A comparison of the roosting behaviour of Gould's wattled bats *Chalinolobus gouldii* using bat boxes and tree hollows in suburban Melbourne

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ABSTRACT

Bats in suburban areas face a number of challenges adapting to what is a highly altered landscape. This is particularly true for species that prefer tree hollows for day roosts because the large, old trees that have developed suitable hollows are often removed from suburban areas. In suburban Melbourne, Victoria, Australia, during the last ten years, nest boxes have increasingly been used to provide additional roosts for bats in suburban parkland and remnant forest. However, little is known of the relative use of natural hollows and bat boxes, or whether the addition of new roosts may alter roosting behaviour. The types of resources available to bats may influence their roosting behaviour and have consequences for social interactions, predation risk and parasite loads. At Gresswell Nature Conservation Reserve, in the northern suburbs of Melbourne, there are both natural hollows and bat boxes available to a population of Gould's wattled bat *Chalinolobus gouldii*. This study investigated the relative use of the two roost types to determine if there were intra-specific differences in roost-use. We used radiotelemetry to locate the roost sites of six males and nine females from January until March 2007; all bats were initially caught while roosting in bat boxes. Roosts were subsequently found in 12 bat boxes and 10 tree hollows. Both sexes used tree hollows and bat boxes, and there was no apparent preference by either sex for either roost type. Individuals moved between the two roost types, indicating the boxes had been incorporated into the overall roosting resource available to the bats. Roost fidelity was variable, with some individuals regularly shifting roosts while others continued to use the same roost for up to 14 days. Bats using boxes shifted to new roosts significantly less often than when in hollows. The roost shifting behaviour of individuals using tree hollows in this study was very similar to that shown by *C. gouldii* using tree hollows in two previous studies in the rural landscape of northern Victoria.

Key words: microbat, *Chalinolobus gouldii*, Gould's wattled bat, roosting behaviour, roost switching, radio telemetry, nest box, tree hollow, urban wildlife

Introduction

Suburbia, the highly modified habitat of choice for so many Australians, still supports populations of some native fauna (Harper *et al.* 2005; Rhodes and Wardell-Johnson 2006; van der Ree and McCarthy 2005). This fragmented landscape presents many barriers to terrestrial and arboreal species (Andren 1994), in the form of roads, buildings and open recreational spaces (Rudd *et al.* 2002), but those animals capable of flight may have an advantage. For example, of the 21 species of microbats (herein referred to as bats) found in Victoria, 16 are found in suburban Melbourne (Department of Sustainability and Environment, Atlas of Victorian Wildlife). Bats are widespread in Melbourne, especially in areas that have remnant native vegetation and parkland with hollow-bearing trees. Hollows can provide protection from predators which is particularly important in the suburban setting where there are high densities of exotic predators including the house cat (*Felis catus*) and black rat (*Rattus rattus*) (Baker *et al.* 2005). Secure day roosts are a vital resource for bats, but their availability is limited by anthropogenic activity (Kunz and Lumsden 2003). The development and expansion of Melbourne since the 1830s has resulted in extensive clearing of the original native vegetation, including hollow-bearing trees.

The installation of wooden nest boxes is often used to increase the availability of hollows for native fauna (Harper *et al.* 2005; Irvine and Bender 1997; Lindenmayer *et al.* 2003; Menkhorst 1984). However, limited knowledge of hollow-use often restricts the ability to provide appropriate substitutes as well as plan for future habitat conservation (Beyer and Goldingay 2006). While recognising that nest boxes are a relatively artificial environment (Moller 1994), they also provide a tool to study species that are largely inaccessible when in tree hollows (Brady *et al.* 2000; Christe *et al.* 1994; Menkhorst 1984; Shilton 1993; Ward 2000).

Supplementing natural roosts with nest boxes may enhance habitat and aid in the establishment or expansion of populations of native fauna (Beyer and Goldingay 2006). Bats make use of more than one roost and often move frequently between roosting sites (Lewis 1995). Therefore, adding additional roosts to an area may influence the way in which bats make use of the natural roosts and their roost fidelity. Roost shifting behaviour of bats is thought to be influenced by aspects of the roost such as microclimate, protection from predators, and the level of parasite infestation (Lewis 1995).

Little is known of the roosting behaviour of bats using nest boxes compared to when using tree-hollows in the same area, and whether there are intra-specific differences in the relative use of the two roost types. To our knowledge, this is the first published study to investigate these differences. Using radiotelemetry, we investigated the roosting behaviour of Gould's wattled bat *Chalinolobus gouldii* using nest boxes and tree hollows in a remnant forest patch in suburban Melbourne, Victoria. These data are then compared with the most extensive available data on the roosting ecology of this species, from rural landscapes of northern Victoria (Lumsden 2004; Lumsden *et al.* 2002a; Lumsden *et al.* 2002b), to explore possible variability in the behaviour of the species in different environments.

Methods

The Gresswell Nature Conservation Reserve (Gresswell NCR) is a 52 ha remnant forest reserve within suburban Melbourne, 13 km north-east the city centre (*Latitude:* −37.72, *Longitude*: 145.05). It is managed by La Trobe University, and is surrounded by moderate density suburban housing (Figure 1). The vegetation is dominated by river red gum *Eucalyptus camaldulensis* grassy woodland, a vegetation type that was once widespread in this region but is now severely depleted (Carr 1983). The site has a history of agricultural use prior to 1907, and firewood collection until it was fenced in 1980. These activities have degraded the area and depleted the number of large, hollow-bearing trees (Ambrose 1982). Intensive revegetation efforts have restored much of the understorey, and to compensate for the limited number of hollows, a large number of nest boxes have been installed over the last ten years. Twenty-eight of these boxes have been designed specifically for bats. The most common design at the site (and the most frequently used by bats) is a two-chambered box with an open base (Figure 2). The external dimensions are approximately $60 \times 20 \times 12$ cm. The internal dimensions of each chamber are $45 \times 15 \times 2$ cm and each entrance is 15×2 cm.
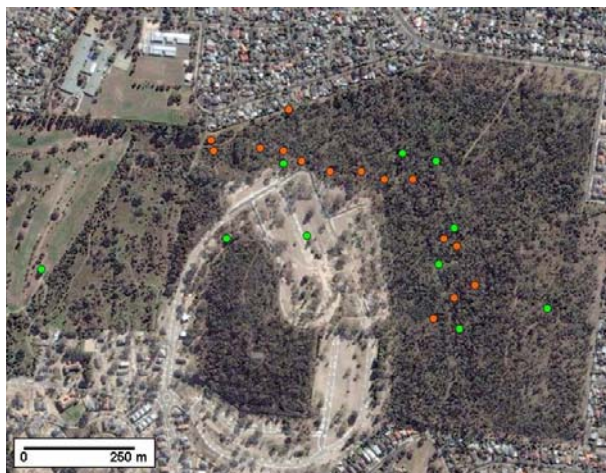

Figure 1. An aerial view of Gresswell Nature Conservation Reserve, Bundoora, Victoria, Australia, with the location of known *Chalinolobus gouldii* roosts in tree hollows (green) and bat boxes (orange). Photo taken in 2006. (Image courtesy of GoogleTM Earth 2007 v 4.0.2742)

Chalinolobus gouldii is the species that most frequently uses the bat boxes at Gresswell NCR. This species is common throughout most of Australia, and uses a wide range of habitat types (Churchill 2008). In suburban Melbourne, it is often the first species to colonise nest boxes (R. Bender pers. comm.).

Figure 2. Bat roosts located with radiotelemetry at Gresswell Nature Conservation Reserve, Bundoora, Victoria; a) a bat-specific nest box used by a male Chalinolobus gouldii; b) a natural tree hollow roost in a dead spout (indicated by the arrow) in a *Eucalyptus camaldulensis*, used by a single female *C. gouldii*.

In January and February 2007, immediately following the breeding season for *C. gouldii*, 15 adult bats were collected, during the day, from nest boxes within the reserve. The six male and nine female *C. gouldii* (testes-abdominal and post-lactating respectively) were fitted with LB-2, 0.6 g radio transmitters (Holohil Systems Ltd, Ontario, Canada), which weighed less than 5% of the bat's body mass (13–17 g), as recommended by Aldridge and Brigham (1988). After trimming a small patch of fur just below the shoulder blades, the transmitters were glued directly onto the skin using Skin Bond (Smith and Nephew, Australia) (Figure 3). Animals were then released at dusk into Gresswell NCR. Animals were tracked until the radio transmitter failed or was groomed off (mean of 9.2 ± 1.0 days, range 3–15 days). The diurnal roost of each individual was located each day that the transmitter remained attached, by searching the area on foot with a hand-held receiver (TR2 Telonics, Mesa, Arizona, U.S.A.). The number of individuals using each day roost was determined by watching the bats emerging from the roost at dusk for tree roosts (for at least 20 mins after the emergence of the first bat, or until it was too dark to make observations), and by a visual count of bats in bat boxes just prior to emergence, by shining a torch up into the box from the ground. The individuals present in most

roosts were counted each evening. Not all roosts could be watched each night due to limited resources, but all roosts were watched at least once. To determine if the transmitters were still attached to the bats, all individuals were located foraging after dusk. The position of each roost was determined by ortho-rectified aerial images. This enabled distances between roosts to be calculated. Roosts that were close-by (< 150 m) were measured manually using a hip-chain (cotton spool and distance counter).

Figure 3. A *Chalinolobus gouldii* fitted with a radio transmitter (Holohil LB-2). Fur has been trimmed to allow firm attachment to skin using Skin Bond cement.

In addition to locating day roosts, we also attempted to identify foraging ranges and night roosts. Five males and five females of the 15 that were radio-tracked were followed for eight nights. To ensure that the foraging data were representative of the entire night, we determined the approximate position of each bat (based on the strength and direction of the transmitter signal, using a single antenna, after calibrating the signal intensity with stationary individuals during the day). This was undertaken at one of four time periods each night: 2100 h (between 0.5 and 1 h after the average emergence time), 2300 h, 0100 h or 0300 h (soon before dawn). By the end of the tracking period there were two fixes for each of the four time periods for each individual.

To investigate the influence of parasite load on roost fidelity, we incorporated data from a parallel study examining the parasite loads of bat boxes in Gresswell NCR (L. Evans unpublished data). Combining these data with the roost shifting data from the bat box roosts only, enabled us to test the hypothesis that a higher number of parasites in the roost would reduce the number of days a bat would spend in that roost. It was not possible to examine closely the tree hollow roosts due to their inaccessibility, as they were high in the tree and typically situated in the outer branches. Parasite loads in the bat boxes were recorded by counting the number of ticks (*Argas dewae*) and bat fly pupae (*Basilia troughtoni*), both of which are known to parasitise *C. gouldii*, and spend at least part of their life cycle within the roost (unlike spinturnicid mites that are located permanently on the animal). Parasite loads were estimated when the bats were first removed from the boxes and again after tracking was complete. These two observations of parasite load were averaged for each box to provide an estimate for parasite load over the tracking period. The boxes fell into two categories: high parasite load boxes (10–14 bat parasites) and lower load boxes (0–3 parasites). The movement patterns of bats were then compared for those animals using boxes with high and low parasite loads using a *t*-test. The parasite load of each bat at capture was tested for the effect on its subsequent roosting behaviour.

Bat parasite loads were divided into three categories that were calculated from a population-wide parasite survey. Three parasites were considered: ticks, bat flies and mites (*Spinturnix novaehollandiae*). The categories included: high (at least two of the three parasite types at a mean infestation level or higher, or at least one type at the high level); mean (one parasite type at a mean level); low (below average load for all parasites).

We used MINITAB® 2004 (v14.12.0) for statistical analyses. For comparisons of behaviour between the sexes and comparative use of the two roost types we used two-tailed *t*-tests and Fisher's exact tests. For the effect of disturbance on roost-shifting behaviour we used Grubb's test for outlier data. We performed a Mann Whitney rank-sum *U*-test to analyse the influence of sex on group size and to analyse distances travelled while foraging. ANOVAs were used to examine other aspects of foraging behaviour, roost shifting frequencies and the distances between roosts. Additionally we compared the roost shifting frequencies based on parasite load using the Kruskal-Wallis test for non-parametric data. For all tests, a 0.05 significance level was applied. Mean values are given ± s.e. except where indicated.

Results

Day roosts

We located 22 day roosts used by bats during the 138 bat tracking days between January and March 2007 (Table 1). Of these, 10 were in tree hollows and 12 in bat boxes. Five of these box roosts were boxes in which the bats had initially been captured, and to which they subsequently returned. The majority of these roosts were within Gresswell NCR, but some bats also used tree hollows and bat boxes in an adjacent golf course and in nearby private suburban backyards (Figure 1). All roosts in tree hollows were in *E. camaldulensis,* with 70% of these in dead spouts in large live trees (Figure 2). The remaining three roosts were: in a central, vertically opening hollow in a live tree, used by a solitary female; in a hollow in a major branch of a large tree (> 1 m DBH [diameter at breast height]), used by a solitary female; and under loose bark on a small stag (< 30 cm DBH), used by a solitary male.

Over half (60%) of the bats used only one type of roost (box or hollow) during the tracking period, the majority of these individuals (six of nine) only used bat boxes. All individuals tracked to tree hollows were found to be roosting solitarily, while those found roosting in boxes were either solitary or in groups of up to 10 individuals, with individuals roosting in a group on 48% of days they used a box.

There were no significant differences between the sexes in their use of the two roost types, their roost fidelity or grouping behaviour (Table 2). Females roosted both solitarily and in groups of up to 10 individuals, while males predominantly roosted alone or with one or two other individuals. The median colony size, calculated from the range of means generated for individuals, was 2.1 ± 0.4, *n* (number of individuals) = 15, *n* (number of radio-tracking days) = 138, and there was no significant difference between the sexes. Similarly, there was no difference in the frequency at which the two sexes were found roosting alone (Table 2).

Combining the sexes, the mean number of consecutive days individuals spent in a roost before shifting to a new one was 4.6 ± 0.7 days. Individuals, on average, remained in the same roost for significantly longer when roosting in boxes than in tree hollows (box: 6.8 ± 1.4 days, *n* (individuals) = 12, *n* (days) = 93; hollow: 2.6 ± 0.9 days, *n* (individuals) = 8, *n* (days) = 45; $t = 2.60$, df = 21, $p = 0.017$). Three individuals (two females and one male) did not switch roosts during the period they were tracked (10–14 days): all three were using boxes. The male roosted alone throughout this time, one female was always in a group of four or more individuals and the second female was either alone, roosting with individuals of another bat species (white-striped freetail-bat *Tadarida australis*) or with one other *C. gouldii*.

Since disturbance is often considered a factor that influences roost shifting behaviour (Lewis 1996), we examined the number of bats that shifted to a new roost after the initial capture (which involved removing them from their roost). The majority of animals (10 of 15) moved to a new roost the day after capture and the sexes responded in a similar way (7/9 females and 3/6 males switched). There was a significant effect of disturbance with a higher proportion of animals shifting to a new roost on the first day (0.67) than on any subsequent day (0.15 ± 0.04) (Figure 4) (Grubb's test for outliers, $z = 2.56$, $p < 0.05$).

Roosting behaviour was also influenced by parasites. Bats using low parasite load boxes remained in roosts for longer (low box load: 10.4 ± 1.5 days, *n* (individuals) = 7, *n* (days) = 65; high box load: 3.4 ± 1.1 days, *n* (individuals) = 5, *n* (days) = 29; $t = 2.31$, df = 8, $p = 0.006$). There was also a trend for individuals to increase the rate at which they shifted roosts when they carried more parasites (Figure 5), but this was not statistically significant (Kruskal-Wallis test: $H = 5.54$, df = 2, $p = 0.063$).

When *C. gouldii* individuals shifted roosts, the distance to the next roost varied from 23 m to 720 m, with bats traveling a similar distance to reach either a new box or tree hollow (box: 225 ± 61 m; hollow: 223 ± 57 m; $t = 0.03$, df = 17, $p = 0.978$). Females moved greater

Table 1. Summarised roosting data for the fifteen *Chalinolobus gouldii* individuals radio-tracked in and around a suburban reserve from late January to March 2007. Mean group sizes are provided with se where a roost was used on more than one occasion.

Individual	Sex	Roost use		Group size		Tracked at night	Total days radio-tracked
		# tree roosts	# box roosts	Tree roost	Box roost		
689BB20	F	2	1	1.0 ± 0.0	4.0	Yes	7
68301F7	F	1	0	1.0 ± 0.0	–	Yes	3
68B0AD2	F	1	1	1.0 ± 0.0	na	No	3
68352CA	F	0	1	–	1.0 ± 0.0	Yes	3
689E878	F	2	0	1.0 ± 0.0	–	No	10
689D087	F	1	1	1.0 ± 0.0	7.5 ± 1.5	No	12
683280A	F	0	2	–	5.0 ± 0.6	Yes	11
6899E9C	F	0	1	–	5.0 ± 0.4	Yes	10
68B993A	F	0	1	–	2.3 ± 0.8	No	13
682D420	M	1	0	1.0 ± 0.0	–	Yes	8
6836154	M	0	2	–	1.6 ± 0.4	Yes	9
6832D28	M	1	1	1.0 ± 0.0	1.5 ± 0.3	No	9
683CD87	M	1	1	1.0 ± 0.0	1.0 ± 0.0	Yes	15
6836684	M	0	2	–	2.0 ± 0.4	Yes	11
689A43A	M	0	1	–	1.0 ± 0.0	Yes	14

Table 2. The relative use of tree hollows and bat boxes as day roosts and a comparison of roosting behaviour between the sexes for *Chalinolobus gouldii* in Gresswell Nature Conservation Reserve, Melbourne, Victoria during January–March 2007.

Roosting behaviour	Males	Females	*p*
Number of individuals tracked	6	9	
Tree hollows used	3	7	0.45[+]
Bat boxes used	7	6	
Median number of individuals in roost	1.17	1.80	0.29*
Median proportion of time spent roosting alone	0.80	0.00	0.09*
Roost fidelity (days) (μ ± s.e.)	6.10 ± 1.3	3.79 ± 0.8	0.14[^]

[^] 2-tailed *t*-test; [+] Fisher's exact test; * Mann-Whitney *U*-test

distances between consecutive roosts than males (female: 250 ± 43 m, male: 112 ± 43 m; t = −2.24, df = 9, p = 0.05, n (individuals) = 15, n (days) = 138). Only 8% of female roosts were within 100 m of the previous roost, while 50% of male roosts were within this range (Figure 6).

Night roosts

All observations of night roosting behaviour occurred between 0100 h and 0200 h. Four individuals were recorded in night roosts. Two females used separate live *E. camaldulensis* trees; both located approximately 400 m from the Gresswell NCR boundary and about 450 m from their day roost. These night roosts were not used by these females as day roosts during the tracking period. Two males were recorded roosting in bat boxes that they also used as day roosts.

Foraging areas

Of the ten individuals tracked at night to determine foraging areas, there was insufficient data on two females

to include them in the analysis. The majority of the successfully tracked individuals (six out of eight) remained within 1.5 km of their day roost. All but one of these six individuals were located on each of the sampling periods over the eight nights of tracking, regardless of the time of night. The other individual (a male) was located on 50% of occasions. Males tended to forage closer to their day roosts than females, but this was not statistically significant (Mann-Whitney U-test: male median: 0.5 km (0.44–0.54 km), female median: 1.2 km (0.53–1.35 km; p = 0.07; n (individuals) = 8, n (nights) = 63). The apparent difference between male and female foraging distances was influenced by two females that, on one occasion, traveled together for at least 7 km from their roosting area, before returning to the same day-roost in Gresswell NCR the following morning. Males and females also spent proportionately different amounts of time foraging inside and outside the reserve. Males spent roughly equal proportions of time foraging inside the reserve as outside (inside: 0.53 ± 0.07 of the observations
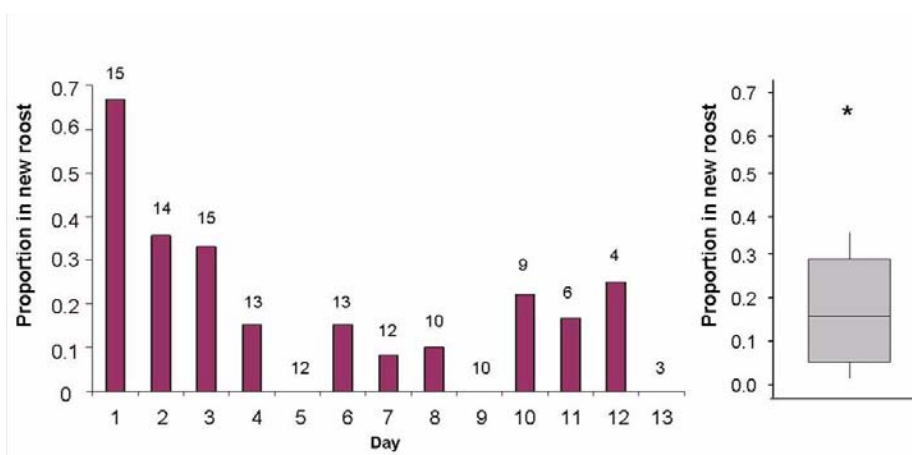

Figure 4. The proportion of individual *Chalinolobus gouldii* that shifted roosts each day during the tracking periods of January–March 2007, when using either tree hollows or bat boxes in the suburban forest remnant, Gresswell Nature Conservation Reserve in Melbourne, Victoria. The sample size is shown above the columns. The box plot illustrates the significant outlier which was day one.
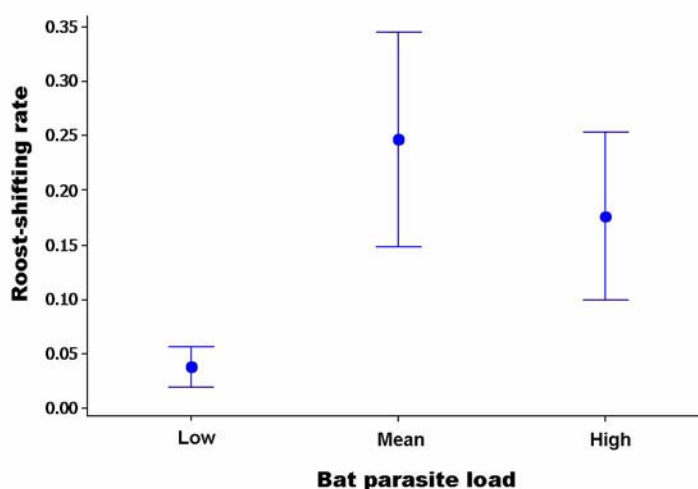

Figure 5. The effect of the parasite load of *Chalinolobus gouldii* on their roost-shifting behaviour when using tree hollows and bat boxes during January–March 2007 in Gresswell Nature Conservation Reserve, Victoria, Australia. Roost shifting rate is the number of roost changes/number of tracking days. The mean ± s.e. is shown for each level of parasite load the bats were carrying.

for males; outside: 0.42 ± 0.10), while females foraged outside the reserve more often than inside (outside: 0.81 ± 0.03; inside: 0.19 ± 0.31) and also spent proportionately more time outside the reserve than did males (ANOVA, $F_{1,6}$ = 8.01, p = 0.03, n (individuals) = 8, n (days) = 63).

Discussion

Roosting behaviour

Chalinolobus gouldii made equal use of natural tree hollows and artificial roosting boxes in Gresswell NCR and the surrounding area. Some individuals used both types of roosts, while others roosted in only one type during the tracking period, with more of these individuals just using boxes. However, as all individuals were initially trapped within bat boxes, there is a possible bias towards individuals roosting in boxes. Individuals moved between roosts in boxes and hollows, indicating that the boxes have been successfully incorporated into the roosting resources available to this population. At the three sites in suburban Melbourne where a large number of bat boxes have been established and are regularly checked, up to six species have been recorded but *C. gouldii* is dominant, representing over 90% of captures (L. Evans, pers. obs.; Robert Bender pers. comm.). It is possible that the provision of additional roosting opportunities has enabled populations of this species to enlarge, but we have no data on abundance prior to the installation of boxes to test this.

When roosting in tree hollows *C. gouldii* appears to be consistent in its choice of roost types. In this and in two studies in northern Victoria (Lumsden *et al.* 2002a; Lumsden 2004), the majority of roosts located for both sexes of *C. gouldii* were in dead spouts on large, live trees. Our finding of a male roosting under loose bark on a small stag for seven consecutive days is unusual, as none of the 150 *C. gouldii* tree roosts located in northern Victoria were under bark – all were in enclosed hollows (Lumsden *et al.* 2002a; Lumsden 2004).

Bats roosting in boxes were found in groups of up to 10 individuals; while in contrast, all individuals using natural hollows roosted alone. Elsewhere, colony sizes in tree hollows typically average nine individuals, although some individuals, more often males than females, will roost alone (Tidemann and Flavel 1987; Lumsden 2004). Colony size varies seasonally, with maternity roosts typically housing larger colonies (Lumsden 2004). All individuals in this study were tracked soon after the breeding season. Compared to other sites in Melbourne, where maternity colonies are formed in bat boxes, at Gresswell NCR, *C. gouldii* has rarely been recorded forming maternity colonies in boxes (L. Evans, pers. obs.). At this site, maternity colonies have been observed only while the females were pregnant or very late in lactation, not during the birthing and early lactation period. It is not known where females in this population form maternity colonies, but they may be in tree hollows or possibly in buildings. *C. gouldii* is known to form maternity colonies in buildings elsewhere in suburban Melbourne (Dixon and Huxley 1989).

Chalinolobus gouldii followed a similar pattern to many tree-roosting species in being faithful to a roost area while shifting roost sites on a regular basis within that area (Kunz and Lumsden 2003). When roosting in tree hollows, individual *C. gouldii* spent an average of 2.6 consecutive days in a roost before shifting to a new one. This is consistent with studies in northern Victoria, where individuals in a fragmented rural landscape spent on average 2.5 ± 0.2 days in a roost, and those in an extensive forested area (Barmah forest) 2.0 ± 0.1 days (Lumsden 2004). In addition, the mean distance between consecutive roosts of 225 m in our study was similar to the distances moved between roosts in northern Victorian fragmented farmland (192 ± 40 m) and in extensive forest (189 ± 19 m, Lumsden 2004). The consistency of these aspects of behaviour when roosting in tree hollows in differing landscapes suggest either a consistent advantage to frequently shifting between consecutive roosts that are
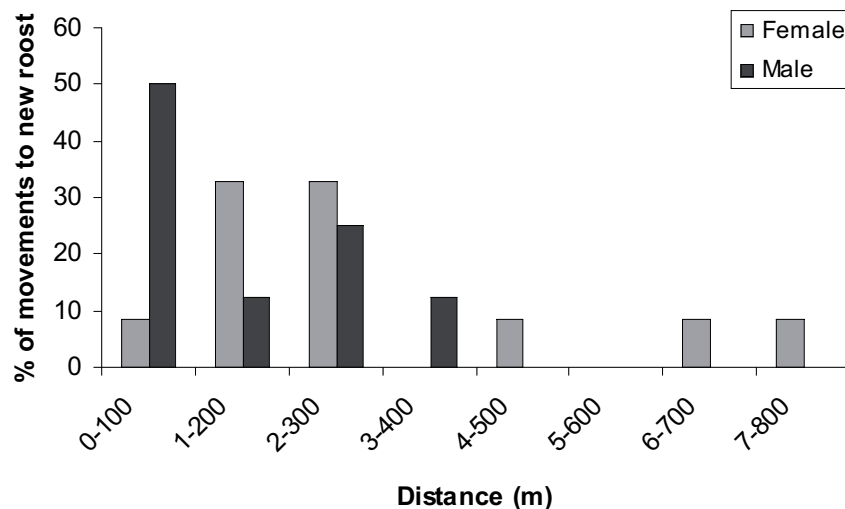

Figure 6. The distance between consecutive roosts for *Chalinolobus gouldii* moving to a new roost during January - March 2007 in a suburban reserve in Melbourne, Victoria. Males (dark grey) and females (light grey) are shown separately.

close by, or a potential cost from them being at greater distances. Further studies are needed to identify these benefits and/or costs.

When roosting in bat boxes, however, *C. gouldii* remained faithful to roosts for a significantly longer period than when roosting in tree hollows, moving on average every 6.8 days. As this was during the same time period, in the same area and often the same individuals, it suggests there is something intrinsically different in the roosting resource provided by the two roost types. The frequency at which individuals change roosts is likely to be influenced by a range of factors: predation risk, disturbance, social interactions, parasite load, the ephemeral nature of roosts and the need to find an appropriate microclimate (Lewis 1995). We were unable to test for possible variables to explain the differences between tree hollow and box roosts because of the inaccessibility of the tree hollows.

There was evidence that disturbance influenced the behaviour of *C. gouldii*. Individuals shifted to a new roost significantly more often on the day after disturbance (i.e. when captured in their roost and fitted with a radio transmitter) than during the remainder of the tracking period (67% vs. 15% of individuals shifted roosts). This may be evidence for roost shifting as a mechanism for predator avoidance, but this does not explain the lower roost shifting frequency observed for animals using bat boxes. It is assumed that animals that shift when disturbed are less likely to be detected and consequently be disturbed or threatened in the future (Lewis 1995).

Parasite loads are frequently suggested as a factor influencing roost fidelity, although only a few studies have tested this theory (Bartonicka 2007; Lewis 1996; Patterson *et al.* 2007; Reckardt and Kerth 2007). The bat boxes in this study had been installed eight years prior and, over this time, a significant population of parasites had accumulated, specifically ticks and the pupae of bat flies, which use cracks in the box and attach to the walls of the box respectively. We found that parasite loads in bat boxes were negatively correlated with the length of time that *C. gouldii* remained in a roost. Individuals using boxes with low parasite loads (0–3 parasites) continued to return to the same roost for a significantly longer period (average of 10 days) than those using high load boxes (10–14 parasites; three days). It is possible that by spending less time in a high parasite load environment a bat could reduce the number of parasites it carries and the associated energetic costs (e.g. Giorgi *et al.* 2001; McKilligan 1996). Studies of bats using boxes in Europe have shown that the number of parasites in a roost can influence the rate of roost shifting in their host (Bartonicka 2007; Patterson *et al.* 2007). Conversely, the roost shifting behaviour of bats can act as a control mechanism to slow the reproductive effort of their parasites (Bartonicka and Gaisler 2006; Reckardt and Kerth 2007).

Male and female *C. gouldii* showed little variation in roosting behaviour in this study. However, additional data from this population (L. Evans unpublished data) suggest that males have a higher roost fidelity than females. There may be a level of roost defense by males, which has been recorded for several bat species (McCracken and Wilkinson 2000), but this has not been

investigated for *C. gouldii*. Males were not significantly more likely to roost on their own than were females, however they tended to roost in smaller groups. The only significant difference in the roosting behaviour between the sexes was that males used roosts that were closer together. The potentially greater use of bat boxes by males may have influenced this result as the boxes were established relatively close together.

Our opportunistic data on night roosting behaviour suggest *C. gouldii* make use of similar roosts during the day and night. In contrast, some species use very different types of roosts during the day and at night (Brigham 1991). Often these night-specific roosts are chosen if foraging areas are some distance from the day roost (> 4 km). Night roosts provide a place for rest, digestion, and protection from predators and inclement weather (Kunz 1982). Given that the foraging areas in this study were generally close to the known day roosts, it may be unnecessary for individuals to select new roosts outside this area to be used as night roosts.

Foraging behaviour

We located individuals foraging throughout the night over multiple nights so we believe we have an accurate representation of their foraging areas at the time of this study. Most of these radio-tracked individuals foraged within 1.5 km of their day roost, behaving similarly to *C. gouldii* roosting in highly fragmented remnant vegetation in rural northern Victoria. Those individuals typically roosted 1 km from their capture site, which was assumed to represent one of their foraging areas (males 0.94 ± 0.52 km, females 1.00 ± 0.50 km; Lumsden 2004). The bats in our study were located foraging both within and outside the boundary of the reserve, with females spending more time foraging outside the reserve than males. Some males in this population, including two of the males radio-tracked in this study, have been observed regularly returning to their day roosts at night (L. Evans unpublished data) so perhaps these males do not travel as far to forage as either females or males that use alternate night roosts. *C. gouldii* does have the potential to move much greater distances when foraging, as illustrated by the two females recorded 7 km from their roosts in this study, and one individual in Lumsden's (2004) study that foraged 21 km from its roost. Where habitats are patchy, individuals may travel greater distances to commute between optimal roosting habitat and optimal foraging habitat (Lumsden *et al.* 2002b). For example, in a study in northern Victoria individual *C. gouldii* roosted within an extensive area of continuous forest but travelled 4–11 km to forage in small remnants in the adjacent farmland (Lumsden *et al.* 2002b).

Chalinolobus gouldii is a relatively fast flying species that typically forages in the open spaces between the canopy of trees and along the edges of vegetation (Lumsden *et al.* 1994; O'Neill and Taylor 1986). It is possible that in both the highly fragmented farmland area and the suburban landscape, the proximity of edges allows bats to travel less to find suitable foraging sites. Bats are often recorded using edges and linear strips of vegetation as feeding areas (Brigham *et al.* 1997; Ekmen and de Jong 1996; Grindal and Brigham 1998; Grindal and Brigham 1999), which may be associated with the generally higher

abundance of insects around edges (Grindal and Brigham 1999; Lewis 1970). Therefore in a highly fragmented habitat, such as suburban Melbourne, *C. gouldii* may not need to travel long distances providing there are roosting sites close to suitable foraging habitat.

Conclusions and implications for management

From data collected in this study and the comparisons made with *C. gouldii* in rural northern Victoria (Lumsden *et al*. 2002a, 2002b; Lumsden 2004), it appears that roosting behaviour is consistent across widely differing environments. The roost-shifting pattern in suburban bats using natural tree roosts is similar to the pattern recorded for *C. gouldii* in tree hollows in both fragmented rural landscapes and in continuous forest. Similarly, the foraging behaviour of bats in fragmented habitats (farmland or suburbia) appears similar, suggesting that it is the remnant trees the bats are responding to and that the matrix between these trees may be less important. This contrasts with the impact of environmental alteration on other native fauna in Melbourne (van der Ree and McCarthy 2005), where changes in the matrix often have severe impacts on the behaviour and survival of individuals.

The introduction of bat boxes into the suburban environment may influence the roost shifting behaviour of *C. gouldii*. Individuals using boxes as day roosts returned to the same box for longer periods than when using tree hollows in the same area. Several variables may influence the use of bat boxes. Sex was not a significant predictor for the use of either roost type. Microclimate, predation risk, social factors, and parasite load may all influence roost-shifting behaviour, and in this study we have evidence to suggest parasite loads may influence patterns of use of boxes.

The addition of nest boxes is, in effect, increasing roosting resources and often, for logistical simplicity, concentrating them in a small area. This has the capacity to affect population dynamics of not only the target species, but also other fauna in the area. In this study area, and two others in suburban Melbourne where nest boxes have been installed, *C. gouldii* is by far the dominant bat species. If an increasing use of boxes over time represents a true increase in the population of *C. gouldii*, there may be impacts on other bat species and on prey species. Although there are a number of studies of the use of bat boxes by one or more bat species (Boyd and Stebbings 1989; Ciechanowski 2005; Dillingham *et al.* 2003; Kerth *et al.* 2001), we know of no studies that have investigated the effects of providing an artificial resource on local bat community dynamics. Monitoring whole communities, not just those using the boxes, pre- and post-box installation, should be an important component of the conservation effort to ensure our intentions are not misguided.

Acknowledgements

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