The use of bat boxes by insectivorous bats and other fauna in the greater Brisbane region

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ABSTRACT

Nest boxes are used world-wide to provide substitute nest sites for a range of hollow-dependent fauna. Most nest box studies are carried out in forested environments to determine whether nest boxes might be a substitute for the loss of hollows. Although nest boxes are popular in urban backyards, little scientific research has been conducted on nest box usage in urban environments in Australia.

The present study explored the use of bat boxes by insectivorous bats in urban Brisbane. Over the three-year study, bat box use in Brisbane increased steadily to over 80%. Five of the 22 hollow-using bat species in the Brisbane region were found in boxes during the study, but most boxes were used only occasionally. In Brisbane, boxes were more likely to be used if they were clustered in groups of at least six boxes within 50 m of one another, in areas with high grass cover within one kilometre, and in areas with high forest cover within five kilometres, especially small and medium sized forest remnants. Regardless of season, boxes of all types were always warmer and had a higher humidity than ambient microclimates. Box size and colour influenced internal microclimates, with unpainted boxes, and large boxes exhibiting greater temperature and humidity gradients during summer. However, bat box microclimates did not influence box choice by bats during this study.

Box acceptance and use by bats remains poorly understood. Acceptance could be influenced by multiple factors, such as landscape variables, natural hollow abundance, box design, locale climate at locations, microclimate inside boxes and the species' ecology. Further research is needed to understand the factors influencing box usage for each species as it is likely that some species have specialised roosting requirements.

While bat boxes have potential to play an important role in conservation and management of hollow-dependent bats, they usually only provide at best a temporary augmentation to natural roosts. Consequently, the primary management goal should be to preserve existing hollow-bearing trees.

Key words: hollow-dependent bats; bat boxes; urban Brisbane; bat box use; bat box microclimate; bat box design; conservation planning.

Introduction

Logging, farming and urbanisation are recognised world-wide as a threat to habitat components of a range of fauna, including hollow-bearing trees (Barclay and Brigham 1996, Gibbons and Lindenmayer 2002, Lindenmayer and Franklin 2002, Smith and Agnew 2002, Lunney 2004, Lunney and Burgin 2004). In south-east Queensland (SEQ), Australia, the number of hollow-bearing trees in many areas of public forest are below targets set by Queensland's Code of Practice for Native Forest Timber Production (Queensland Department of Natural Resources 1998). Furthermore, hollow-bearing trees in the greater Brisbane region, the largest urban area within SEQ, are under-represented in parklands, forest reserves and on private property alike (Rhodes and Wardell-Johnson 2006). Ongoing loss of natural hollows is likely to have significant and long-term impacts on Australian fauna. Over 300 native Australian vertebrate species use tree hollows for shelter (Gibbons and Lindenmayer 2002) and 127 of these occur in SEQ (Smith and Lees 1998). Of the 26 insectivorous bat species found in this region 22 are hollow-dependent (Churchill 1998, Van Dyck and Strahan 2008).

Nest boxes have been used as wildlife management tools world-wide and have been shown to maintain or increase populations of some species of birds and mammals (Thomas *et al*. 1979, Schemnitz 1980, Menkhorst 1984, Stebbings and Walsh 1985, Wardell-Johnson 1986, Tidemann and Flavel 1987, Tuttle and Hensley 2000, Smith and Agnew 2002, Harper *et al*. 2005a, Long *et al*. 2006). Nest boxes can also be used as a tool for studying the biology of hollow-using species, because they allow researchers access to nests that are otherwise difficult to reach (Menkhorst 1984, Gerell and Lundberg 1985, Nagel and Nagel 1988, Boyd and Stebbings 1989, Lundberg and Gerell 1996, O'Shea 1998, Park *et al*. 1998, Kerth *et al*. 2001).

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In metropolitan areas where hollow-bearing trees are limited (Holmes 1996, Harper *et al*. 2005b, Rhodes and Wardell-Johnson 2006), nest boxes might be the only source of hollows for wildlife populations and might, therefore, provide essential roosting habitat for insectivorous bats, enabling these species to persist in urban environments. In Europe and the U.S., bat boxes have been shown to provide suitable roosts for many bat species, especially where roost sites have became scarce (Stebbings and Walsh 1985, Schwarting 1994a,b, Dietrich 1998, Tuttle and Hensley 2000, Flaquer *et al*. 2006). Bats use nest boxes as solitary, dispersal, migration, mating, or maternity roosts (König and König 1995, Dietrich 1998) with the time each bat spends in boxes depending on its status as a transient, immigrant or resident bat (Boyd and Stebbings 1989). However, in many situations immigration into boxes by adults appears to be a minor source of recruitment; the majority of bats using boxes tend to be females born in the boxes and returning to reuse the boxes as maternity roosts (Boyd and Stebbings 1989, Brittingham and Williams 2000, Bender and Irvine 2001, Flaquer *et al*. 2006).

In Australia, there have been few systematic studies of the use of bat boxes (Golding 1979b, Bender and Irvine 1995, O'Shea 1998, Bender and Irvine 2001, Smith and Agnew 2002, Bender 2005). While some useful information is available on design, construction and placement of nest boxes in Australia, little attention has been paid to outcomes (Gibbons and Lindenmayer 2002); most studies are descriptive and there has been little discussion of landscape factors which might contribute to occupancy rates (Smith and Agnew 2002). Also lacking in Australia are comparisons of different bat box designs and species usage. In general, most Australian bat box designs have been adapted from those used in the northern hemisphere (Stebbings and Walsh 1985, Tuttle and Hensley 2000). However, roosting requirements of northern hemisphere bats might differ to that of Australian species due to their long evolutionary history of roosting in trees with different cavity characteristics. For example in the northern hemisphere, cavities are found in conifer and deciduous trees and snags compared to cavities in large eucalypts in Australia (Kunz and Lumsden 2003). In nature, competition for available roost space has resulted in species exhibiting preferences for roost sites with markedly different physical dimensions and other parameters (Menkhorst 1984) yet these issues have not been considered when comparing the suitability of boxes to different species.

Bats belong to the Order Chiroptera, the second largest order of mammals, with approximately one thousand species world-wide (Kunz and Fenton 2003). Despite this, remarkably little is known of the life history and conservation status of the majority of species (Barclay and Harder 2003). This lack of information is seriously constraining attempts to understand how bats are being impacted by global threats such as habitat loss and urbanisation. Food and roosting habitat are essential for the survival of hollow-dwelling bats (Schwarting 1994b, Barclay and Brigham 1996, Racey and Entwistle 2003). As the only mammals capable of flight, bats have been falsely portrayed as able to compensate for changes in availability of habitat and food sources by moving to new areas in search of these resources (Parnaby and Hamilton-Smith 2004). However, the loss of old-growth forests and mature trees due to logging and urbanisation has progressively reduced the availability of roosting habitat, forcing bats to move even when food resources are plentiful (Boyd and Stebbings 1989, Sheffield *et al*. 1992, Parnaby and Hamilton-Smith 2004).

The present study of 70 bat boxes monitored over a three-year period in the greater Brisbane region, SEQ, Australia, and is part of a broader study (Rhodes 2006) of roost use by the white-striped free-tailed bat *Tadarida australis* (Gray, 1838; Rhodes and Richards 2008). This species is a large molossid endemic to mainland Australia. In metropolitan Brisbane, subtropical coastal Australia, it prefers to roost in cavities of old and dead eucalypts. However, hollow availability for this species is limited in metropolitan Brisbane (Rhodes and Wardell-Johnson 2006). Specifically, we aimed to investigate (i) whether bat boxes are accepted by *T. australis* or other insectivorous bats in a subtropical metropolitan city; (ii) which bat species adapt to artificial roosts most readily; and (iii) if the use of bat boxes depends on microclimate, landscape characteristics, or number of boxes in an area. We also discuss whether bat boxes can be used as a potential tool for the conservation of insectivorous bats in metropolitan Brisbane.

Methods

Study area and bat species

Field sites were located in the coastal lowlands of the greater Brisbane region (< 120 m altitude), SEQ, Australia (27° 30' S, 153° 0' E; Fig. 1). The greater Brisbane region comprises some 3000 km^2 (Poole 1995), and it is estimated that the population in this region will increase from 1.6 million in 2004 to 2.3 million by 2026 (Queensland Government 2004). The climate is subtropical with annual summer rainfall of 1146 mm per year, predominantly dry winters, and an average maximum temperature of 25.5° C (Bureau of Meteorology 2006).

The topography of the greater Brisbane region is characterised by coastal plains, sub-coastal ranges, occasional mountain peaks above 1000 m with drainage systems and valleys. Vegetation types vary from rainforest, to open eucalypt forests and woodlands, melaleuca forests and woodlands as well as heathlands and mangroves (Catterall and Kingston 1993).

Metropolitan Brisbane is dominated by a mosaic of mostly cleared urban settings with grassed lawns, low-growing ornamental plants, leafy cover of low native and introduced subtropical or tropical trees and sparse tall eucalypts, parklands with scattered mature eucalypts, and predominantly small bushland remnants (Catterall and Kingston 1993, Catterall *et al*. 1998). These small reserves consist of young regrowth, with few trees larger than 40 cm diameter (Catterall *et al*. 1998).

Despite dense urbanisation there are several large bushland remnants in the greater Brisbane region, especially the Brisbane Forest Park which covers 28,000 ha, with its western boundary only 4 km from

Brisbane's central business district (Fig. 1). The fringes of the metropolitan area is primarily composed of cleared pastures with scattered mature trees and larger bushland remnants (Catterall and Kingston 1993).

Construction and design of boxes

Bat boxes were built from 15 mm laminated plywood (Australian Nestbox Company, Gordon Park, Queensland, Australia). Privately owned boxes were coated with a dark green, non-toxic exterior paint to increase longevity under subtropical weather conditions (Tuttle and Hensley 2000). Bat boxes on experimental sites remained unpainted. Aluminium plates covered removable lids of each box to minimise moisture entry and to reduce bird damage (Fig. 2). Lids were secured with two screws onto the box as cockatoos are known to gain entry by chewing on the lids and forcing the lids open (F. Box, pers. comm. 2000). Grooves were inserted onto all inner walls (including landing pad and inner lid) to allow better hanging conditions for the bats (Tuttle

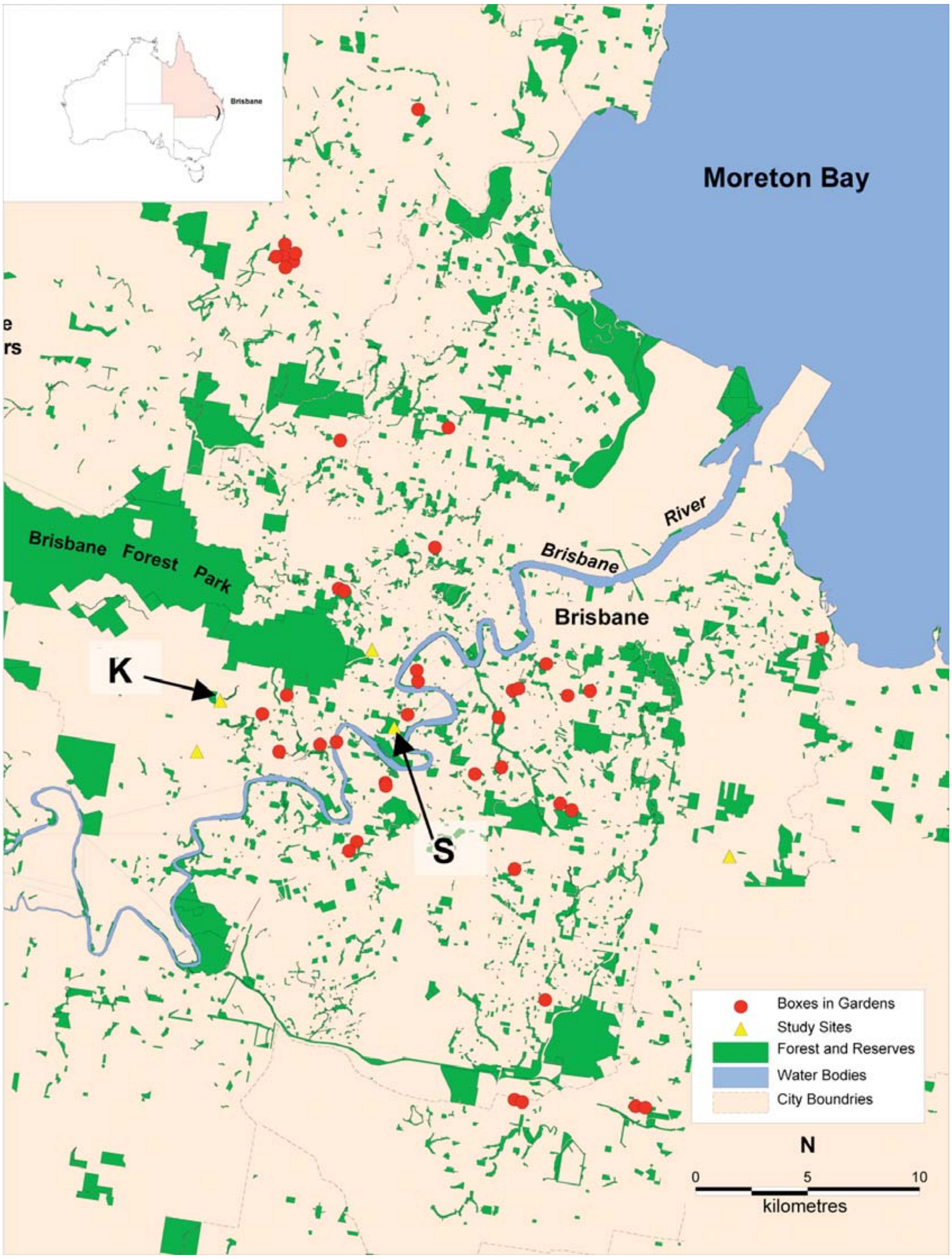

Figure 1. Location of bat boxes in backyards (n = 40; red circles) and on experimental sites (n = 5; yellow triangles) in relation to land-cover types in the greater Brisbane region, south-east Queensland, Australia. Forests and reserves include Commonwealth, State and Brisbane City Council forests, but not private tenures.
K is Kenmore Hill Experimental Site; S is St Lucia Experimental Site.

and Hensley 2000, Wendorf 2004). The boxes were mounted directly onto the trees with two long screws. A metal spacer was placed on each screw between box and tree to allow tree-growth (Fig. 2).

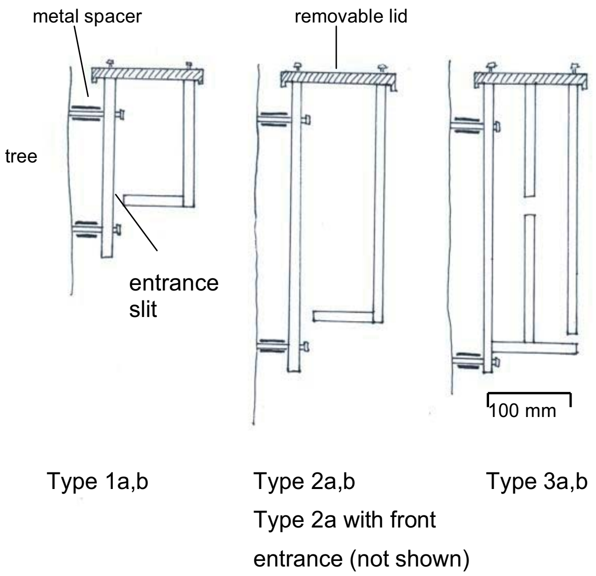

Figure 2. Side views of the bat box designs used in the present study.

We tested three basic box types (Fig. 2, Table 1) which varied in dimensions, internal volumes and size of entrance slits. Box types 1a,b were adapted from the Stebbings and Walsh design (1985), which was found to successfully attract bats in the U.K. (Boyd and Stebbings 1989) and in Victoria, temperate southern Australia (Bender and Irvine 1995, 2000). The back wall extended below the box to allow the bats to land and climb up into the box through the slit on the underside (Fig. 2). Box type 1a had an entrance slit of 15 x 117 mm to allow most bat species to enter while it excluded larger hollow-using vertebrates, such as the common brushtail possum *Trichosurous vulpecula* or sugar gliders *Petaurus breviceps*; Bender and Irvine 2000). Box type 1b had a smaller entrance slit (12 × 117 mm) to exclude larger bat species.

Box types 2 and 3 had larger internal volumes. Type 2a had an 18 x 202 mm front entrance slit, while box type 2b had a bottom entrance slit of 18 × 202 mm with the back wall extended below (Fig. 2, Table 1). The slightly larger entrances of 18 mm were chosen to test whether these might attract larger bat species.

Types 3a,b were adapted from Richards and Tidemann (1988) and had front facing entrance slits, located at the lower end of the front boards. They also consisted of two internal chambers, separated by a wooden board with a round access hole (3 cm diameter) placed in the middle. The entrance slit of type 3a measured 15 × 202 mm and type 3b measured 12 x 202 mm (Fig. 2, Table 1).

Experimental Procedure

We sought people interested in being involved in a long-term bat conservation study through a broad media appeal (radio stations, State and local newspapers; newspapers of Griffith University and The University of Queensland; and newsletters of naturalist organisations). As a result 34 participants purchased 52 bat boxes, supplemented with 18 boxes that we added subsequently.

A total of 70 boxes were installed between October and November 2000. Boxes were mounted on average 4.98 m ± 0.03 SE (n = 70, range 4.1–5.5 m) above ground, on a tree trunk free of branches (Stebbings and Walsh 1985, Tuttle and Hensley 2000). Boxes faced eastwards to ensure exposure to the morning sun and to avoid the hot afternoon sun.

Boxes in backyards

For the first part of the study we installed 35 type 1a boxes on trees in 27 private properties (Figs 1, 2). Where private properties did not have suitable trees, type 1a boxes (n = 5) were erected in three nearby public parklands. All of these boxes (*boxes in backyards* hereafter) were located randomly throughout metropolitan Brisbane (Fig. 1).

Boxes on experimental sites

A range of different bat box designs (types 1a,b, 2a,b and 3a,b; Fig. 2) were tested at five sites (n = 30; Fig. 1). The sites (*experimental sites* hereafter) were located on private properties (n = 3; in the suburbs of Kenmore Hills, Pullenvale and Burbank) and on public land (n = 2; St. Lucia Golf Links and Toowong Cemetery). All experimental sites consisted of open woodland with tall

Table 1. Number of boxes, height, width and length, internal volume, the entrance size and general specifications of box types 1a,b, 2a,b and 3a,b used in the present study in Brisbane.

Box type[a]	No. of boxes (n)[b]	Height (mm)	Width (mm)	Length (mm)	Internal volume (cm^3)	Entrance size (mm)	Specifications
1a	40 (B) 5 (E)	170	120	98	2000	15 × 117	Bottom entrance
1b	5 (E)	170	120	98	2000	12 × 117	Bottom entrance
2a	5 (E)	430	205	98	8600	18 × 202	Front entrance
2b	5 (E)	430	205	98	8600	18 × 202	Bottom entrance
3a	5 (E)	430	205	100	8800	15 × 202	Front entrance, double compart.[c]
3b	5 (E)	430	205	100	8800	12 × 202	Front entrance, double compart.

[a] 1a and 1b are small boxes; 2a–3b are large boxes.
[b] Number of boxes installed in backyards (B) and on experimental sites (E).
[c] Compart. – compartment

eucalypt stands, with few or no hollows. We used only sites from which the understorey had been thinned or removed and replaced by lawn. On each experimental site, six boxes were installed on separate tall trees (native *Eucalyptus* species) 25–50 m apart. On one experimental site (Toowong Cemetery), only four boxes could be installed in close proximity because of a lack of suitable tall trees. The remaining two boxes were located at a distance of 100 and 150 m from these boxes.

Bat box inspections and handling of bats

Due to the subtropical climate and the lack of distinctive seasons in Brisbane, we divided the year into two main seasons based on climate (Bureau of Meteorology 2006): Warm wet months (October–April, *summer* hereafter) and cold dry months (May–September, *winter* hereafter). During summer the average minimum temperatures do not fall below 15° C while the maximum temperatures often exceeds 30° C, although seldom more than 35° C. Winter is characterised by average minimum temperatures below 15° C (9.5 – 13.8° C) and maximum temperatures of 20 to 25° C. Relative humidity remains stable throughout the year (61–71%), but mean annual rainfall during the summer reaches 122 mm compared to 58 mm in winter (Bureau of Meteorology 2006).

Boxes were monitored over a period of 30 months (January 2001 – June 2003; n = 544). Each box was checked at least once during each season and up to eight times per box (2–4 times/year). In 2001 boxes were inspected four times a year (twice per season), but due to logistical reasons boxes were only checked once per season in 2002 and 2003.

Boxes were individually inspected by opening the lid and removing the bats for identification. Species, gender, mass, forearm length, and reproductive status were recorded. Individuals were placed immediately back into the box after handling. In the absence of bats, the box was assessed for any signs of bat occupancy (guano, urine stains). Number and location of fresh bat droppings as well as the size and location of fresh urine stains were recorded. This allowed the tracking of box use between inspections and seasons (Nagel and Nagel 1988, Arnett and Hayes 2000). The rate of box usage (%) was calculated as the number of times boxes were used divided by the number of boxes checked (some boxes were not accessible on all occasions). Fauna other than bats occupying the boxes was also recorded.

Temperature and relative humidity

In 2002 and 2003 we monitored temperature (degree Celsius) and relative humidity (%). Before inspecting boxes, we measured ambient temperatures and relative humidity ("T_a, RH_a" hereafter), as well as temperatures and relative humidity inside boxes ("T_{box}, RH_{box}" hereafter) with a commercially available temperature data logger (HOBO-Temp, Onset Computer Corporation, Pocasset, MA) and a custom-made relative humidity data-logger (Griffith University, Nathan, Queensland). Internal measurements were taken by inserting temperature and relative humidity sensors simultaneously 15 cm into each box (measured from the entrance slit). In boxes with two compartments, only the first was accessible with sensors. Ambient measurements were taken 15 cm below each entrance slit. All measurements were obtained within one minute period and the data obtained at the 30 second mark were used for analysis.

The exact time (hr/min/sec), length of recordings (in seconds), as well as general weather and cloud conditions were recorded during each measurement. Relative humidity was recorded immediately, while temperature data was downloaded after each field day onto a laptop, using BoxCar Pro, version 4, software for Windows (Onset Computer Corporation, Pocasset, MA) and later cross-checked with the timing of measurements.

We measured box temperature and relative humidity twice per box per season; however temperature data logger failure, and the occupancy of ants in boxes prevented some data collection. Overall, 71 temperature readings (40 during summer and 31 during winter) and 144 relative humidity readings (48 during summer and 96 during winter) were conducted between January 2002 and June 2003.

The effects of seasonality on bat box temperature and relative humidity, the effects of box design (small = box types 1a,b; large = types 2a,b and 3a,b) and stain (painted/unpainted) on box temperature and relative humidity were analysed. We examined actual temperature and relative humidity data and additionally the difference in temperature and relative humidity between internal and ambient measurements (T_{box}–T_a and RH_{box}–RH_a). This was to analyse the direct comparison of microclimates between different boxes. As bat box inspections were conducted over different days and different seasons, ambient temperature and weather changed accordingly.

At experimental sites we analysed the effects of microclimate on box choice by bats. Temperature and relative humidity of boxes containing bats during measurements were compared with readings for boxes which did not contain bats. We distinguished between boxes housing bats versus boxes with evidence of use (e.g., bat guano or stains) because all boxes on experimental sites were used during this study. We assessed whether there was a difference in temperature and relative humidity between used and unused boxes at the time measurements were taken. These comparisons were possible on experimental sites as boxes on each site were located near each other and were checked in close succession. Therefore, microclimate data could be used to test the hypothesis that temperature and relative humidity influenced box choice by bats.

Landscape characteristics

Environmental attributes of each bat box site were analysed to investigate whether landscape variables, such as land cover types and physical attributes, influenced box occupancy. We measured each attribute in five different circular buffers (100, 500, 1000, 2000, 5000 m) centred around each bat box location.

Percentages of four land cover types were measured by overlaying five different radii (see above), each with a grid system of 100 identical elements each over a topographic image map (scale 1: 25,000; State of Queensland Department of Land 1995). These included the percentage of grass, build-up area, permanent open water (such as river, creek, dams, sea) and total forest cover (dry sclerophyll forest).

In addition, we measured 12 physical landscape variables for each bat box on a topographic aerial image map (scale 1: 25,000; 5 m contour interval; The State of Queensland Department of Lands, 1995): altitude (to the nearest 5 m), distance to nearest open water body (river, creek or dam), distance to the nearest forest patch, with forest patch size of three size classes (1–20, 20–100, and > 100 ha). The number of bat boxes within different buffers (100, 500, 1000, 2000, 3000, 4000, 5000 m) were also measured as the literature suggests that a high number of boxes in one area attracts more bats (Schwarting 1990, 1994a).

Statistical Analysis

Data are presented as mean and/or median ± standard error (SE) and range. Data sets were checked for normality (Wilk-Shapiro statistics, *W*) and non parametric statistics were applied because many data-sets were not normally distributed. Temperature and relative humidity data were analysed with Mann-Whitney *U*-tests with pairwise comparison of ranks (Zar 1999). Spearman's rank order correlations (Zar 1999) were used to compare variables of box usage by bats (number of times boxes were used by bats in winter, summer and overall; presence/absence of bats in boxes and the number of species in boxes) against the four types of land cover and the 12 physical landscape variables (see previous paragraph). Additionally, box usage by bats (number of times boxes were used by bats in summer, winter and over both seasons; presence/absence of dwelling bats in boxes; and the number of species in boxes) was correlated against number of times boxes were used by ants in summer, winter and over both seasons. Statistical significance was assessed at an alpha of 0.05. Analyses of the data were performed using STATISTICA 4.5 for Windows 97 (StatSoft, Tulsa, Oklahoma).

Results

Bat box usage

All but three bat boxes were used at least once during the three-year study (37 boxes in backyards and all 30 boxes on experimental sites). Usage increased steadily with up to 87% of boxes being used (Figs 3a, b). In most cases bat box usage was confirmed from the occurrence of fresh bat guano and stains inside boxes. On some occasions, bats were observed inside boxes (see below). Ants excluded bats by building nests inside boxes and blocking-off the entrance slits with bark material, even when the boxes had been used in the previous season by bats (Figs 3a, b). In contrast to bat occupancy, ant presence remained relatively stable throughout the project regardless of the year and season (Figs 3a, b). In backyards, ants occupied on average 21.1% of boxes (± 2.6 SE; range: 12.2 – 33.3%; n = 8), while the rate was about half on experimental sites (11.6 ± 1.9 SE; range: 3.3 – 20%; n = 8). Ants were therefore competing with bats for the available roosting space.

Bat species

Twenty-four bats of five species were observed in boxes on five occasions during winters of 2001–2003. Bats were observed on two of the five experimental sites (St. Lucia Golf Links and Kenmore Hills; Fig. 1; Table 2). No bats were observed during summer or in backyard boxes. Some bats escaped while being retrieved from the boxes and therefore could not be measured (Table 2). All bats were adults and non-reproductive. Most roosting groups consisted of one male and several females. Only twice did bats roost as individuals; an unidentified vespertilionid and a male Gould's Long-eared Bat *Nyctophilus gouldi* (Tomes, 1858).

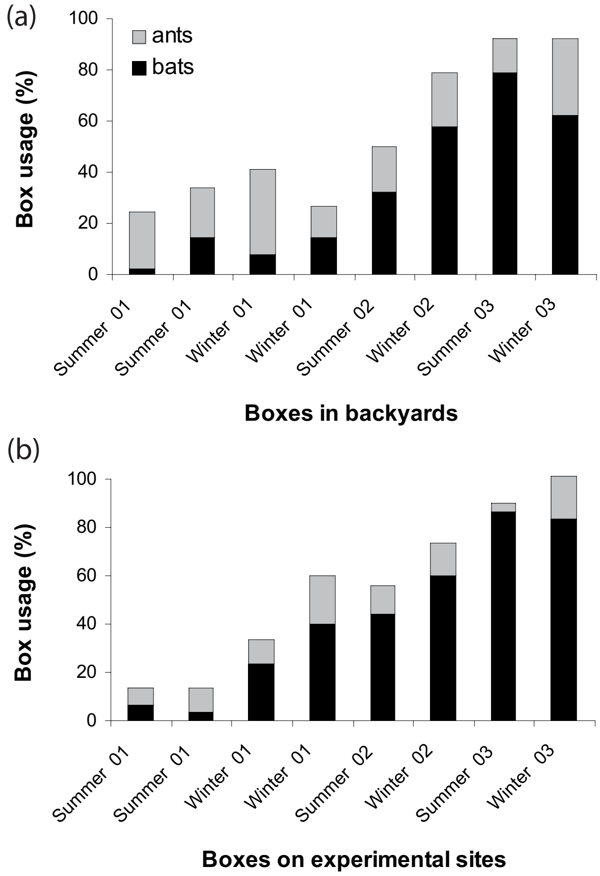

Figure 3. Cumulative use (%) of bat boxes that had been used at least once during the study period. Boxes were located in a) backyards (n = 40) and b) experimental sites (n = 30) for bats (black) and ants (grey). Proof of bat usage was determined by either locating bats inside boxes or by indirect signs, such as bat guano and urine stains. During 2001 boxes were checked every three months, resulting in two inspections per season. Summer (October–April); winter (May–September).

We observed eight Gould's Wattled Bats *Chalinolobus gouldii* (Gray, 1841), five Eastern Long-eared Bats *Nyctophilus bifax* (Thomas, 1915), four *N. gouldi*, six Greater Broad-nosed Bats *Scoteanax rueppellii* (Peters, 1866), and one small vespertilionid (Table 2; Plate 2). Identification of this vespertilionid bat was impossible, as we were unable to retrieve this bat from the narrow compartment of its box. Its appearance was consistent with either a Broad-nosed Bat *Scotorepens* species, a Little Bent-winged bat *Miniopterus australis* (Tomes, 1858) or a Chocolate Wattled Bat *Chalinolobus morio* (Gray, 1841). All three species occur in this region (Churchill 1998) and are likely to use bat boxes (Smith and Agnew 2002, Bender 2005). Two bat species, *N. bifax* and *S. rueppellii*, are listed as rare in Brisbane (Brisbane City Council 2000).

Large bat droppings were found in large quantities (> 50) in box type 2a (Kenmore Hill experimental site). The guano was similar to those found in box type 3a where *S. rueppellii* was roosting and the guano size was much larger than the guano found in the remaining boxes. *Scoteanax rueppellii* might have roosted first in box type 2a prior to moving into 3a. However, it also could have been guano from another large sized bat species.

Fauna other than bats

Bat boxes were used by a range of vertebrate and invertebrate fauna in addition to bats (Figs 4a, b). These were identified to genus or species and combined into broad taxonomic groups for analysis. As with bats, the rate of box usage (%) was calculated as the number of times boxes were used divided by the number of boxes checked.

After bats, spiders were the second most frequent faunal group, occupying 30.1% of boxes during summer and 25.7% during winter (Figs. 4a, b). Most spiders consisted of several species of huntsman that were pooled into one taxonomic group of huntsman (Figs. 4a, b): Over the three-year project 29.9% were Grey Huntsman *Holconia immanis*, 18.4% were Giant Green Huntsman *Typostola sp*., 9.8% were Brown Huntsman *Heteropoda jugulans*, 23% were unidentified huntsman, and 1.7% were unidentified huntsman hatchlings. Additionally, boxes hosted a range of other spiders: 6.3% Red House Spiders *Nesticodes rufipes*, 0.6% Daddy-Long-Legs *Pholcus phalangiodes* and 10.3% unidentified spiders.

Occasionally ants were seen foraging inside boxes but most represented established colonies, which filled the box completely and sealed the entrance with bark and other plant material. More than eight ant species used the boxes, the majority belonging to the genus *Polyrhachis*. During summer ant nests were found in 13.3% of all boxes, while during winter it increased slightly to 16% (Figs 4a, b).

Cockroaches frequently occupied boxes, especially during summer (17.4%) while usage dropped in winter to 8.7% (Figs 4a, b). The majority of cockroaches (all data combined) were German Cockroaches *Blattella germanica*

Table 2. Dates, bat species, number of bats observed, gender ratio and box site location in Brisbane.

Species[a]	Dates	Gender ratio[b]	No of times (*n*) bat box type was used[c]						Site[d]
			1a	1b	2a	2b	3a	3b	
C. gouldii (7/8)	30/06/2003	6F, 1M	1		1				S
N. bifax (4/5)	10/06/2001	3F, 1M					1		K
N. gouldi (4/4)	10/09/2001 3/06/2003	1F, 3M	1	2					K
S. rueppellii (6/6)	04/06/2002 23/06/2003	5F, 1M					2		K
Vespertilionid[e] (0/1)	04/06/2002	1?						1	K

[a] Species: Bat species (Number of individuals measured/total number of bats found in box).
[b] Gender ratio: number of females (F) to males (M); ? – not identified.
[c] No of times (*n*) a bat box type was used: Number of times bat species occupied box type 1a–3b.
[d] Site: Box site location; S – St Lucia experimental site; K – Kenmore Hills experimental site.
[e] Vespertilionid: Unidentified vespertilionid bat, see text for more detail.

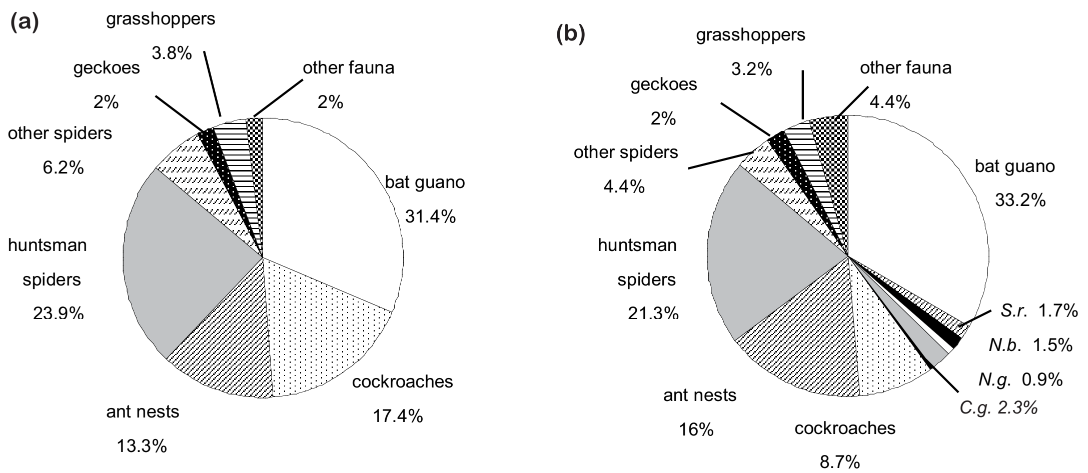

Figure 4. Overall mean percentages of fauna found in bat boxes during a) summer and b) winter between January 2001 and June 2003 (*n* = 544 individual bat box inspections). Data included bat guano, which was used as an indication that bat boxes had been used by bats prior to inspections. Except for bat species, fauna presented in these graphs were lumped into broad taxonomic groups (see text for more detail).
S.r. – *Scoteanax rueppellii*; N.b. – *Nyctophilus bifax*; N.g. – *Nyctophilus gouldi*; C.g. – *Chalinolobus gouldii*; Vesp. – unidentified Vespertilionidae (see text for details); other fauna – fauna, which occupied boxes infrequently, such as snakes, wasps, caterpillars, *etc*. (see text for detail).

(54.3%), followed by Australian Cockroaches *Periplaneta australasiae* (12.3%), Bush Cockroaches *Methana marginalis* (8.6%), American Cockroaches *Periplaneta americana* (3.7%), and Barred Cockroaches *Cosmozosteria subzonata* (1.3%). 19.8% of recorded cockroaches were not identified to species.

Hedge Grasshoppers *Valanga irregularis* were encountered on 3.8% of inspections during summer and 3.2% during winter. Grasshoppers and geckoes often shared the same box. Geckos were found in the same ratio in summer and winter (2%). Geckoes were most likely to be the native Dubious Dtella *Gehrya dubia* or the introduced Asian House Gecko *Hemidactylus frenatus* but confirmation was impossible as geckos escaped the boxes before identification could take place.

Other animals ("*other fauna*") used the boxes infrequently during summer (2%) and winter (4.4%; Figs. 4a, b). These included unidentified skinks (n = 8), mud wasp nests (n = 5), caterpillars (n = 2), unidentified crickets (n = 2), one Common Tree Snake *Dendrelaphis punctulatus* and one scorpion *Liocheles waigiensis*. Furthermore we detected bite marks from Galahs *Cacatua roseicapilla* (n = 3) on the lid and scratch marks on the box (n = 1), especially around the entrance slit. These were most likely made by a Lace Monitor *Varanus varius*, a known predator of bats and a common species in Brisbane (Mansergh and Huxley 1985, Queensland Museum Publication 1995).

Effects of season, design and paint on bat box temperature and relative humidity

Effects of seasonality on bat box temperature and relative humidity

T_{box} and T_a were significantly warmer during summer, while RH_{box} and RH_a were significantly higher during winter (P for all measurements ∑ 0.02; Table 3a). This was a direct response to seasonal climatic fluctuations. There were no differences in T_{box}, T_a, RH_{box}, or RH_a between seasons (Table 3b). T_{box} was always significantly higher than T_a during summer (U = 371, P = 0.001; n = 41, 41) and winter (U = 272, P = 0.02; n = 29, 29; Table 3c). RH_{box} trended to be higher especially during summer, but the differences were not statistically significant (Table 3c).

Effects of design on bat box temperature and relative humidity

Temperature and relative humidity measured in small boxes (types 1a,b) and large boxes (types 2a,b; 3a,b) were compared to assess the effects of bat box design on box temperature and relative humidity. To avoid biases in data collected at different times, only differences between internal and ambient temperature (T_{box}–T_a) and relative humidity (RH_{box}–RH_a) were compared (Table 4). In small boxes the differences were not significant, indicating that the differences of temperatures and relative humidity remained stable throughout the seasons (Table 4a). In comparison, large boxes had significant higher temperatures (U = 12, P = 0.04; n = 8, 8) and relative humidity (U = 120, P = 0.02; n = 15, 29) during summer (Table 4a).

However, when differences in temperature and relative humidity were compared between bat box types (small/large) within the same season, large boxes had significantly larger differences in temperature (U = 40, P = 0.004; n = 31, 8) and relative humidity (U = 108.5, P = 0.002; n = 33, 15) during summer (Table 4b). No significant difference between box types was found during winter (Table 4b).

Effects of paint on bat box temperature and relative humidity

Differences in temperature (T_{box}–T_a) and relative humidity (RH_{box}–RH_a) in small boxes (types 1a,b) were compared between painted and unpainted boxes within the same season (Table 5). During summer, unpainted boxes had significantly greater differences between ambient and internal temperatures (U = 11, P = 0.03; n = 29, 3) but no significant differences between ambient and internal relative humidity (U = 43, P = 0.07; n = 27, 6). There were no significant differences in temperature (U = 36.5, P = 0.9; n = 19, 4) and relative humidity (U = 334.5, P = 0.8; n = 54, 13) between painted and unpainted boxes during winter (Table 5).

Effects of microclimate on bat box choice

On experimental sites internal temperature, ambient temperature and relative humidity were compared between boxes housing bats during inspections and those which did not contain bats. None of the four measurements (T_{box}–T_a and RH_{box}–RH_a) were significantly different between both groups (P for all measurements ≥ 0.3; Table 6). Therefore, we found no evidence to support the hypothesis that bat box' microclimates influence box choice by bats during this study.

Landscape characteristics, ant infestation and number of bat boxes in an area

Spearman's rank order correlation was used to associate box usage by bats with environmental factors, such as land cover types, physical landscape variables, ant infestation and number of boxes in an area (Table 7). The most significant results were negative correlation between box success ('*number of times boxes were used by bats*') and ant infestations, regardless of the season (for all measurements: R_s ≥ –0.29, P ≤ 0.02; Table 7). Of the four land cover types and the 12 physical landscape variables, only the distances to small forest remnants (1–20 ha; all measurements R_s ≥ 0.3, P < 0.02) and medium sized forest remnants (20–100 ha; all measurements R_s ≥ 0.29, P < 0.02) had a significant influence on box success. The percentage of grass in a 5000 m radius was negatively associated with box success (R_s = –0.31, P < 0.01). The presence/absence of bats ('*bats in boxes*') was significantly correlated with the number of boxes, especially within a 2 km radius (R_s = 0.42, P < 0.001; Table 7), the percentage of grass within a 1 km (R_s = 0.24, P = 0.05), as well as the percentage of forest within a 5 km radius of a box (R_s = 0.23, P = 0.05). Similarly, the chance of attracting more than one species ('*number of bat species*') into boxes increased with the number of boxes, especially in a 2 km radius (R_s = 0.42, P < 0.001), the percentage of grass within 1 km radius (R_s = 0.24, P < 0.05), and percentage of forest cover within 5 km radius around a bat box (R_s = 0.24, P = 0.05; Table 7). The percentage of build-up areas was weakly negatively correlated with number of bat species (R_s = –0.23, P = 0.06; Table 7).

Table 3. Comparison of temperatures and relative humidity measured in 70 bat boxes in 2002 and 2003. Variables were compared with Mann-Whitney *U*-tests between a) internal and ambient measurements within the same season; b) T_{box}–T_a and RH_{box}–RH_a between seasons; and c) measurements of the same variable (e.g., T_{box}) between the two seasons (summer: October–April, winter: May–September).

Variable 1 Name; *n*	Variable 2 Name; *n*	Unit	Variable 1 Mean	Variable 1 Median	Variable 1 SE	Variable 1 Range	Variable 2 Mean	Variable 2 Median	Variable 2 SE	Variable 2 Range	U	P
a) Actual data measured between seasons												
T_{box}, summer; 41	T_{box}, winter; 29	°C	27.9	28	0.4	19.1–31.1	19.8	19.1	0.6	15.5–28.5	45.5	<0.001
T_a, summer; 41	T_a, winter; 29	°C	25.9	25.6	0.4	16.2–30.2	18.1	18.4	0.6	14–27.6	57	<0.001
RH_{box}, summer; 52	RH_{box}, winter; 98	%	51.3	48.5	1.7	33–83	56.8	57.5	1.3	32–83	1874	<0.01
RH_a, summer; 51	RH_a, winter; 97	%	48.8	47	1.6	31–78	54.7	54.5	1.5	28–80	1877.5	0.02
b) Differences of internal and ambient measurements between seasons												
T_{box}–T_a, summer; 40	T_{box}–T_a winter; 30	°C	1.9	1.6	0.2	(–0.4)–5	1.7	1.5	0.2	(–2)–4.2	561	0.6
RH_{box}–RH_a, summer; 48	RH_{box}–RH_a, winter; 96	%	1.8	2	0.5	(–7)–9	2.2	1	0.4	(–5)–16	2272.5	0.9
c) Actual internal versus ambient measurements, same season												
T_{box}, summer; 41	T_a, summer; 41	°C	27.9	28	0.4	19.1–31.1	25.9	25.6	0.4	16.2–30.2	371	0.001
T_{box}, winter; 29	T_a, winter; 29	°C	19.8	19.1	0.6	15.5–28.5	18.1	18.4	0.6	14–27.6	272	0.02
RH_{box}, summer; 52	**RH_a, summer; 51**	%	51.3	48.5	1.7	33–83	48.8	47	1.6	31–78	1142	0.2
RH_{box}, winter; 98	RH_a, winter; 97	%	56.8	57.5	1.3	32–83	54.7	54.5	1.5	28–80	4371	0.3

Table 4. Comparison of differences in temperatures and relative humidity (T_{box}–T_a and RH_{box}–RH_a). Temperature and relative humidity measured outside boxes were sometimes higher than inside boxes, resulting in negative values (listed in brackets). Data were compared a) between same box types and different seasons, and b) same season but different box types (Mann-Whitney *U*-tests).

Variable 1 Name; *n*	Variable 2 Name; *n*	Unit	Variable 1 Mean	Variable 1 Median	Variable 1 SE	Variable 1 Range	Variable 2 Mean	Variable 2 Median	Variable 2 SE	Variable 2 Range	U	P
a) Same box type, different seasons[a]												
Small boxes: T_{box}–T_a, summer; 31	Small boxes: T_{box}–T_a, winter; 23	°C	1.6	1.3	0.2	(–0.4)–5	1.7	1.5	0.2	0.3–4	315.5	0.5
Small boxes: RH_{box}–RH_a, summer; 33	Small boxes: RH_{box}–RH_a, winter; 67	%	1.9	1.5	0.4	(–7)–16	2.4	2	0.5	(–5)–16	901	0.1
Large boxes: T_{box}–T_a, summer; 8	Large boxes: T_{box}–T_a, winter; 8	°C	3	2.7	0.4	2–4.8	1.6	1.6	0.6	(–2)–4.2	12	0.04
Large boxes: RH_{box}–RH_a, summer; 15	Large boxes: RH_{box}–RH_a; 29	%	3.7	3	0.6	0–9	1.9	0.5	0.6	(–2.5)–10	120	0.02
b) Same season, different box types[b]												
Small boxes: T_{box}–T_a, summer; 31	Large boxes: T_{box}–T_a, summer; 8	°C	1.6	1.3	0.2	(–0.4)–5	3	2.7	0.4	2–4.8	40	0.004
Small boxes: RH_{box}–RH_a, summer; 33	Large boxes: RH_{box}–RH_a, summer; 15	%	1.9	1.5	0.4	(–7)–16	3.7	3	0.6	0–9	108.5	0.002
Small boxes: T_{box}–T_a, winter; 23	Large boxes: T_{box}–T_a, winter; 8	°C	1.7	1.5	0.2	0.3–4	1.6	1.6	0.6	(–2)–4.2	90	0.9
Small boxes: RH_{box}–RH_a, winter; 67	Large boxes: RH_{box}–RH_a, winter; 29	%	2.4	2	0.5	(–5)–16	1.9	0.5	0.6	(–2.5)–10	858.5	0.4

[a] Box types: small bat boxes – types 1a,b; large bat boxes – types 2a,b and 3a,b (see Fig. 2 and text for details).

Table 5. Comparison of differences in temperatures and relative humidity (T_{box}–T_a and RH_{box}–RH_a) between painted and unpainted boxes of the same box design (types 1a,b) during summer and winter (Mann-Whitney *U*-tests). Temperature and relative humidity measured outside boxes were sometimes higher than inside boxes, resulting in negative values (listed in brackets).

Variable 1	Variable 2	Unit	Variable 1				Variable 2				U	P
Name; *n*	**Name; *n***		**Mean**	**Median**	**SE**	**Range**	**Mean**	**Median**	**SE**	**Range**		
Painted: T_{box}–T_a, summer[a]; 29	Unpainted: T_{box}–T_a, summer; 3	°C	1.5	1.3	0.2	(–0.4)–4.4	3.1	2.4	0.9	2–5	11	0.03
Painted: RH_{box}–RH_a, summer; 27	Unpainted: RH_{box}–RH_a, summer; 6	%	1.3	1.5	0.6	(–7)–9	–0.7	–1	0.7	(–3)–2	43	0.07
Painted: T_{box}–T_a, winter; 19	Unpainted: T_{box}–T_a, winter; 4	°C	1.7	1.5	0.2	0.3–4	1.9	1.6	0.7	0.7–3.7	36.5	0.9
Painted: RH_{box}–RH_a, winter; 54	Unpainted: RH_{box}–RH_a, winter; 13	%	2.4	2	0.5	(–5)–16	2.2	1	1.1	(–5)–12	334.5	0.8

[a] Seasons: Summer: October–April; Winter: May–September.

Table 6. Temperature and relative humidity compared between boxes housing bats during inspections and those which did not contain bats (Mann-Whitney *U*-tests). Boxes were located on experimental sites.

Variable 1	Variable 2	Unit	Variable 1				Variable 2				U	P
Name; *n*	**Name; *n***		**Mean**	**Median**	**SE**	**Range**	**Mean**	**Median**	**SE**	**Range**		
T_{box}: boxes with bats, 4	T_{box}: boxes without bats, 8	°C	21	21	0.5	19.8–22.2	20.9	21.4	1.0	16.8–25.2	53	0.9
T_a: boxes with bats, 4	T_a: boxes without bats, 8	°C	19.4	19.3	0.2	19.1–19.8	18.9	18.8	0.7	15.5–21.9	10	0.3
RH_{box}: boxes with bats, 11	RH_{box}: boxes without bats, 31	%	62	63	4.4	35–79	60.4	64	2.5	33–80	162.5	0.8
RH_a: boxes with bats, 11	RH_a: boxes without bats, 31	%	59.7	64	5.3	32–80	58.5	64	2.9	28–80	653.5	0.7

Table 7. Most significant results from the Spearman's rank order correlation matrix (see text for more detail). The 34 variables which were compared against each other are listed as footnotes[a].

Variable 1	Variable 2	N	R_s	P
No of times boxes were used by bats (winter)	No of times boxes were used by ants (winter)	68	–0.46	<0.0001
No of times boxes were used by bats (all seasons)	No of times boxes were used by ants (winter)	68	–0.41	<0.001
No of times boxes were used by bats (all seasons)	No of times boxes were used by ants (all seasons)	68	–0.38	<0.002
No of times boxes were used by bats (summer)	No of times boxes were used by ants (summer)	68	–0.29	<0.02
No of times boxes were used by bats (winter)	Distance to forest remnant (20–100 ha)	68	0.4	<0.001
No of times boxes were used by bats (all seasons)	Distance to forest remnant (20–100 ha)	68	0.29	<0.02
No of times boxes were used by bats (winter)	Distance to forest remnant (1–20 ha)	68	0.36	<0.01
No of times boxes were used by bats (all seasons)	Distance to forest remnant (1–20 ha)	68	0.3	<0.02
No of times boxes were used by bats (winter)	% of grass cover in 5000 m radius	68	–0.31	<0.01
Bats in boxes	No of boxes in 2000 m	68	0.42	<0.001
Bats in boxes	% of grass cover in 1000 m radius	68	0.24	0.05
Bats in boxes	% of forest cover in 5000 m radius	68	0.23	0.05
No of bat species	No of boxes in 2000 m radius	68	0.42	<0.001
No of bat species	No of boxes in 3000 m radius	68	0.3	<0.02
No of bat species	% of forest cover in 5000 m radius	68	0.24	0.05
[No of bat species	% of build-up in 500 m radius	68	–0.23	0.06]

[a] 1 – No. of times boxes were used by bats (all seasons). 2 – No. of times boxes were used by bats during summer. 3 – No. of times boxes were used by bats during winter. 4 – Bats in boxes: presence/absence of bats. 5 – No. of bat species. 6 – Colony present (more than one bat). 7 – Ant infestation: presence/absence. 8 – No. of ant infestations (all seasons). 9 – No. of ant infestations (summer). 10 – No. of ant infestations (winter). 11 – Distance to nearest water body. 12 – Distance to forest 1–20 ha. 13 – Distance to forest 20–100 ha. 14 – Distance to forest >100 ha. 15 – No. of boxes in 100 m radius. 16 – No. of boxes in 500 m radius. 17 – No. of boxes in 1000m radius. 18 – No. of boxes in 2000 m radius. 19 – No. of boxes in 3000 m radius. 20 – No. of boxes in 4000 m radius. 21 – No. of boxes in 5000 m radius.
22 – Altitude. 23 – % of grass cover in 500 m radius. 24 – % of grass cover in 1000 m radius. 25 – % of grass cover in 5000 m radius. 26 – % of forest cover in 500 m radius. 27 – % of forest cover in 1000 m radius. 28 – % of forest cover in 5000 m radius. 29 – % of build-up area in 500 m radius. 30 – % of build-up area in 1000 m radius. 31 – % of build-up area in 5000 m radius. 32 – % of water in 500 m radius. 33 – % of water in 1000 m radius. 34 – % of water in 5000 m radius

Discussion

General bat box use and bat box design

Over the three-year period of this study, all but three boxes were used by bats, and box use increased steadily to over 80%. Evidence of use was, however, based mostly on the presence of fresh bat guano and urine stains inside the box (Haensel 1987, Nagel and Nagel 1988, Schwarting 1990, Shilton 1994, Arnett and Hayes 2000, Chambers *et al*. 2002).

The total number of bats observed in boxes during this study was very low compared to other Australian studies undertaken in Victoria (Organ Pipes NP; Bender 2005, Bender and Irvine 2000, 2001) but similar to another box study in SEQ (Smith and Agnew 2002). One explanation for the low number of bats could be that the present study was conducted over a three-year period. Bender and Irvine (2002) reported that it took two years before bats first used the boxes installed in the Organ Pipes NP. Hence, the shorter time scale of this study might not indicate the true potential of boxes as alternative roosting sites. To overcome this bias, bat box studies should be conducted over a much longer period to allow a more precise understanding of general box use and acceptance by bats.

Infrequent box usage by bats has been reported in several bat box studies, where single individuals often used boxes for a day before moving on (Nagel and Nagel 1988, Shilton 1994, König and König 1995, O'Shea 1998). This roost switching behaviour likely reflects natural roost lability of some microchiropterans as many bat species shift daily between natural roost sites (e.g., Lewis 1995, O'Donnell and Sedgeley 1999, Willis and Brigham 2004).

To enhance usage rates, Schwarting (1990, 1994a) suggested an increase in the number of boxes in order to allow bats to remain in an area. In particular, the author recommended installing boxes in clusters of five in close proximity (not more than 50 m apart) and with many boxes distributed evenly throughout an area and all habitat types (Schwarting 1990, 1994a). The data of the present study suggests that clusters of six boxes on one site (as found on experimental sites) were more likely to keep bats in an area than single distributed boxes over a large area (backyard sites). Bats were present during box inspection only on experimental sites and the amount of guano found was higher in boxes on experimental sites than in backyard boxes.

On the other hand, Boyd and Stebbings (1989) advised the setting of boxes on trees in two groups of four and in two different heights facing all directions. This has the additional advantage of bats being able to choose a suitable box depending on the season as some studies have found the aspect of boxes to be an important factor in the use of boxes, especially during the breeding season (Schwarting 1990, 1994a, Flaquer *et al*. 2006). In contrast, Shilton (1994) and Smith and Agnew (2002) found no preference for box aspect.

In the present study there was an apparent preference by smaller and medium sized bat species for boxes with small and medium (12 or 15 mm) entrance slits and often also the smaller internal volumes while the largest bat species detected here, the greater broad-nosed bats, roosted in a large box with 18 mm entrance slits (Table 2). Due to the small sample sizes; however, we were unable to undertake detailed analyses. In the USA boxes had better use rates if the internal volumes were larger (Tuttle and Hensley 2000) while the opposite was found in Europe (Gerell 1985).

Other box studies emphasise the importance of bat box design. The physical sizes of bat boxes are often not the limiting factor to the group size of bats as most can hold many more bats than is usually found in them (Park *et al*. 1998). Therefore, box design might be more important. Crevice roosting bats, for instance, prefer different box designs than bats which use large tree cavities. Schwarting (1994a) found that partitions inside the box especially attracted crevice-roosting bat species. Similarly, Flaquer *et al*. (2006) had twice as many bats in boxes with compartments than in boxes without compartments and that the abundance of bats varied seasonally according to box type. In the present study, northern long-eared bats, greater broad-nosed bats and an unidentified vespertilionid roosted only in boxes with compartments, while the *C. gouldii and* *N. gouldi* occupied boxes without compartments.

Box use is also improved by providing protection from wind and moisture, although ventilation is important (Heise 1980, Tuttle and Hensley 2000). In boxes with entrance slits on the bottom of the box, the chimney effect draws air up and traps warm air in the top part of the box. This is particularly important for boxes in temperate regions (Schwarting 1994a). While box designs that have a sealed base and an entrance near the top might improve thermal qualities of boxes during cold weather, they also require regular cleaning as they harbour more parasites than boxes without bottom panels (Tuttle and Hensley 2000). It is interesting to note that in the present study, bats were only present during winter box inspections.

In Germany, box success was improved by providing sawdust–concrete or porous concrete boxes as they give better protection against woodpeckers and weather (Gerell 1985, Schwarting 1990, 1994a). Partitions and landing areas can be roughened, scratched or grooved horizontally, or covered with durable UV resistant plastic screening to attract bats (Tuttle and Hensley 2000). The location of boxes will also influence box success as boxes on poles and houses were used twice as quickly and in bigger numbers as the same boxes mounted on trees (Tuttle and Hensley 2000, Flaquer *et al*. 2006).

Bat species use of bat boxes

Five species of bats used bat boxes during this study. Two of these species are commonly found in Brisbane (*C. gouldii* and *N. gouldi*), while two are of significance (*N. bifax and S. rueppellii*), being listed in Brisbane City Council's Natural Assets Planning Scheme as *'rare or are uncommon in Brisbane and becoming rare'* (Brisbane City Council 2000). The fifth species, a small vespertilionid, could not be identified because it could not be extracted from a crevice in the box.

Interspecific competition

The entrances of bat boxes used in the present study were designed to exclude predators (Schwarting 1994a) and other arboreal mammals, such as common brushtail possums, common ringtail possums, feathertail gliders, sugar gliders, squirrel gliders and yellow-footed antechinus. These marsupials have been found to use nest boxes originally designed for bats in Australia (Bender and Irvine 2000, 2001, Smith and Agnew 2002). Similarly, in the northern hemisphere, wasps, hornets, birds, mice and squirrels use bat boxes regularly (Gerell 1985, Schwarting 1990, König and König 1995, Tuttle and Hensley 2000).

While the boxes used in this study successfully excluded arboreal mammals occurring in Brisbane (such as the possums and gliders), they did not prevent frequent ant infestations. Ants occupied up to 30% of boxes and in some areas were present year round. Similarly, in temperate Australia, ants and wasps occupied many boxes which would be usually used by bats (Bender and Irvine 2000, 2001).

In the present study the application of talcum powder inside the boxes and water-proof marine grease around the metal spacers between tree and box proved effective in repelling ants. The sticky grease prevented ants from crossing while talcum blocked the stigmas, the breathing holes in the cuticula of ants, and nests were quickly abandoned after application. Although both methods reduced ant occupancy temporarily, it did not appear to reduce bat occupancy. However, bat urine usually decreased the effectiveness of talcum and the grease on the spacers also dried out over time. Therefore, these measures only reduced ant infestation for up to three months.

In 2002, we trialled three bat boxes without bottom panels and with three internal compartments on trees where boxes had been regularly infested with ants (Goodrich 2002, Rhodes 2002). We placed the boxes one metre below the ant infested boxes and found that the open bottom boxes were never infested while the others remained filled with ant nests. On one experimental site (Kenmore Hills), bats used the new box within three weeks of mounting and continued to use it (D. Tobart, pers. comm. 2002 and 2009). This suggests that box design can help reduce ant infestations in subtropical areas. Similarly, in the US, open bottom boxes are also less likely to be occupied by birds, mice and squirrels (Tuttle and Hensley 2000).

Smith and Agnew (2002) suggested that a box type similar to the designs in this study will exclude reptiles and birds. We frequently found geckos in backyard boxes and on one occasion found a common tree snake in a double compartment box (type 3a). While the geckos most likely did not influence box usage by bats, the common tree snake might be regarded as a potential predator.

Microclimate in bat boxes

In Brisbane, box occupancy fell during summer, and bats were observed only during winter. Similarly, in a nest box study in subtropical SEQ, 150 km north of Brisbane, occupancy rates of nest boxes fell during summer (Smith and Agnew 2002). Overall, bat boxes in Brisbane had higher temperatures and relative humidity than the ambient microclimate. Overheating is a known problem in boxes during hot summer days (König and König 1995, Lourenço and Palmeirim 2004). In a study of microclimates of nest boxes and natural cavities McComb and Noble (1981) showed that next boxes were generally hotter and had a lower relative humidity compared to natural cavities. Solar radiation on the flat surface of nest boxes results in rapid and uniform heating of the box surface. Natural cavities, in comparison, are usually round or oval in outline and are progressively heated throughout the day (McComb and Noble 1981).

Colour, for example, can be used to influence box temperatures with dark colours tending to increase temperature inside boxes while lighter colours have the opposite effect (Tuttle and Hensley 2000). In Mediterranean climates, black boxes are selected by the soprano pipistrelle *Pipistrellus pygmaeus* over white and grey boxes as the temperatures measured inside the black boxes resembled the temperature inside house roosts (Lourenço and Palmeirim 2004). However, black boxes were abandoned on very hot days when the temperature exceeded the thermal neutral zone of this species (Lourenço and Palmeirim 2004).

In Brisbane, summer temperatures in bat boxes ($_{Tbox}$) rarely exceeded 30° C. Therefore, overheating was most likely not the reason for the drop of box occupancy and the lack of bats observed in boxes. A more likely explanation for the pattern we observed is that bats form large maternity colonies during summer and might therefore prefer natural roosts with larger volumes. Furthermore, maternity colonies and pregnant females are often found in roosts, including bat boxes, with high temperatures to minimise energetic costs of thermoregulation (Kerth *et al*. 2001, Flaquer *et al*. 2006). High roost temperatures accelerate gestation, the growth of young and increase the survival during winter (Kerth *et al*. 2001, Sedgeley 2001, Speakman and Thomas 2003). Therefore, bat boxes provided for summer populations should be much larger than the boxes used in this study with a wider thermal range (Lourenço and Palmeirim (2004) .

In winter, bats might have switched to cooler boxes to reduce metabolic rate and energy expenditure by lowering their body temperature (Kerth *et al*. 2001, Chruszcz and Barclay 2002, Speakman and Thomas 2003, Turbill 2006). The energy saved during torpor by bats of the sizes found in this study could be up to 90% of the resting metabolic rate (C. Willis, pers. comm. 2006; Speakman and Thomas 2003). More research needs to be conducted to link bat box design, box microclimate, bat box use and thermoregulatory needs of subtropical bats in Australia.

Landscape characteristics and box occupancy

In Brisbane, boxes were more likely to be used if they were situated close to a small (1–20 ha) and medium (20–100 ha) sized forest reserves, while boxes mounted next to the Brisbane Forest Park, the largest reserve in Brisbane, were rarely used. It is likely that small and medium sized forest might be depleted of natural hollows as many forest reserves in Brisbane consist of young regrowth, with few trees larger than 40 cm in diameter (Catterall *et al*. 1998). Younger trees harbour usually fewer hollows as hollow formation and numbers of hollows are significantly related to tree diameter, tree health, tree age, tree location and fire events (reviewed in Gibbons and Lindenmayer 2002). Bats, therefore, might have used bat boxes in the near vicinity of young regrowth forest reserves. Large forest reserves, on the other hand, might still provide an abundant range of natural roost sites. Similarly, Smith and Agnew (2002) argue that where hollows occur in high numbers, native mammals tend to use this in preference to nest boxes. In Germany; however, the use of boxes is independent of hollow density in forests, but instead depends on where boxes are placed (Schwarting 1994a,b). Boxes along forest paths or on forest edges were primarily used as dispersal and migration roosts, while boxes inside forest are predominantly used as maternity roosts (Schwarting 1994a). In another study, proximity to water was an important factor in bat box choice (Tuttle and Hensley 2000). In the present study; however, we did not find evidence that percentage of water or distance to water influenced box occupancy, probably because the study area had many permanent water bodies and boxes were located on average 380 m from any permanent water source.

In Brisbane, boxes were more likely to contain bats if they were installed in an area with high grass cover within one kilometre and high forest cover within five kilometres. Grass cover might affect insect abundance (Emery and Emery 2004) and therefore prey availability for bats. Bats might have chosen a bat box away from their natural hollows in forests to reduce commuting costs (Boyd and Stebbings 1989). At this stage, no systematic study has been conducted in the urban land use of microchiroptans in Brisbane, with the exception of *T. australis* (Rhodes 2006, Rhodes 2007, Rhodes and Catterall 2008, Rhodes and Wardell-Johnson 2006, Rhodes *et al*. 2006) and little information is available on the roosting and foraging ecology of other urban bat populations in the greater Brisbane region. More studies are therefore needed to investigate roosting and foraging home-ranges of these bats in order to make appropriate management recommendations on the suitability of bat boxes in urban areas.

Cost and benefits of bat boxes

Bats are characterised by a life history similar to large mammals with high survival and low reproduction rates (Barclay and Harder 2003). Therefore, bat populations recover slowly from disturbances and loss of suitable roosts, especially maternity sites (Barclay and Harder

2003). In these cases, bat boxes can be an important tool in the conservation of a bat species (Lourenço and Palmeirim 2004, Flaquer *et al*. 2006). Other studies have shown that nest boxes can be successful in increasing the populations of insectivorous birds or bats in order to control outbreaks of insect pests (Thomas *et al*. 1979, Walton 2001). Furthermore, nest boxes have successfully maintained populations of several species of squirrels, waterfowl, kestrels, owls and martins in farmland or urban environment (Schemnitz 1980). Boyd and Stebbings (1989) argued that frequent recaptures of individual bats in boxes indicate that there are few alternative roost sites in areas such as forestry plantations. The increase of the population in boxes is explained, therefore, by the reduced commuting distance from previously used roosts.

However, occupancy of boxes also varies between sexes, species, seasons and where boxes are located (Shilton 1994, König and König 1995, Schmidt 1998). Bat boxes are often used only for a short period of time and occasionally as maternity colonies and the causes of failure are poorly understood (Wolz 1986, Neilson and Fenton 1994, Lourenço and Palmeirim 2004). Furthermore, different hollow-depending species use boxes of different designs and during different seasons for different reasons (Menkhorst 1984). For example, a 30-year study of bat boxes in Germany has revealed that the same bat species use different bat box designs as dispersal, mating, migrating, winter and maternity roosts (König and König 1995, Dietrich 1998). Bats usually need several years before they accept boxes (Dietrich 1998, Bender and Irvine 2001). Experience also showed that even after 19 years, new bat species were attracted into boxes because the box design was changed (Dietrich 1998), highlighting the need to understand bat box designs for each species if boxes are to be used as a conservation tool.

This study aimed to investigate the attraction of different bat species to different box design. It succeeded in attracting at least five bat species although some of these were common and opportunistic species such as *C. gouldii* and *N. gouldi*. These bat species readily occupy bat boxes, regardless of the design and location (O'Shea 1998, Bender and Irvine 2001, Smith and Agnew 2002, Bender 2005).

In marked contrast to these species, *T. australis* was not found in boxes during this study. However, individual males of that species were found in bat boxes in the Organ Pipes NP, southern Victoria (Bender 2005). These boxes were of similar size and design to those of the present study (Stebbings and Walsh design, box type 1). Individuals were found in boxes during one season, but were not found in boxes during the following year. A new bat box design was subsequently trialled at the Organ Pipes NP, based on the roost tree characteristics of the species defined by Rhodes and Wardell-Johnson (2006). These boxes have been occupied by *C. gouldii* but *T. australis* have not been found (L. Evans pers. comm. 2006). However, the species was found in bat boxes erected in an urban park in Melbourne, Victoria, in groups of up to eight individuals (Evans *et al*. 2006). The species was selective in the use of boxes, using only boxes that were long, rectangular and upright, and were similar to the tree hollows used by this species in Brisbane.

The dimensions and design of bat boxes used in this study were formulated prior to clarification of the roost characteristics of this species in tree hollows by Rhodes and Wardell-Johnson (2006). The pattern of occupation of bat boxes at Organ Pipes NP and Melbourne suggests that the *T. australis* has very specific roosting requirements that are not fully understood. This has important implications for the use of nest boxes as a management tool to supplement or replace the use of natural roosts in hollows. In particular, it highlights the importance of a detailed understanding of roosting requirements of individuals species, to the success of bat boxes in a management context.

There is little information on the effects of artificially increasing population levels of common native, introduced or pest species on populations of other species in the same study area (Gibbons and Lindenmayer 2002). Catterall (2004) found in a study of bird diversity in Brisbane, that formerly forested areas that were cleared and urbanised showed avifaunal changes over time, where large-bodied birds exclude small foliage-feeding birds.

Overseas studies have shown that boxes are often occupied by dominant bat species (Gerell 1985, Nagel and Nagel 1988, Schwarting 1990, König and König 1995), and that these often evict other, usually smaller, bat species (e.g., *Myotis myotis* evicts *M. daubentoni*; *Pipistrellus nathusii* evicts *P. pipistrellus*; and *Nyctalus noctula* and *N. leisleri* evict *P. nathusii*; König and König 1995). On the other hand, some boxes might be used by several species simultaneously (Schmidt 1988). The reasons why some bats evict other bats and other species roost in mixed groups remain unclear (König and König 1995). Bender (2005) found that box occupancy became increasingly dominated by one bat species, *C. gouldii*, and suggested that installation of boxes could have altered the local composition of bat species to the advantage of that species. Further research should be conducted to understand bat box requirements of different Australian bat species, and should be preferably focused on endangered species.

Nest boxes can also be an important tool for education and research into the biology of hollow-using species, as they allow access to nests that would otherwise be inaccessible (Menkhorst 1984). Boxes in my study attracted two bat *species (S. rueppellii* and *N. bifax*) declared as significant in Brisbane with one species, *S. rueppellii*, returning over two successive winters. The ecology of these species is largely unstudied (Hoye and Richards 2008, Parnaby and Churchill 2008, Churchill 1998, Brisbane City Council 2000). If these bats can be successfully attracted into bat boxes and during different seasons of the year, boxes might be used to study these species in more detail, similar to studies elsewhere (Golding 1979a, Boyd and Stebbings 1989, Lundberg and Gerell 1996, Park *et al*. 1998, Kerth and König 1999, Kerth *et al*. 2001).

Conclusion

Extensive logging, farming and urbanisation lead to the loss of natural habitat and consequently the decline of hollow-dependent fauna (Gibbons and Lindenmayer 2002, Lindenmayer and Franklin 2002, Lunney 2004). In areas affected by these processes, nest boxes have successfully been used to assist population recoveries of some bat species although this has yet to be demonstrated for most Australian bat species (Schemnitz 1980, Menkhorst 1984, Lourenço and Palmeirim 2004, Flaquer *et al*. 2006). However, while nest boxes could have the potential to play an important role in conservation and management of hollow-dependent fauna, they usually only provide a temporary substitute for natural roosts (Gibbons and Lindenmayer 2002, Wendorf 2004). However, for Australian bats, it has not been demonstrated that bat box designs used so far can achieve even a temporary substitute for hollows, given that: a) very few bat species regularly use boxes in Australian studies; b) box use is often only seasonal; and c) critically, maternity colony use has not been demonstrated for most Australian bat species. Hence, this present study and other studies of bats carried out in Australia have really only given an indication that bat boxes have the potential to provide a temporary ancillary addition to other roost structures (Golding 1979b, Bender and Irvine 1995, O'Shea 1998, Bender and Irvine 2001, Smith and Agnew 2002, Bender 2005). Consequently, the primary goal should be to preserve hollow-bearing trees or other roost sites (such as caves) with appropriate management plans and inventories (Gibbons and Lindenmayer 2002). The present bat box study was successful in attracting five bat species into boxes although this represented less than a quarter of the 22 bat species known to use hollows in the SEQ region, and reproductive females were not found of any species. However, box choice by these species is still poorly understood and future research should focus on the systematic study of box design, microclimate, landscape factors and different species usage throughout seasons and years. In areas with a remaining high biodiversity of native species, such as subtropical Brisbane, the ultimate goal should be to preserve overall biodiversity and to avoid upsetting community dynamics in favour of species that can adapt more easily to boxes.

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Appendix

Author, Monika Rhodes, checks a bat box located in the Toowong Cemetery, Brisbane. Photo: B. Thomson

Four of the five bat species found in bat boxes during the present study: a) Eastern Long-eared Bat *Nyctophilus bifax*; b) Gould's Long-eared Bat *Nyctophilus gouldi*; c) Gould's Wattled Bat *Chalinolobus gouldii*; and d) Greater Broad-nosed Bat *Scoteanax rueppellii*. Photos: a) T. Low; b–d) M. Rhodes.