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Effects of entrance size, tree size and landscape context on nest box occupancy: Considerations for management and biodiversity offsets

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ABSTRACT

The effectiveness of nest boxes as a management and biodiversity offset tool remains equivocal and controversial. Improving nest box programs requires urgent empirical research to identify the spatial factors that affect occupancy outcomes. Understanding which fine, local and landscape-level attributes influence nest box selection by wildlife can assist practitioners in refining nest box designs and placement in the field. We asked: Does entrance size, tree size and landscape context affect nest box occupancy? We monitored 144 nest boxes with six different entrance sizes (20, 35, 55, 75, 95 and 115 mm diameter), secured to individual trees of three sizes (small 20–50 cm DBH, medium 51–80 cm and large >80 cm) situated in four different landscape contexts with varying degrees of modification (reserves, pasture, urban parklands and urban built-up areas). We found that six common native and exotic species accounted for 89% of nest box occupancies. Entrance size had a significant effect on overall occupancy. Nest boxes with larger entrance sizes (115, 95, 75 and 55 mm) were occupied more ($\geqslant$77% of nest boxes occupied) than nest boxes with smaller entrance sizes (35 and 20 mm; $\leqslant$45% of nest boxes occupied). Tree size and landscape context had no significant effect on overall occupancy. However, multinomial analysis revealed that entrance size and landscape context affected occupancy by common fauna (i.e. species that occupied $\geqslant$5% of nest boxes). Nest boxes with small (20 and 35 mm), intermediate (55 and 75 mm) and large (95 and 115 mm) entrance sizes were predominately occupied by the European honey bee *Apis mellifera*, common exotic (e.g. common myna *Acridotheres tristis*) and native birds (e.g. eastern rosella *Platycercus eximius*), and the common brushtail possum *Trichosurus vulpecula*, respectively. Nest boxes in reserves and pasture had near equal occupancy by common fauna while nest boxes in urban parklands and urban built-up areas were predominately occupied by the common brushtail possum and the European honey bee. Establishing nest boxes with different entrance sizes could maximise occupancy by a variety of common hollow-nesting species. Targeting occupancy by some species requires consideration of landscape context but not tree size. Nest boxes were predominately occupied by a few common native and exotic species, suggesting that nest boxes may not be highly effective management and biodiversity offset tools for rare and threatened taxa in modified landscapes. Management policies and practices aimed at avoiding the loss of large, hollow-bearing trees must be prioritised.

1. Introduction

Tree hollows (or cavities) are a critical habitat resource for fauna globally (Gibbons and Lindenmayer, 2002; Cockle et al., 2011). Hollows provide shelter and breeding opportunities for mammals (Lindenmayer et al., 1990), birds (Newton, 1994), reptiles (Webb and Shine, 1997), and invertebrates (Ranius, 2002). In modified landscapes worldwide (e.g. agricultural land, production forests and urban environments), human activities, such as land clearance, logging and managed tree removal, have facilitated the decline of large, hollow-bearing trees (Gibbons et al., 2010; Lindenmayer et al., 2012; Le Roux et al., 2014b; McIntyre et al., 2015). Reduced availability of hollow-bearing trees can have serious conservation implications for hollow-using fauna, especially for obligate hollow-nesters that may face population bottlenecks

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and extinction (Cockle et al., 2010; Manning et al., 2012). Time lags associated with hollow formation mean that some management strategies aimed at arresting hollow decline (e.g. increasing tree recruitment) will be unable to alleviate short-term deficits in hollow availability (Gibbons et al., 2008; Manning et al., 2012; Le Roux et al., 2014b). Nest boxes offer an alternative management strategy that bypasses the time needed for hollows to form naturally, potentially providing immediate benefits for hollow-using species (Lindenmayer et al., 2009; Berthier et al., 2012).

In some cases, the recovery of hollow-nesting animal populations has partly been attributed to nest box additions (e.g. southern flying squirrels *Glaucomys volans* in logged plantations; Taulman et al., 1998; see also Goldingay et al., 2015). However, in many other cases, the efficacy of nest box programs remains questionable and controversial because of low occupancy rates and exploitation by non-target fauna (Grarock et al., 2013; Priol et al., 2014). A further limitation of nest box programs is the rapid rate of nest box attrition due to damage and decay of materials. Lindenmayer et al. (2009) found that most nest boxes had decayed and fallen from trees within ten years limiting long-term effectiveness for the critically endangered Leadbeater's possum *Gymnobelideus leadbeateri*. In contrast, natural hollows likely persist over much longer time periods (Gibbons et al., 2000; Ranius et al., 2009; Lindenmayer et al., 2015). A further limitation for practitioners is the high financial costs that may be associated with nest box construction, monitoring and maintenance (McKenney and Lindenmayer, 1994). These studies highlight that nest box programs supplementing natural hollows over large areas, long time periods, and for threatened species, can be exceptionally challenging to implement.

Despite the limitations outlined above, nest boxes are increasingly being employed as an engineering 'solution' to compensate for the loss of large, hollow-bearing trees removed due to human activities (e.g. Goldingay and Stevens, 2009; Roads and Traffic Authority, 2011; Peste et al., 2015). However, before nest boxes can be used effectively as a management and biodiversity offset tool, it is imperative to first identify ways of improving nest box design and placement in the field. Goldingay et al. (2015) recently highlighted that refinements to nest box design could limit nest box use by pest fauna and improve nest box occupancy by some threatened species over a 10 year period. Previous research studies, predominately undertaken in Europe and North America, have found that nest box selection by fauna (mostly birds) can be affected in complex ways by a variety of fine, local, and landscape-level attributes (e.g. Herlugson, 1981; Finch, 1989; Blem and Blem, 1991; Bortolotti, 1994; Bolton et al., 2004; Ardia et al., 2006; Smith et al., 2007; Lambrechts et al., 2010; Björklund et al., 2013). By comparison, fewer Australian studies have empirically tested whether species show a preference for specific nest box designs and placement (e.g. Menkhorst, 1984; Smith and Agnew, 2002; Harper et al., 2005; Goldingay et al., 2007, 2015; Durant et al., 2009; Lindenmayer et al., 2009, 2015; Rueegger et al., 2013). More studies are still urgently needed to investigate nest box selection by fauna and, in doing so, also evaluate whether nest box programs can effectively achieve applied conservation objectives.

In this study, we asked: Does entrance size, tree size, and landscape context affect nest box occupancy? These spatial factors were investigated because they can be relatively easily manipulated at the construction and installation phase of nest box programs to potentially influence on-the-ground occupancy outcomes. We tested five predictions (see Table 1): (1) nest boxes with larger entrance sizes will be occupied more than nest boxes with smaller entrance sizes; (2) nest boxes with larger and smaller entrance sizes will be occupied by proportionally larger and smaller-bodied animals, respectively; (3) nest boxes secured to small and medium sized trees, which support fewer natural hollows, will be occupied more than nest boxes secured to large trees, which support more natural hollows; (4) nest boxes placed in modified landscapes, which support fewer hollow-bearing trees, will be occupied more than nest boxes placed in a semi-natural landscape, which supports more hollow-bearing trees; and (5) common adaptable native and exotic species will occupy more nest boxes placed in modified landscapes than nest boxes placed in a semi-natural landscape.

2. Materials and methods

2.1. Study area

We conducted our study in Canberra, Australian Capital Territory (ACT), southeastern Australia. Canberra (covering an area of approximately 810 km^2) is located in a fragmented landscape comprising: urban areas supporting 375,000 people; agricultural land for livestock grazing; and 34 nature reserves managed for conservation (ACT Government, 2011). Land clearance for farming and

Table 1
A summary of study predictions and ecological justifications underpinning these.

Factor	Prediction	Ecological justification
Entrance size	(i) Nest boxes with larger entrance sizes will be occupied more than nest boxes with smaller entrance sizes	Small hollows tend to be naturally more abundant than large hollows and may thus be in less demand by fauna (e.g. Gibbons et al., 2002; Le Roux et al., 2014a). Larger hollows are also likely to be accessed by more species than smaller hollows (e.g. Gibbons and Lindenmayer, 2002)
Entrance size	(ii) Nest boxes with larger and smaller entrance sizes will be preferentially occupied by large and small-bodied animals, respectively	Animals tend to occupy hollows with entrance sizes proportional to their body size to minimise risk of predation, reduce competition at nest sites, and because hollows are of a size that is accessible (e.g. Beyer and Goldingay, 2006; Goldingay and Stevens, 2009)
Tree size	(iii) Nest boxes secured to small (20–50 cm DBH) and medium sized trees (51–80 cm DBH), which support fewer natural hollows, will be occupied more than nest boxes secured to large trees (>80 cm DBH), which support more natural hollows	The number of hollows available at a tree can affect the likelihood of hollow occupancy (e.g. Gibbons et al., 2002; Koch et al., 2008)
Landscape context	(iv) Nest boxes placed in modified landscapes (pasture, urban parklands, urban built-up areas), which support fewer hollow-bearing trees, will be occupied more than nest boxes placed in a semi-natural landscape (reserve), which supports more hollow-bearing trees	The number of hollow-bearing trees available in the landscape can affect the likelihood of hollow occupancy (e.g. Smith and Agnew, 2002; Cockle et al., 2010)
Landscape context	(v) Common adaptable native and exotic species will preferentially occupy nest boxes placed in modified landscapes than nest boxes placed in a semi-natural landscape	Introduced exotic pest and common native species tend to be tolerant of human disturbance and have a high propensity to persist in modified landscapes and exploit limited resources (Lindenmayer et al., 2009; Grarock et al., 2013)