = 3$, $P = 0.001$). Nest boxes reduced in functionality from 10–11 years to 18–25 years (Odds Ratio (OR) = 0.01, 95%CI = 0.003–0.061). Compared to the nailed backing board the odds of nest boxes being functional was significantly higher for the box hung on a nail (OR = 5.44, 95%CI = 2.92–10.11). The backing board hung on a nail showed no significant difference ($P = 0.29$) to the nailed backing board. Compared to Red Ironbark the odds of nest boxes being functional decreased significantly for yellow box (OR = 0.11, 95%CI = 0.03–0.36), grey box (OR = 0.26, 95%CI = 0.10–0.67) and other species (OR = 0.05, 95% CI = 0.004–0.57).

Species detected in the nest boxes

Brush-tailed Phascogales were seen in 15 of the 165 functional nest boxes (Table 1). A further 79 boxes contained their distinctive nests so 57% of the functional boxes in total showed use by Brush-tailed Phascogales. Sugar gliders were seen in 25 of the functional nest boxes. A further 36 boxes contained their distinctive nests so 37% of the functional boxes in total showed use by Sugar Gliders. Common Ringtail Possums (*Pseudocheirus peregrinus*) were recorded in nine nest boxes. None of these were scored as functional for Brush-tailed Phascogales because the entrance hole had been greatly enlarged. Australian Owlet-nightjars (*Aegotheles cristatus*) were observed in three nest boxes and evidence of their breeding was present in another four nest boxes. None of these were scored as functional for phascogales due to large entrance size. Honeybees were found to have active hives in six functional nest boxes. Honeycomb was present in five nest boxes where bees had vacated. Bees had been removed from another three nest boxes in earlier maintenance. All of these bee used boxes were scored as functional. Four showed evidence of subsequent use by Sugar Gliders and three showed evidence of use by Brush-tailed Phascogales.

Table 1. The number of nest boxes used by different species. Percentages relate to the number of functional boxes

	Number of boxes
Total in census	303
Functional	165
Brush-tailed Phascogales	
Observed	15 (9%)
Nests only	79 (48%)
Sugar Gliders	
Observed	25 (15%)
Nests only	36 (22%)
Honeybees present	
Observed	6 (4%)
Old honeycomb	5 (3%)
Common ringtail possum	9
Australian Owlet-nightjar	7

Did nest box design attributes influence use by target species?

Missing attribute data reduced the data set for this analysis to 151 boxes. Whether a nest box was used by a Brush-tailed Phascogale was significantly influenced by the explanatory variables

(χ^2 = 32.43, df = 6, P = 0.001). The variable 'inspection panel' had a marginally significant influence on Brush-tailed Phascogale use (Wald = 6.20, df = 2, P = 0.045). Compared to the hinged lid the odds of nest boxes being used by Brush-tailed Phascogales was significantly higher (Wald = 6.19, df = 1, P = 0.013) for the tilting front panel (OR = 4.00, 95% CI = 1.34–11.92) but was not significant (Wald = 1.67, df = 1, P = 0.20) for the grooved panel of which there were only six cases. The variables tree species (P = 0.05) and DBH (P = 0.65) did not have a significant influence. Whether a nest box was used by a Sugar Glider was significantly influenced by the explanatory variables (χ^2 = 23.89, df = 6, P = 0.001). However, none of the explanatory variables individually had a significant influence: DBH (P = 0.57), tree species (P = 0.06) and inspection panel (P = 0.18).

Discussion

Factors influencing whether a nest box was functional

It is expected that nest boxes will deteriorate over time and become nonfunctional. This also applies to natural tree hollows (Lindenmayer *et al.* 1997; Beyer *et al.* 2008; Saunders *et al.* 2014). In the central highlands of Victoria, Lindenmayer *et al.* (2009) recorded that 51% of nest boxes had fallen from trees after 10 years. Falling from trees was one of several outcomes that contributed to a loss of functionality in our study but we found that 84% of boxes were functional for the target species after 10–11 years and 60% after almost 20 years. In south-east Queensland (Qld), Smith *et al.* (2015) found that 89% of boxes remained functional after 10 years. The difference between these studies may reflect differences in box construction material, mode of attachment to trees and local rainfall or habitat type. We also found that boxes attached to Red Ironbark trees had a much greater likelihood of remaining functional, which may relate to the slower growth of this species relative to the other species. We were unable to examine the influence of construction material because it was highly correlated with years installed. Plywood and pine boxes appeared to last better than hardwood but that may reflect other aspects of individual projects.

Some maintenance was applied to nest boxes over time in all previous studies. In our study maintenance was mostly directed towards removing bees from boxes and was infrequent or did not occur for several years before our census. The boxes in place for 25 years received no maintenance in the last 15 years. Goldingay *et al.* (2015) demonstrated that nest boxes used by the Squirrel Glider in south-east Qld could be kept in a functional state over 10 years with minimal maintenance. Sites with high rainfall such as that in the study by Lindenmayer *et al.* (2009) with ~1600 mm p.a., may be associated with faster tree growth and may lead to the detachment of nest boxes that are nailed to trees. The different methods of attaching nest boxes to trees showed a highly significant influence in our study. Hanging boxes on a large nail was much more likely to be associated with functional nest boxes compared to boxes nailed through a backing board. In other studies nest boxes have been attached by metal strips (e.g. Lindenmayer *et al.* 2017) or by fencing wire (e.g. Goldingay *et al.* 2015) which may also influence long-term functionality. Long-term studies of nest boxes conducted overseas (Adamík & Král 2008; Goodenough *et al.* 2008; Corrigan *et al.* 2011; Schölin & Källander 2011; Shutler *et al.* 2012; Hipkiss *et al.* 2013; Burgess 2014; Lambrechts *et al.* 2016) provided no details on the method of attaching nest boxes to trees. However, this is a topic that requires further research.

Frequency of use by target species

A key concern about nest box projects in Australia has been the low frequency of use by target species and high use by some nontarget species in some studies. It is difficult to know what level of nest box use by a target species should be considered as a criterion for success. Lindenmayer *et al.* (2017) suggested that 10% occupancy (i.e. occupied during inspection) was a plausible expectation for the Squirrel Glider. This was based on their field studies on the south-west slopes of New South Wales (NSW) of tree hollow use by the Squirrel Glider. The nest boxes they monitored fell short of that level with only 2% of nest boxes potentially useful to the Squirrel Glider showing any use (occupied or with a nest). Without any better estimates of predicted occupancy and recognising that the actual value will be influenced by the local availability of hollow-bearing trees, a species' home range size and abundance of other hollow-users, we adopt the 10% value to test against our data. Of the 165 boxes scored as functional in 2016, we observed the Phascogale within 9% of boxes and the Sugar Glider within 15% of boxes. This difference is likely to reflect differences in home range size (minimum convex polygon) of these species (Phascogale: 41–106 ha, Soderquist 1995; Sugar Glider: 5.4 ha, Quin *et al.* 1992), that our census spanned the period of Phascogale male die-off and that phascogales deep in nesting material may have been overlooked. The Phascogale may also use a large number (>10) of nest trees when available (van der Ree *et al.* 2006). The number of boxes used (i.e. occupied or with a characteristic nest) by the Phascogale was 57% and by the Sugar Glider 37%. These values reveal that the nest boxes in our study were highly suited for use by the target species. In the study of Goldingay *et al.* (2015), the Sugar Glider occupied 25–28% of a 'glider' nest box design in two study landscapes in NSW (R.L. Goldingay, unpublished data). Other studies employing specific nest box designs have also satisfied the 10% criterion though some only provide data on percentage use and not on percentage occupied. In south-west Western Australia, Rhind and Bradley (2002) reported use of 95% of nest boxes by the Brush-tailed Phascogale. Harley (2006) reported that 75% of 150 nest boxes targeting Leadbeater's Possum (*Gymnobelideus leadbeateri*) at Yellingbo were used by that species. Rueegger *et al.* (2012) installed nest boxes to target the Eastern Pygmy-possum (*Cercartetus nanus*) and reported use of 78% of boxes with up to 30% occupied in a single month. At three separate locations in Victoria Ward (1990, 2000) reported use of 23%, 38% and 50% of nest boxes with designs targeting the Feathertail Glider (*Acrobates pygmaeus*). Goldingay *et al.* (2007) observed the use of 25% of nest boxes with a narrow entrance targeting the Feathertail Glider and recorded 15% occupied in the last census (R.L. Goldingay, unpublished data). Our study essentially provides a proof-of-concept that nest boxes could be used to support populations of the Brush-tailed Phascogale over many decades.

Nest box design can have a major influence on the frequency of use by different species. Generally, species prefer entrance sizes close to their body diameter (Soderquist *et al.* 1996; Beyer & Goldingay 2006; Goldingay & Stevens 2009). Lindenmayer *et al.* (2017) used a box of 6–8 cm diameter for the Squirrel Glider but this box is likely to allow the Ringtail Possum and the Common Brushtail Possum (*Trichosurus vulpecula*) to enter. Potential interactions with larger species can lead to smaller species avoiding boxes with larger entrances (Menkhorst 1984; Traill & Lill 1997; Goldingay *et al.* 2007). The lack of success in attracting some species to nest boxes may reflect a lack of knowledge of design elements favourable to those species. However, some species may simply avoid nest boxes. Many nest box designs that are stated to target certain species have received limited field testing and some suggested designs are contradicted by recent research. The high frequency of use by two species in our study reflects the fact that the boxes were made and installed within a narrow range of design elements. For example, all boxes had entrances of 35–45 mm wide which ensured the boxes were most suited to the target species (see Soderquist *et al.* 1996).

Use by nontarget species

Nontarget species may be quite prevalent in some studies. Most concerns have been raised about the Feral Honeybee. The level of use of nest boxes by honeybees has varied across studies. In recent studies in southern NSW honeybees have occupied 33% of boxes (Lindenmayer *et al.* 2016), 13% of boxes (Le Roux *et al.* 2016) and 9% of boxes (Lindenmayer *et al.* 2017). Soderquist *et al.* (1996) reported that 39–57% of 14–18 nest boxes were occupied by honeybees at two locations in Victoria. Goldingay *et al.* (2015) found honeybees used ~10% of boxes near Sydney and in north-east NSW but they pointed out that bee occupation does not appear to be a serious issue over time at many locations because the bees moved on after about 1 year. Smith *et al.* (2015) stated honeybees were not a concern in their study in south-east Qld. What is overlooked by many studies is that Honeybees do not only target nest boxes but are found in natural tree hollows too. Occupancy levels of 4–52% of natural hollows have been recorded (Goldingay 2009). In our study, only 4% of functional nest boxes were occupied by bees. Another 3% of boxes had been occupied by Honeybees previously. These levels are acceptable and do not warrant any maintenance response. Levels of occupancy >10% may warrant removal of the hives (Soderquist *et al.* 1996) and/or the installation of additional nest boxes but a response may depend on the number or locations of nest boxes unused by any species. Knowledge of the frequency of occupation of natural hollows in areas with nest boxes would provide further insight on this issue.

Introduced birds such as the Common Starling (*Sturnus vulgaris*) and the Common Myna (*Acridotheres tristis*) have occupied nest boxes in some studies, occupying 49% of boxes (Lindenmayer *et al.* 2016), 2% of boxes (Lindenmayer *et al.* 2017) and 12% of boxes (Le Roux *et al.* 2016) near Canberra and southern NSW. These species compete with native species for tree hollows only in some areas of disturbed habitat (Goldingay *et al.* 2015). Pell and Tidemann (1997) recorded these birds using 76% of natural hollows in their study areas in suburban Canberra. These birds can be excluded if native mammals are the targets by installing rear-entry nest boxes. The Black Rat (*Rattus rattus*) has also occupied nest boxes in some studies occupying 4–14% of boxes (Le Roux *et al.* 2016; Lindenmayer *et al.* 2016, 2017). This percentage is relatively small compared to 31–46% of boxes unoccupied in two of the studies, so have not influenced the occupancy of the target species. Black Rats have not been documented in other studies so they might only be a concern in disturbed or altered or degraded ecosystems. Species such as the Common Brushtail Possum and the Common Ringtail Possum may be more of an issue if they expand the entrances of small-entrance boxes. In our study, the entrances of 36 nest boxes were enlarged by possums or parrots, and the Ringtail Possum was seen in 10 of these boxes. This situation can be overcome by reinforcing entrances with metal surrounds (Traill & Lill 1997) or using a nest box with a rear-entry that larger species cannot access (R.L. Goldingay, unpublished data).

Implications

There are three main implications that arise from this study. These relate to success in targeting species, empirical evidence on nest box degradation over 25 years and the cost of managing a nest box programme. The nest boxes we studied had been in place for 10–25 years. We found that 57% were used by the Brush-tailed Phascogale and 37% were used by the Sugar Glider in the year of our census. These are very high levels of use by target species, which reflect the appropriateness of the installed nest box designs and the paucity of natural tree hollows in our study area. For comparison, Gibbons *et al.* (2002) recorded that 29% of tree hollows with entrances of 2–5 cm diameter (the approximate range in nest boxes here) were used by any mammals or birds (based on animals, hair, feathers and/or nests). Although in a different study area, a value of 29% of tree hollows showing any use provides a potential benchmark, though that includes all birds and mammals. Whether the nest boxes in our study have provided population support to the Brush-tailed Phascogale and the Sugar Glider requires detailed investigation.

This is the first study conducted in Australia to provide a detailed investigation of nest boxes installed over a period of 10–25 years. This revealed that 60% of boxes were still functional after almost 20 years. This declined substantially to 28% after 25 years but that may reflect the absence of maintenance in the last 15 years for those boxes. Our time periods represent different nest box projects managed by different people so the percentage remaining functional over time may be increased with more frequent maintenance, and with the more robust method of attachment to a tree. The key point here is a demonstration of the percentage that may remain functional after 20 years. The high level may reflect the low rainfall study area. Therefore, long-term investigations in high rainfall areas are needed. Evidence from the Northern Hemisphere is that nest box programmes can operate for decades and have high rates of species' usage.

Lindenmayer *et al.* (2017) estimated the costs for maintaining a nest box programme over a 90-year period. This was premised on two maintenance checks per year or 180 checks in total. Our study suggests that one check every 5 years (i.e. 18 checks over 90 years) could be adequate in our study area, which would reduce the cost of such a programme by as much as 90%. The checking of the boxes in this case was conducted by community groups as suggested by Soderquist *et al.* (1996), so the cost of that activity was only their travel costs. Further research is needed into the frequency of maintenance and its influence on nest box functionality. Nest boxes have a role to play as both a research tool and a management tool (Beyer & Goldingay 2006; Harley 2006; Goldingay & Stevens 2009). Neither has been fully realised. As a management tool, there is a need to recognise where local circumstances may not be suitable. Research into how effective nest boxes can be in Australia is in its infancy. Further studies are needed to identify factors that limit their effectiveness and how they may be resolved. Our study represents a small-scale experiment that encompassed a relatively small number of nest boxes. However, it provides the basis for scaling up with a much larger number of nest boxes to support local populations of the Brush-tailed Phascogale and the Sugar Glider, and which takes into account factors associated with boxes remaining functional over periods of decades.

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