The use of bathouses as day roosts in macadamia orchards, South Africa

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An ever growing human population and agricultural intensification has led to a worldwide threat of extinction to about one quarter of all bat species, despite the valuable ecosystem service of pest control provided by bats. The loss of roost sites is one of the major drivers of this decline, while the roost site preference and artificial roost site use by African bat species is little understood. In this study, we focus on the preference of artificial roost sites by insectivorous bats in macadamia orchards in South Africa (Levubu, Limpopo). From June 2016 to July 2017 we scanned 31 bathouses, mounted on poles on six macadamia orchards, for bats or any other occupants such as wasps, birds and bees. Twenty-one multi-chambered bathouses of three slightly different designs were erected on poles, in sets of three. Additionally, five Rocket boxes, four bathouses, in sets of two (black and white) and one colony bathouse were erected. Bats were counted and visually identified to family or species level. From December 2016 to end of March 2017, three IButtons were installed to record temperature variation between the set of three bathouses. We related the occupancy of bathouses in the different types of houses to the environmental variables distance to water, altitude and height of bathouse as well as the difference in mean temperature between the set of three bathouses. The central bathouse in the set of three and the black bathouse in the set of two had a significantly positive effect on bathouse occupancy. There was a significant difference in the mean temperature between the houses in the set of three, with a significant difference in temperature of 0.46°C between the central and the first bathouse. The Yellow-bellied house bat (*Scotophilus dinganii*) was by far the most recorded and the only species observed to co-habitat a bathouse with other animal species, in particular honeybees. Our study confirms previous assumptions in that the microclimate of bathouses, respectively their insulation, sun exposure and color appear to be important factors influencing bathouse occupancy. The two preferred bathouses in our study were the black, in the set of black and white, as well as the central, and on average warmest- bathouse, in the set of three. In conclusion, warm and well-insulated bathouses mounted freestanding on poles and in sets appeared to work best in northern South Africa. Further research on co-habitation of bathouses and displacement behavior as well as the potential importance of altitude and distance to water is needed.

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Abstract

An ever growing human population and agricultural intensification has led to a worldwide threat of extinction to about one quarter of all bat species, despite the valuable ecosystem service of pest control provided by bats. The loss of roost sites is one of the major drivers of this decline, while the roost site preference and artificial roost site use by African bat species is little understood. In this study, we focus on the preference of artificial roost sites by insectivorous bats in macadamia orchards in South Africa (Levubu, Limpopo).

From June 2016 to July 2017 we scanned 31 bathouses, mounted on poles on six macadamia orchards, for bats or any other occupants such as wasps, birds and bees. Twenty-one multi-chambered bathouses of three slightly different designs were erected on poles, in sets of three. Additionally, five Rocket boxes, four bathouses, in sets of two (black and white) and one colony bathouse were erected.

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Keywords: Bat houses, bat boxes, artificial roost, Bat, Chiropteran, Africa

Introduction

In Europe, artificial bat roosts (`bathouses/batboxes´) have long been tested and reviewed to compensate for a loss of natural roost sites, particularly in silviculture (Bäumler 1988; Issel&Issel 1955; Natuschke 1960; Schwenke 1983). More recently, the value of insectivorous bats for agriculture and the use of bathouses in agricultural landscapes has received growing attention (Boyles et al. 2011; Cleveland et al. 2006; Flaquer et al. 2006; Kunz et al. 2011; Lopez-Hoffman et al. 2014; Maas et al. 2013; Puig-Montserrat et al. 2015; Wanger et al. 2014). Nevertheless, an ever growing human population and related ongoing land use change, especially agricultural intensification, has led to a worldwide threat of extinction to about one quarter of all bat species (see Fig. 1.3 in Voigt & Kingston 2016; Mickleburgh et al. 2002, Tilman et al. 2011; Tscharntke et al. 2012). The loss of roost sites is one of the major drivers of this decline (Mickleburgh et al. 2002). However, despite their valuable ecosystem service of pest control, there is a particular lack of knowledge regarding the roost site preferences of African bat species (Monadjem et al. 2009; Monadjem et al. 2010a; Taylor 2000). The review of Rügger et al. (2016) suggests that peer-reviewed studies focusing on artificial roost site use by African bat species are literally non-existent. By far the most studies have been conducted in Europe followed by North America and Australia and a very few studies which have been conducted in Asia (Rügger et al. 2016). Summarizing the studies conducted globally so far, bat species seem to have a general preference for bathouses with a large volume, multi-compartments and those mounted on poles or houses compared to bathouses mounted on trees (Rügger et al. 2016). There also seems to be a preference for bathouses build from 'woodcement' (Dodds& Bilston 2013; Gerell 1985; Haensel& Tismer; 1999, Rügger et al. 2016), although these studies are all limited to one climatic region in Europe ('mild temperate/fully humid/warm summers'), according to the Köppen climate classification. Generally, the microclimate of bathouses, respectively insulation, sun exposure and color seems to be an important factor influencing bathouse occupancy (Fukui et al. 2010; Gerell 1985; Kerth et al. 2001; Lourenço& Palmeirim 2004; Rügger et al. 2016; Shek et al. 2012). Looking at different designs and colors of bathouses, studies suggest that preferences also vary greatly depending on the reproductive state of females (Baranauskas 2009; Fukui et al. 2010; Flaquer et al. 2006; Kerth et al. 2001). Furthermore, many bat species seem to be sensitive to competition for bathouses by other species, mostly by birds and social bees, ants and wasps (Baranauskas 2009; Dodds& Bilston 2013; Issel&Issel 1955; Meddings et al. 2011; Schwenke 1983).

There is certainly a great need for research on artificial roost site use, especially in Africa, and this is the first study looking at the occupancy of bathouses in South Africa. Successful bathouse design and deployment seem to relate mostly to the climatic region and bat species targeted, while the pressure of land use change and loss of roost sites is increasing. The objective of this study was, therefore, to gain insight into the preference of artificial roost sites by insectivorous bats in macadamia orchards in South Africa. The main research question was, what are key features of occupied artificial roost sites (bathouses)?

We hypothesized that bathouses providing a warm microclimate and those erected close to water sources will do particularly well.

Methods

Study area and bathouse design

The study was conducted in the fruit growing area of Levubu, Limpopo, South Africa, which accounts for the second highest production of macadamia in the country (see Figure 1). The climate in the study area is subtropical with around 1000 mm of annual rainfall. Other dominant land use types other than macadamia are pecan, avocado and banana orchards as well as pine and gum plantations (Taylor et al. 2017).

The Subtropical Fruit Association of South Africa (Subtrop) arranged for twenty-one multi-chambered bathouses to be mounted on poles, in sets of three, on four macadamia orchards in the Levuvhu river Valley, Limpopo, South Africa, in 2014. Every set of three houses compromised one 6-Chamber bathouse in the middle as well as an Old George bathouse and a Nursery bathouse to either side (see Figure 2). The 6-chamber bat house design is constructed of four side walls with five intersecting walls within the box, creating six equal length chamber. Both the Nursery bathouse and the Old George bathouse vary slightly in their chamber design. The Old George model is different from the other designs, in that several of the spacers between the different chambers are set at an angle (Freed&Falxa, 2010). Whereas, the Nursery bathouse has four chambers getting shorter in length towards the back of the house (see Figure 2). These bathouses were maintained in May 2016 and five two-chambered Rocket boxes (see Figure 2) were put up close to all but one set of three bathouses. Rocket boxes allow the bats to move in a 360° degrees within the house and choose from a range of temperatures respectively sun exposure. An additional four four-chambered bathouses, in sets of two (painted black and white in order to provide different microclimates), also mounted on poles and one colony bathouses were added in March 2016 on two additional macadamia orchards (see Figure 2). All bat houses are constructed of wood and mounted on pine poles also see Supplement 1 for detailed information.

As proposed for warm climates by the North American bat house research project, all bathouses erected for this study have open bottoms. They are also places near watersources and natural vegetation, wherever possible. Except for the colony bathouse, several bathouses were erected at each location, which is proposed to positively influence occupancy by providing different microclimates. Alternating between different bathouses might also be necessary for bats to avoid predators and high ectoparasite loads (Kiser&Kiser 2004).

Bathouse occupancy

All bathouses were scanned monthly from June 2016 to July 2017 for bats or any other occupants such as wasps, birds and bees unless weather prevented access, by reflecting sunlight with mirrors into the houses. . This process was kept as short as possible to avoid any major disturbance to occupant bats. Bats were counted and identified visually to family or species level referring to Monadjem et al. (2010b) and species records of Weier et al. (2018). Bat houses solely occupied by wasps or bees were cleared during maintenance in May 2016. During 1st of December to 20th of March 2017, three IButtons were successfully installed with a tongue and sticky tape at each of the entrances of a set of three bathouses to record temperature variation between the bathouses 1.5 hourly. While scanning the houses and fitting the IButtons we tried to avoid touching the bathouse or the poles close to the house to keep disturbance to a minimum (Tuttle et al. 2013).

Additionally, we recorded the distance to the closest water source (Google Earth), the cardinal direction facing (Digital Compass, Axiomatic Inc.), the altitude above sea level (GPS Waypoints, Bluecover Technologies) and the height on poles of each bathouse.

Data analyses

All statistical analyses was conducted with R (version 3.4, R Core Team 2017). The relatively small sample size of 31 bathouses (with 21 of them erected in sets of three) leads to a correlation between the type of bathouse and the cardinal direction the different houses are facing and not all possible combinations of the different bathouse types and cardinal directions are available for statistical analyses. Therefore, we fitted a model to analyze the relationship of the response variable 'presence or absence of bats' and the predictor variables 'type of bathouse', 'altitude', 'distance to water' and 'height of the bathouse'.

After testing the model for normal distribution and constant errors variance, we applied a generalized linear mixed model (GLMM) with a binomial distribution. The bathouse of the type 'colony' had to be removed from the analyses, as it remained unoccupied throughout our study. The variables 'farm' and 'month' were used as random factors to account for pseudo replication and all the numeric predictor variables were scaled. We used the dregde function (package 'MuMIn' by Barton 2017) based on the lowest values of the Akaike information criterion (AICc), corrected for a small-sample size, to select final models.

In order to analyze differences in temperature recorded between one of the sets of three houses we fitted an ANOVA and used the Tukey test for multiple comparison. Additionally, we used some summary statistics to look at differences in range and mean of temperature.

Results

We recorded a total of 166 individual bats within the 31 bathouses, from June 2016 to July 2017, with a maximum of 5 individual bats in one bathouse. The highest average number of bats was recorded in March and May (on average 0.53 bats per bathouse), whereas the lowest average numbers were recorded in August and November (0.3). We recorded Yellow-bellied house bats (*Scotophilus dinganii*) on 43 occasions, small Plain-faced bats (*Vespertilionidae*) on nine occasions, Free-tailed bats

(*Molossidae*) on 21 occasions and Mauritian tomb bat (*Taphozous mauritianus*) on three occasions (also see Supplement 2).

Type of bathouse

The first five models selected by dredge, analyzing the relationship of the response variable 'presence or absence of bats' with the predictor variable(s) 1) 'type of bathouse' and 'altitude', 2) 'type of bathouse', 3) 'type of bathouse', 'altitude' and 'height of the bathouse', 4)'type of bathouse', 'altitude' and 'distance to water', 5) 'type of bathouse' and 'distance to water' were all within a delta AICc of <2. After testing all five models, which each retained 'type of bathouse' as the only significant variable, we decided for the second and simplest final model.
The bathouse occupancy on the macadamia orchards was influenced by the type of bathouse, which was the only variable retained in the final GLMM model. The central bathouse (β=1.43, SE= 0.41, p<0.001) in the set of three and the black bathouse in the set of two (β=2.30, SE=0.56, p<0.001) had a significantly positive effect on bathouse occupancy (see Table 1 and Figure 3).

Temperature

The ANOVA showed that there was a significant difference in the mean temperature values between the houses in the set of three ($F_{(2,5682)}$ = 4.34 , p=0.0139), in the summer months December 2016 to April 2017. A post hoc Tukey test showed that there was a significant difference in temperature of 0.46°C between the second, 6-Chamber bathouse, and the first bathouse (p=0.016, an Nursery bathouse, and a marginal significant difference between the third, Old George bathouse, and the second house (p=0.55). The temperature range was between 12.5 and 40.5°C in the first bathouse and between 12 and 41°C in the second and third bathouse. The mean temperature was the warmest in the second (central) bathouse with 23.52°C compared to 23.06°C in the first bathouse and 23.13°C in the third bathouse.

Other bathouse occupants

We observed a number of other animals occupying the bathouses in the presence and absence of bats. Namely, we encountered Lesser Galago (*Galago moholi*), Tree squirrel (*Paraxerus* *cepapi*) and nests which could also belong to Dormouse (*Myoxidae*), Lizards (*Lacertilia*), social wasps (*Vespidae*) and Honeybees (*Apis*). We twice (May 2017 and June 2016) observed Yellow-bellied house bats (*Scotophilus dinganii*) sharing a bathouse with an active honeybee hive.

Discussion

From 220 individual bats observed during our study, the highest average number of bats were recorded in March and May, whereas the lowest average numbers were recorded in August and November. The bathouse type was a significant variable influencing bathouse occupancy, with a preference for the black house, from the set black and white, the 6-Chamber model, and the central and on average warmest house in the set of three. The two warmest houses, because of color (black) and insulation (central house of three) are, therefore, the preferred types of bathouses occupied by bats.

The highest (March and May) and lowest (November and August) average numbers of bats recorded during our study matches the high (December to end of May) and the low (June to end of November) season of pest insect species occurrence on macadamia orchards, according to Weier et al. (2018). The study of Weier et al. (2018), conducted in the same study area, shows that not only bat activity is nearly doubled in the high season but also that bat activity increases with Hemipteran abundance. This also supports the assumption that insectivorous bat species track outbreaks of insect pest species such as stinkbugs (Taylor et al. 2013; Taylor et al. 2017; McCracken et al. 2012). We, therefore, also suggest that colonization of bathouses on and around macadamia orchards is highest in times of high prey availability of pest insect species particularly stinkbugs (see Figure 4).

Our study confirms previous assumptions in that the microclimate of bathouses respectively insulation, sun exposure and color are important factors influencing bathouse occupancy (Fukui et al. 2010; Gerell 1985; Kerth et al. 2001; Lourenço& Palmeirim 2004; Rügger et al. 2016; Shek et al. 2012).

Bats generally preferred the black houses, in the set of black and white and 6-Chamber models, the central bathouse in the set of three. However, the 6-Chamber models were mounted flanked either side by other houses, which provided additional insulation. We suggest that this insulation affected the preference by bats rather than the bat house design. It would be worth investigating how occupancy changes if this central bathouse, the 6-Chamber model, is erected individually. However, we suggest that the insulation to either side of the 6-Chamber bathouse by an additional bathouse had a significant effect on bat occupancy. The colony bathouse remained unoccupied throughout this study. In order to distinguish if this is an effect of the location or the type of bathouse, several colony bathouses need to be erected and monitored. We also suggest that the colony bathouse might have remained unoccupied because it did not provide any other artificial roost sites in close vicinity so alternating between different bathouses was not possible. The Rocket box design did particularly well in the United States and Canada with 62% overall occupancy (Kiser&Kiser, 2004) but was the last design erected during our study in May 2016. Occupancy of the Rocket boxes might, therefore, still increase with time (Kiser&Kiser, 2004). One component the Rocket box and the Colony bathouse are missing, compared to the other designs erected, is a landing patch (see Figure 2).

Yellow-bellied house bats were by far the most recorded (42 times compared to nine observations of small plain-faced bats). This species is naturally tree cavity roosting but well known to utilize anthropogenic structures particularly rooftops (Monadjem et al. 2010a). Given the large size of Yellow-bellied house bats (weighing up to 37 grams), they might have a competitive advantage over smaller bat species (Monadjem et al. 2010a). However, displacement behaviour between different bat species could only be confirmed by fitting cameras to bathouses such as in the study of Kerth et al. (2001).

The distance to water, the altitude above sea level and the height of bathouses did not significantly influence bathouse occupancy in our study. While water availability is known to influence bat activity (Crisol-Martínez et al. 2016; Grindal et al. 1999; Rainho& Palmeirim 2011), the bathouses in this study were erected within 2 to 680 meters from the closest water source, all within the known home range of even small plain-faced bats (Monadjem et al. 2010b). We also suggest that the distance to water might become more significant in regions that are more arid than our subtropical study area. There might also be a difference in this response during dry season which we suggest should be analyzed once a large data set becomes available. The altitude above sea level did range from 607 to 932 meters in this study and did, therefore, not provide a great variation in temperature.

While we observed a number of other animals in the bathouses during this study, the present bathouse design did not seem to attract birds such as reported by Dodds& Bilston (2013). Interestingly, while there are contrasting observations on whether wasps displace bats from bathouses (Rügger et al. 2016), we did not observe co-habitation with wasps but with active beehives. However, tree squirrel and/or dormice might be able to displace bats as we only found a bathouse occupied by bats with a nest present once, in which case the nest seemed abandoned for some time.

The collection of bat faecal pellets, for a parallel project on bat diet, also suggests that the occupancy of bathouses is much higher than what we observed by recording the presence of individual bats during our monthly visits, as we often collected faecal pellets under unoccupied bathouses. While alternating between different roosts is well known especially for pregnant bats (Kerth et al. 2001) as well as fission and fusions behaviour (Kerth&König 1999) our study focused on the use of bathouses as a day roost and different occupancy numbers might be observed when conducting nightly visits.

All of the bathouses in this study are freestanding with no direct cover by trees or houses to either side. While we were unable to analyze the influence of the cardinal direction respectively sun exposure on bathouse occupancy, we suggest that future studies should consider this variable, particularly if bathouses are mounted onto the walls of houses and receive shadow from at the back. It would also be ideal to additionally test bathouses mounted back-to-back to provide additional insulation as proposed by Kiser and Kiser (2004).

It should also be noted that we found dead bats in or under bat houses on three occasions. Although we can currently not make an informed statement regarding the cause of these deaths, we would like to advice caution when it comes to placing bathouses within orchards, which are frequently sprayed with pesticides. We recommend to rather erect bathouses at the edges of orchards, in some distance to the crops which will be sprayed.

Conclusions

We suggest that warm and well insulated bathouses mounted freestanding on poles and in sets work best in northern South Africa. Further research should focus on co-habitation of bathouses and displacement behavior as well as add a greater variation in altitude and distance of bathouses to water. There is also a vast scope to experiment with different colors and position of bathouses.

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Table 1(on next page)

Final model testing the relationship between the occupancy of bathouses and the different types of bathouses in macadamia orchards, Levubu, South Africa (significance level of bold $p < 0.05$).

[a]Null model

Variable	Estimate	SE	Z	p-Value	AICc
Type of bathouse					367.48[a]
6 Chamber	**1.43**	**0.41**	**3.45**	**0.000**	**364.58**
Black	**2.30**	**0.56**	**4.08**	**0.000**	**364.58**
4 Chamber	0.50	0.45	1.10	0.268	**364.58**
Rocket box	-0.50	0.62	-0.81	0.415	**364.58**
White	0.57	0.67	0.85	0.394	**364.58**

Figure 1

Map of South Africa showing the location of the study area (white circle) in Levubu, Limpopo, South Africa (QGIS version 2.18.11).

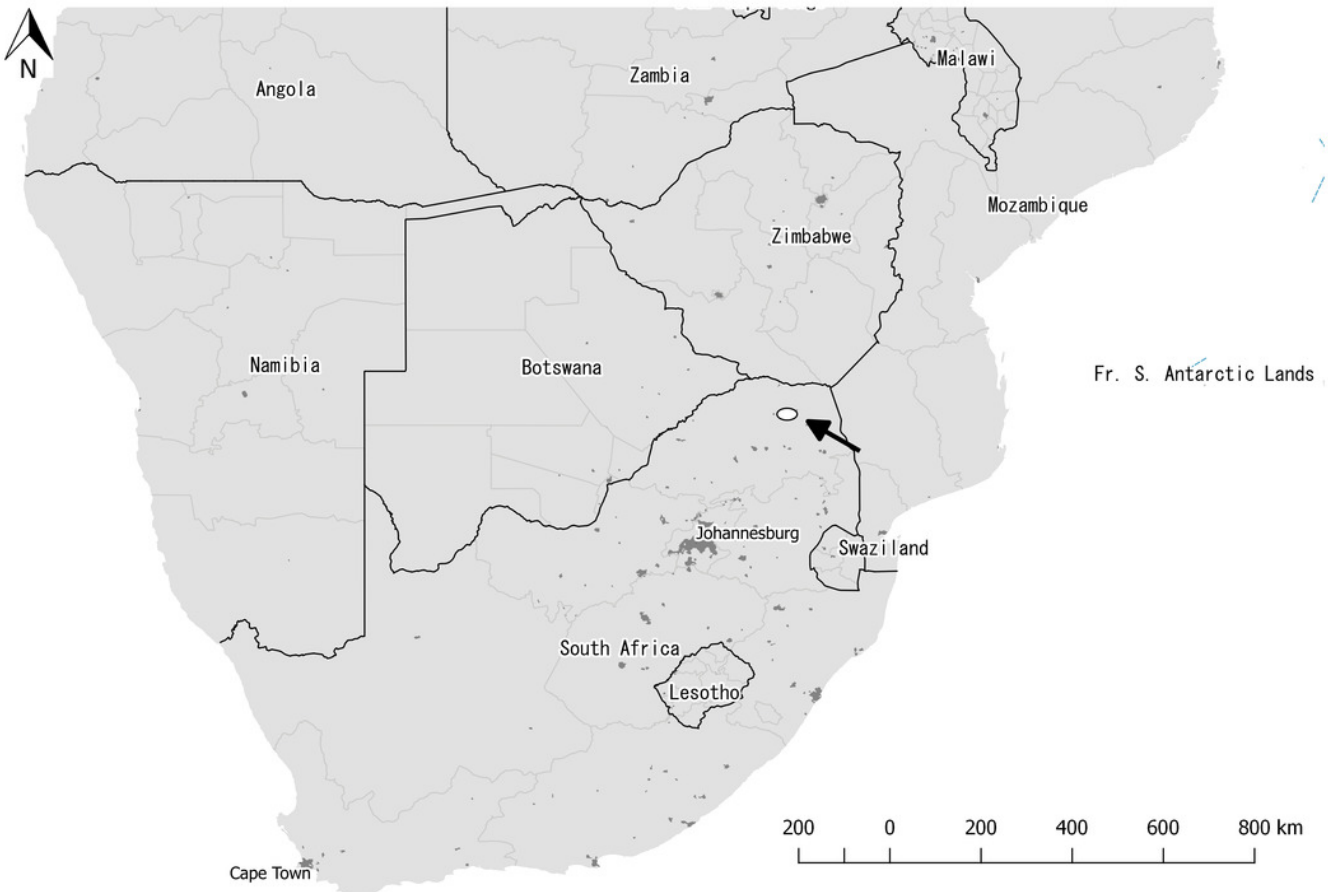


Figure 2(on next page)

Showing the different bathouse designs from the front and below, erected in the study area Levubu, Limpopo, South Africa. Photo credit: S.M. Weier

1) showing the set of three houses 2) showing the set of black and white bathouses 3) showing the Rocket box design and 4) showing the colony bathouse. The below view showing the a) Old George b) 6-Chamber and the c) Nursery bathouse.

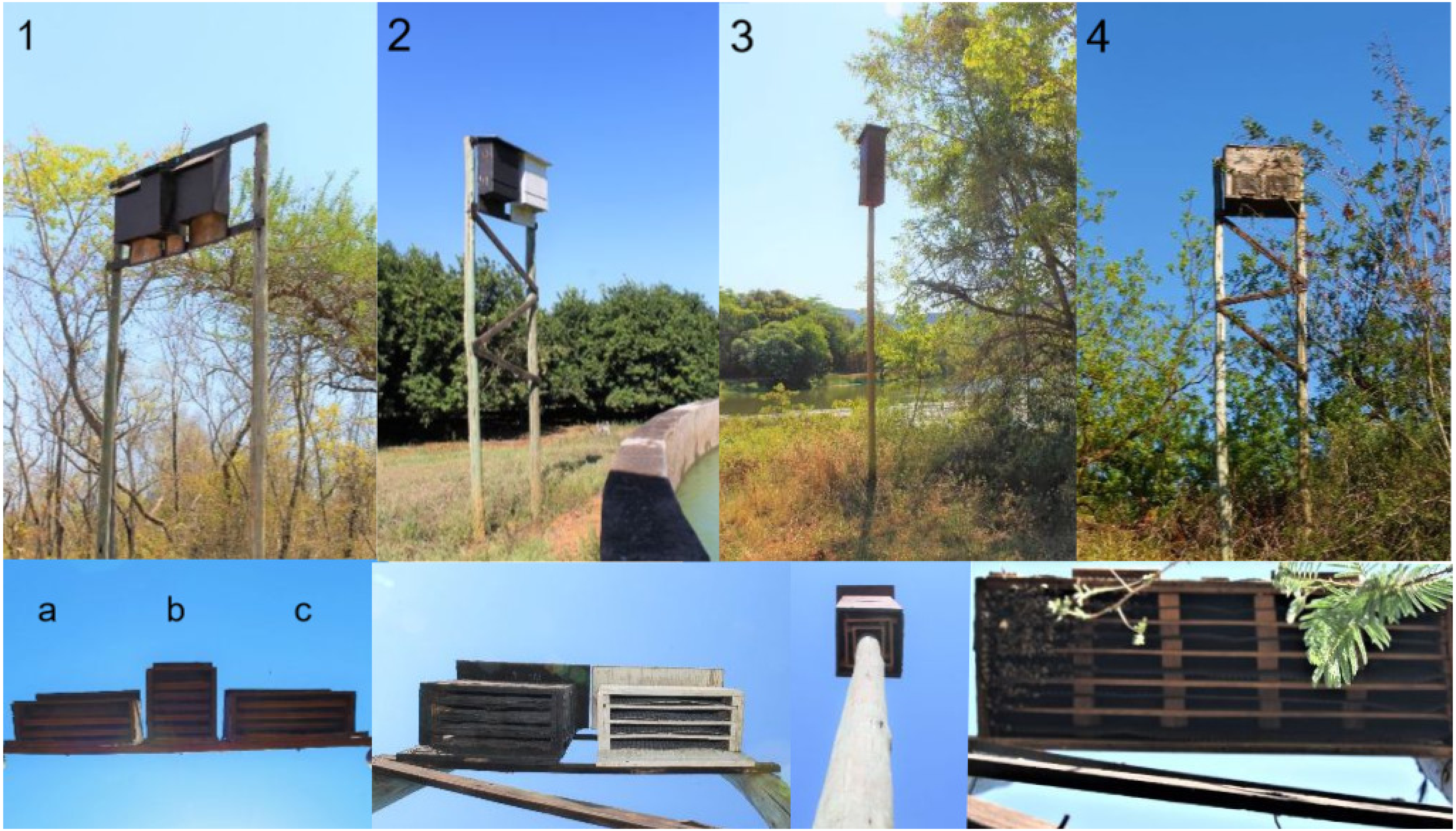
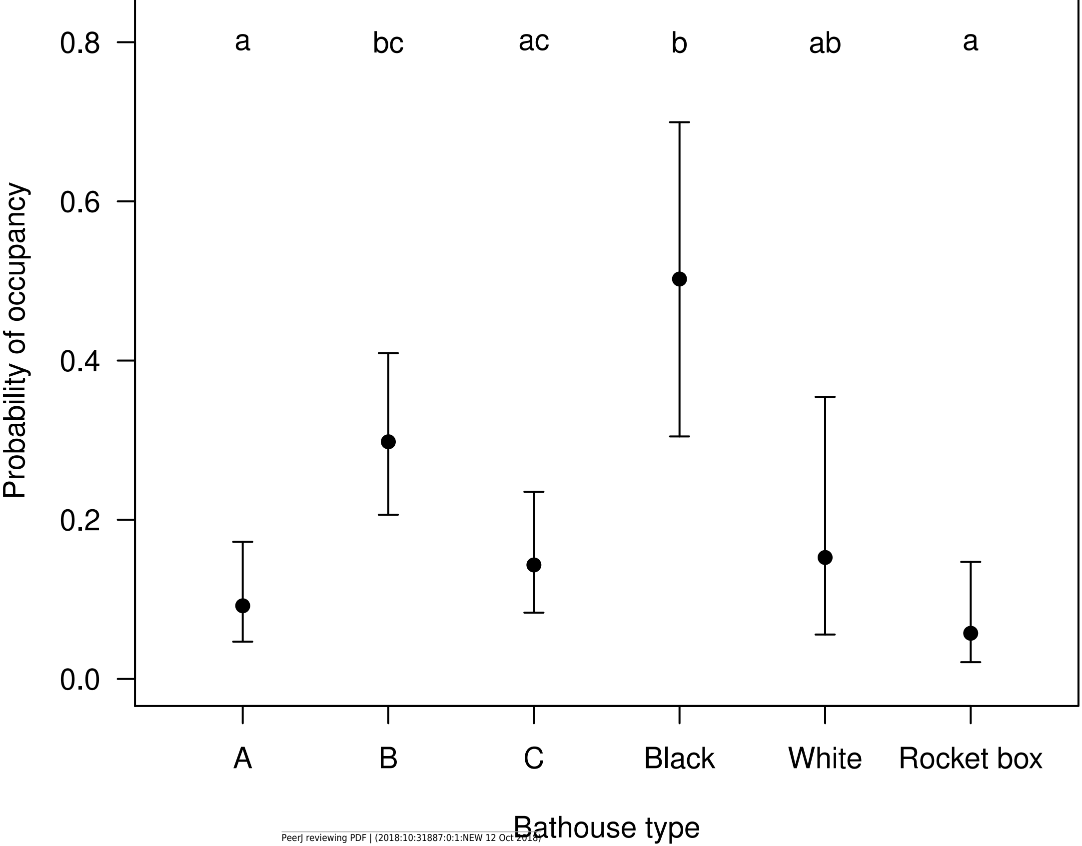

1
2
3
4
a
b
c

Figure 3(on next page)

Figure 3 Showing the probability of a certain type of bat house being occupied with in the study area Levubu, Limpopo, South Africa. Whereas, bathouse A (=Old George), bathouse B (=6-Chamber) and bathouse C (=Nursery) are always set up in sets of three wi

Bathouse A (=Old George), bathouse B (=6-Chamber) and bathouse C (=Nursery) are always set up in sets of three with the 6-Chamber bathouse in the middle. The black and white pained bathouses are also erected in sets. Annotated letters show same probability of occupancy (same letter) or a significant difference in occupancy levels (different letter). Confidence intervals of 95%.



0.8
0.6
0.4
0.2
0.0
Probability of occupancy
a
bc
ac
b
ab
a
A
B
C
Black
White
Rocket box
Bathouse type

Figure 4

A Common Slit-faced Bat (Nycteris thebaica) foraging on a green vegetable stinkbug (Nezara viridula) in the study area Levubu, Limpopo, South Africa. Photo credit: ©MerlinTuttle.org

Note: Auto Gamma Correction was used for the image. This only affects the reviewing manuscript. See original source image if needed for review.