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

Sina M Weier Corresp., [1] , **Valerie MG Linden** [1] , **Ingo Grass** [2] , **Teja Tscharntke** [2] , **Peter J Taylor** [1,3]

[1] SARChI Chair on Biodiversity & Change, School of Mathematical & Natural Science, University of Venda, Thohoyandou, Limpopo, South Africa
[2] Agroecology, Department of Crop Sciences, University of Goettingen, Göttingen, Germany
[3] School of Life Sciences, University of KwaZulu-Natal, Durban, KwaZulu-Natal, South Africa

Corresponding Author: Sina M Weier
Email address: sinaweier.univen@gmail.com

Despite the valuable ecosystem service of pest control provided by bats, an ever growing human population and agricultural intensification has led to a worldwide threat of extinction to about one quarter of all bat species. 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 bat houses, mounted on poles on six macadamia orchards, for bats or any other occupants such as wasps, birds and bees. Twenty-one multi-chambered bat houses of three different designs (6-Chambered, Nursery and Old George bat houses) were erected on poles, in sets of three. Additionally, five Rocket boxes, four bat houses, in sets of two (black and white) and one colony bat house 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 one set of three bat houses. We related the occupancy of bat houses in the different types of houses to the environmental variables distance to water, altitude and height of bat house as well as the difference in mean temperature between the set of three bat houses. The central bat house in the set of three and the black bat house in the set of two had a significantly positive effect on bat house 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 bat house. The Yellow-bellied house bat (*Scotophilus dinganii*) was by far the most recorded and the only species observed to co-habitat a bat house with other animal species, in particular honeybees. Our study might confirm previous assumptions in that the microclimate of bat houses, respectively their insulation, sun exposure and color appear to be important factors, positively influencing bat house occupancy. The two preferred bat houses in our study were the black, in the set of black and white, as well as the central house, in the set of three. In conclusion from the different bat houses tested in this study, the designs we assume the warmest and best insulated, which were mounted freestanding on poles and in sets worked best to attract bat house occupancy in northern South Africa. Further research on the preferred microclimate of bat species especially on the response to temperature variation within bat houses, co-habitation of bat houses and displacement behavior as well as the potential importance of altitude and distance to water is needed.

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Sina M. Weier[1], Valerie M. G. Linden[1], Ingo Grass[2], Teja Tscharntke[2] and Peter J. Taylor[1,3]

[1] SARChI Chair on Biodiversity & Change, School of Mathematical & Natural Science, University of Venda, Thohoyandou, South Africa

[2] Agroecology, Department of Crop Sciences, University of Goettingen, Grisebachstrasse 6, 37077 Göttingen, Germany

[3]School of Life Sciences, University of KwaZulu-Natal, Biological Sciences Building, South Ring Road, Westville Campus, Durban, KwaZulu-Natal 3630, South Africa

Corresponding author:
Sina Weier
PO Box 144, Vivo, Limpopo, 0924, South Africa
Email: sinaweier.univen@gmail.com

Abstract

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From June 2016 to July 2017 we scanned 31 bat houses, mounted on poles on six macadamia orchards, for bats or any other occupants such as wasps, birds and bees. Twenty-one multi-chambered bat houses of three different designs (6-Chambered, Nursery and Old George bat houses) were erected on poles, in sets of three. Additionally, five Rocket boxes, four bat houses, in sets of two (black and white) and one colony bat house 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 one set of three bat houses. We related the occupancy of bat houses in the different types of houses to the environmental variables distance to water, altitude and height of bat house as well as the difference in mean temperature between the set of three bat houses. The central bat house in the set of three and the black bat house in the set of two had a significantly positive effect on bat house 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 bat house. The Yellow-bellied house bat (*Scotophilus dinganii*) was by far the most recorded and the only species observed to co-habitat a bat house with other animal species, in particular honeybees. Our study might confirm previous assumptions in that the microclimate of bat houses, respectively their insulation, sun exposure and color appear to be important factors, positively influencing bat house occupancy. The two preferred bat houses in our study were the black, in the set of black and white, as well as the central house, in the set of three. In conclusion from the different bat houses tested in this study, the designs we assume the warmest and best insulated, which were mounted freestanding on poles and in sets worked best to attract bat house occupancy in northern South Africa. Further research on the preferred microclimate of bat

species especially on the response to temperature variation within bat houses, co-habitation of bat houses and displacement behavior as well as the potential importance of altitude and distance to water is needed.

Introduction

In Europe, artificial bat roosts 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 bat houses 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; Taylor et al., 2018; 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; Park, 2015) and 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). Given the accelerating land use change from natural to agricultural landscapes especially in the third world and the assumed decline in South African bat populations (Voigt & Kingston, 2016), proactive management of bat populations is indispensable to sustain their long-term ecosystem services (Cumming et al., 2014; Taylor et al., 2017; Tuttle et al., 2013). Proactive management of bat population will require to fill existing knowledge gaps on roost site preferences for African bat species and the means of successful conservation of bats in intensive agricultural systems in particular (Monadjem et al., 2009; Park, 2015; Taylor, 2000).

Peer-reviewed studies focusing on artificial roost site use by African bat species are literally non-existent and by far the most studies have been conducted in Europe followed by North America and Australia (Rueegger, 2016).

Summarizing the studies conducted globally so far, bat species seem to have a general preference for bat houses with a large volume, multi-compartments and those mounted on poles or houses compared to bat houses mounted on trees (Rueegger, 2016). There also seems to be a preference for bat houses build from 'woodcement' (Dodds& Bilston 2013; Gerell 1985; Haensel& Tismer; 1999), 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 bat houses, respectively insulation, sun exposure and color seems to be an important factor influencing bat house occupancy (Fukui et al. 2010; Rueegger, 2016; Shek et al. 2012). Looking at different designs and colors of bat houses, 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 bat houses by other species, mostly by birds and social bees, ants and wasps (Baranauskas 2009; Dodds& Bilston 2013; Meddings et al. 2011).

There is certainly a great need for research on artificial roost site use, especially in Africa, and this is the first peer-reviewed study looking at the occupancy of bat houses in South Africa.

Successful bat house 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 (bat houses)?

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

Materials and methods

Study area and bat house 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 bat houses 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 bat house in the middle as well as an Old George bat house and a

Nursery bat house to either side (see Figure 2). Both the Nursery bat house and the Old George bat house 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 bat house has four chambers getting shorter in length towards the back of the house (see Figure 2). These bat houses 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 bat houses. The freestanding rocket boxes allow the bats to move around in 360° degrees within the house and choose from a range of temperatures respectively sun exposure. An additional four four-chambered bat houses, in sets of two (painted black and white in order to provide different microclimates), also mounted on poles and one colony bat houses were erected 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 Supplementary Table 1 for detailed information.

As proposed for warm climates by the 'North American bat house research project', all bat houses erected for this study have open bottoms (Kiser&Kiser 2004). They are also placed near water sources and natural vegetation, wherever possible. Except for the colony bat house, several bat houses were erected at each location, which is proposed to positively influence occupancy by providing different microclimates (Sedgeley, 2001). Alternating between different bat houses might also be necessary for bats to avoid predators and high ectoparasite loads (Lewis, 1995; Reckardt&Kerth, 2006).

Bat house occupancy

All bat houses 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. We are working under the ongoing permit (No. 001-CPM403-00010) for research on small mammals from the Limpopo Department of Economic Development, Environment and Tourism. During 1st of December to 20th of March 2017, three IButtons (Thermochron, DS1921G-F5) were successfully installed with a tongue and sticky tape at each of the three entrances of one set of three bat houses to record temperature variation between the bat houses 1.5 hourly. While scanning the houses and fitting the IButtons we tried to avoid touching the bat house 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 bat house.

Data analyses

All statistical analyses was conducted with R (version 3.4, R Core Team 2017). The bat house of the type ‘colony’ was not used for analyses, as there was only one bathouse of this type.

The relatively small sample size of 31 bat houses (with 21 of them erected in sets of three) lead to a correlation between the type of bat house and the cardinal direction the different houses are facing. Additionally, not all possible combinations of the different bat house 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 bat house’, ‘altitude’, ‘distance to water’ and ‘height of the bat house’ (see Supplementary Table 2).

After testing the model for normal distribution and constant errors variance, we applied a generalized linear mixed model (GLMM) with a binomial distribution (package ‘lme4’ by Bates et al. 2015). 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 (package ‘stats’ by

R Core Team 2017). Additionally, we used the summary statistics base function 'tapply' to look at differences in range and mean of temperature (version 3.4, R Core Team 2017).

Results

We recorded a total of 166 individual bats within the 31 bat houses, from June 2016 to July 2017, with a maximum of 5 individual bats in one bat house (DatasetS1). The highest average number of bats was recorded in March and May (on average 0.53 bats per bat house), 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 Supplementary Table 3).

Type of bat house

The first five models selected by dredge, analyzing the relationship of the response variable 'presence or absence of bats' with the predictor variable(s) were all within a delta AICc of <2 (see Supplementary Table 2). After testing all five models, which each retained 'type of bat house' as the only significant variable, we decided for the simplest final model (presence of bats~type of bathouse).

The bat house occupancy on the macadamia orchards was influenced by the type of bat house, in that the central bat house (β=1.43, SE= 0.41, $p<0.001$) in the set of three and the black bat house in the set of two (β=2.30, SE=0.56, $p<0.001$) had a significantly positive effect on the presence of bats (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 (DatasetS2). A post hoc Tukey test showed that there was a significant difference in temperature of 0.46°C between the second, 6-Chamber bat house, and the first bat house (p=0.016, an Nursery bat house, and a marginal significant difference between the third, Old George bat house, and the second house (p=0.055). The temperature range was between a minimum of 12.5 and maximum of 40.5°C in the Nursery bat house and between min. 12 and max. 41°C in the second and third bat house (6- Chamber and Old George house). The mean temperature was the warmest in the second (central) bat house with 23.52°C compared to 23.06°C in the first bat house and 23.13°C in the third bat house. The ambient temperature recorded in Ratombo (about 7 km as the crow flies from the Ibuttons used in this study) over the last 30 years, from December to end of March, shows a mean daily minimum of 18-19°C and a mean daily maximum of 27-28°C with peaks of up to 35°C in December (Meteoblue, 2018).

Other bat house occupants

We observed a number of other animals occupying the bat houses 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 bat house with an active honeybee hive.

Discussion

From 166 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 bat house type was a significant variable influencing bat house occupancy, with a preference for the black house, from the set black and white, and the 6-Chamber model, the central house in the set of three. We assume that these are the two warmest houses, because of color (black) and insulation (central house of three and 6-chambered) and are, therefore, the preferred types of bat houses 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, suggest that colonization of bat houses in and around macadamia orchards might be highest in times of high prey availability of pest insect species particularly stinkbugs (see Figure 4).

Our study might confirm previous assumptions in that the microclimate of bat houses respectively insulation, sun exposure and color are important factors influencing bat house occupancy (Fukui et al. 2010; Kerth et al. 2001; Lourenço& Palmeirim 2004; Sedgeley, 2001; Shek et al. 2012).

Bats generally preferred the black houses, in the set of black and white, and 6-Chamber models, the central bat house in the set of three. The 6-Chamber models were mounted flanked either side by other houses and had the most chambers of all erected bat houses, which provided additional insulation (see Figure 2). 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 bat house, the 6-Chamber model, is erected individually. However, we suggest that the insulation to either side of the 6-Chamber bat house by an additional bat house and the amount of chambers had a significant effect on bat house occupancy respectively microclimate. It should be noted, however, that only one set of three houses was measured with Ibuttons in our study and temperature deductions are based on this data. Future studies should aim at a higher sample size in order to investigate possible temperature variances caused by environmental factors. Because black colors absorb wavelength and therefore energy and white colors reflect them, it is reasonable to assume that the black bat houses in the sets of two are significantly warmer than the white bat houses. However, precise information on the differences in temperature would provide further insight into the preferred microclimate of bathouses by different bat species.

The colony bat house remained unoccupied throughout this study. In order to distinguish if this is an effect of the location or the type of bat house, several colony bat houses need to be erected and monitored. We also suggest that the colony bat house might have remained unoccupied because it did not provide any other artificial roost sites in close vicinity so alternating between different bat houses was not possible. The Rocket box design did particularly well in the United States and Canada with 62% overall occupancy (Kiser&Kiser, 2004), therefore, occupancy of the Rocket boxes might still increase with time (Agnelli et al., 2011). However, one component, which both the Rocket box and the Colony bat house 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 can only be confirmed by for example fitting cameras to bat houses, such as in the study of Kerth et al. (2001). Furthermore, it is not yet known what effect the installation of artificial roosts have on the local community composition of bats and if it might lead to displacement behaviour of rare species by common species (Russo&Ancillotto, 2015).

The distance to water, the altitude above sea level and the height of bat houses did not significantly influence bat house 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 bat houses 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 the 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 bat houses during this study, the present bat house 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 bat houses (Rueegger, 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 bat house occupied by bats with a mammal 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 bat houses 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 bat houses. While alternating between different roosts is well known especially for pregnant bats (Kerth et al. 2001; Reckardt& Kerth, 2006) as well as fission and fusions behaviour (Kerth&König 1999), our study focused on the use of bat houses as a day roost and different occupancy numbers might be observed when conducting nightly visits.

As visits were conducted monthly, we could not exclude the possibility that signs of bat presence such as faeces were washed away by rain or disintegrated in the sun beforehand. We did, therefore, not include this in our analyses. However, this variable should be kept in mind for future studies and might be a possible variable to use for studying winter roost occupancy during the dry months in northern South Africa, especially if data is collected over several years.

All of the bat houses 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 bat house occupancy, we suggest that future studies should consider this variable, particularly if bat houses are mounted onto the walls of houses and receive shadow from at the back. It would also be ideal to, additionally, test bat houses mounted back-to-back to provide additional insulation as proposed by Kiser and Kiser (2004) and control temperature variation between all houses of different designs.

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 bat houses within orchards, which are frequently sprayed with pesticides. We recommend to rather erect bat houses at the edges of orchards, in some distance to the crops which will be sprayed.

Conclusions

From the experience gained so far in northern South Africa, the bat houses we assume the warmest and best insulated, which were mounted freestanding on poles and in sets worked best to attract bat house occupancy. Further research is necessary and should focus on co-habitation of bat houses and displacement behavior as well as add a greater variation in altitude and distance of bat houses to water. There is also a vast scope to experiment with different colors, designs and position of bat houses and to look into the preferred microclimate of different bat species especially their response to temperature variation within bat houses.

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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 $p < 0.05$).

Variable	Estimate	SE	Z	p-Value	AICc
Null model					388.2
Type of bathouse					**364.6**
6-Chamber	**1.43**	**0.41**	**3.45**	**0.000**	
Black	**2.30**	**0.56**	**4.08**	**0.000**	
Nursery box	0.50	0.45	1.10	0.268	
Rocket box	-0.50	0.62	-0.81	0.415	
White	0.57	0.67	0.85	0.394	

Figure 1

Map showing the aerial image of the study area with the location of the different bat houses and the study area in Levubu, Limpopo, South Africa (Google Maps 2018;QGIS version 2.18.11).

A) Study area with the location of each bat house B) showing a detailed example of one study site and C) the location of the study area (white circle) in Levubu, Limpopo, South Africa.

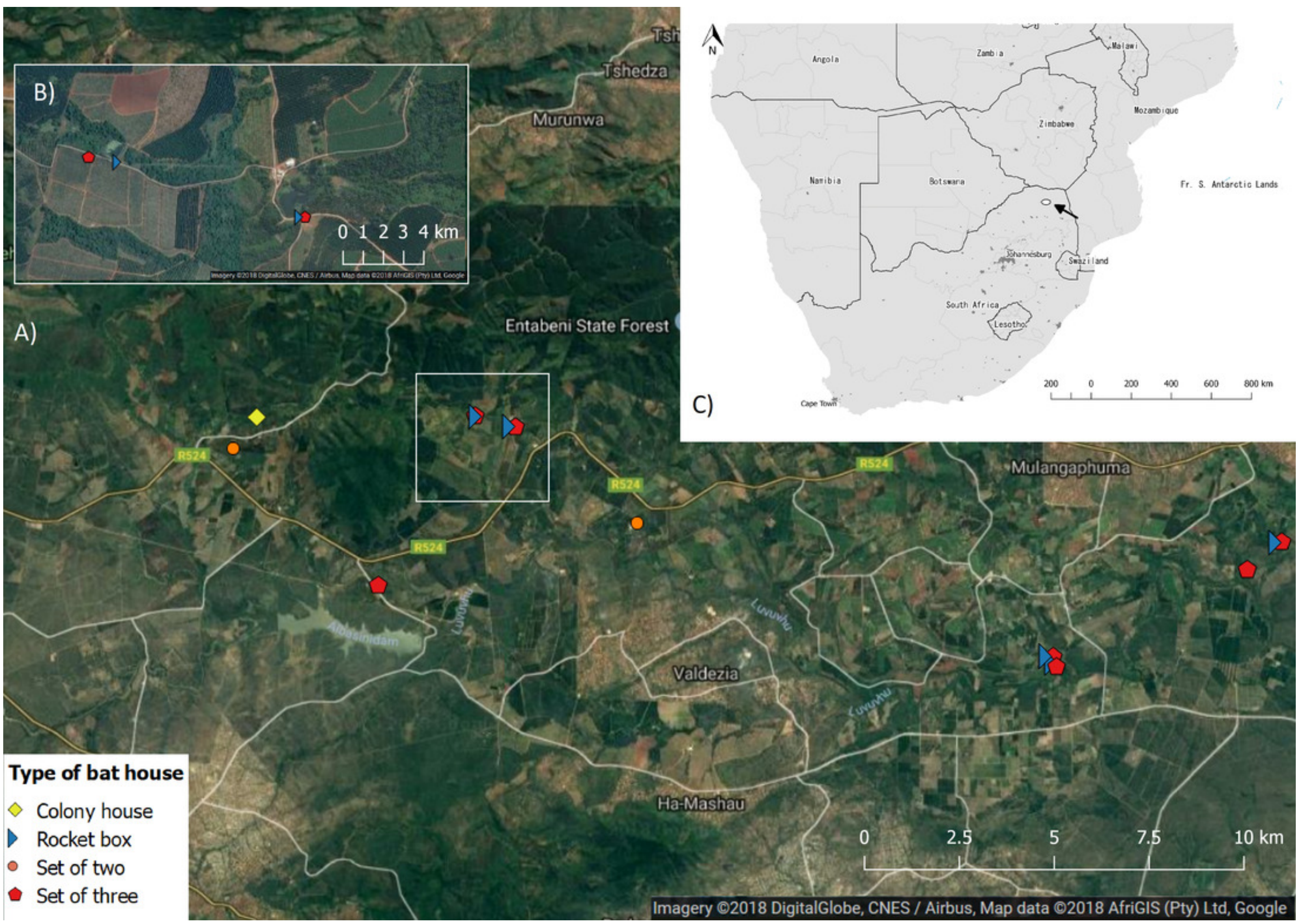

Figure 2

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

A) showing the set of three houses B) showing the set of black and white bat houses C) showing the Rocket box design and D) showing the Colony bat house. The below view showing E) the Old George, the 6-Chamber and the Nursery bat house (left to right) F) black and white house G) Rocket box H) Colony bat house.

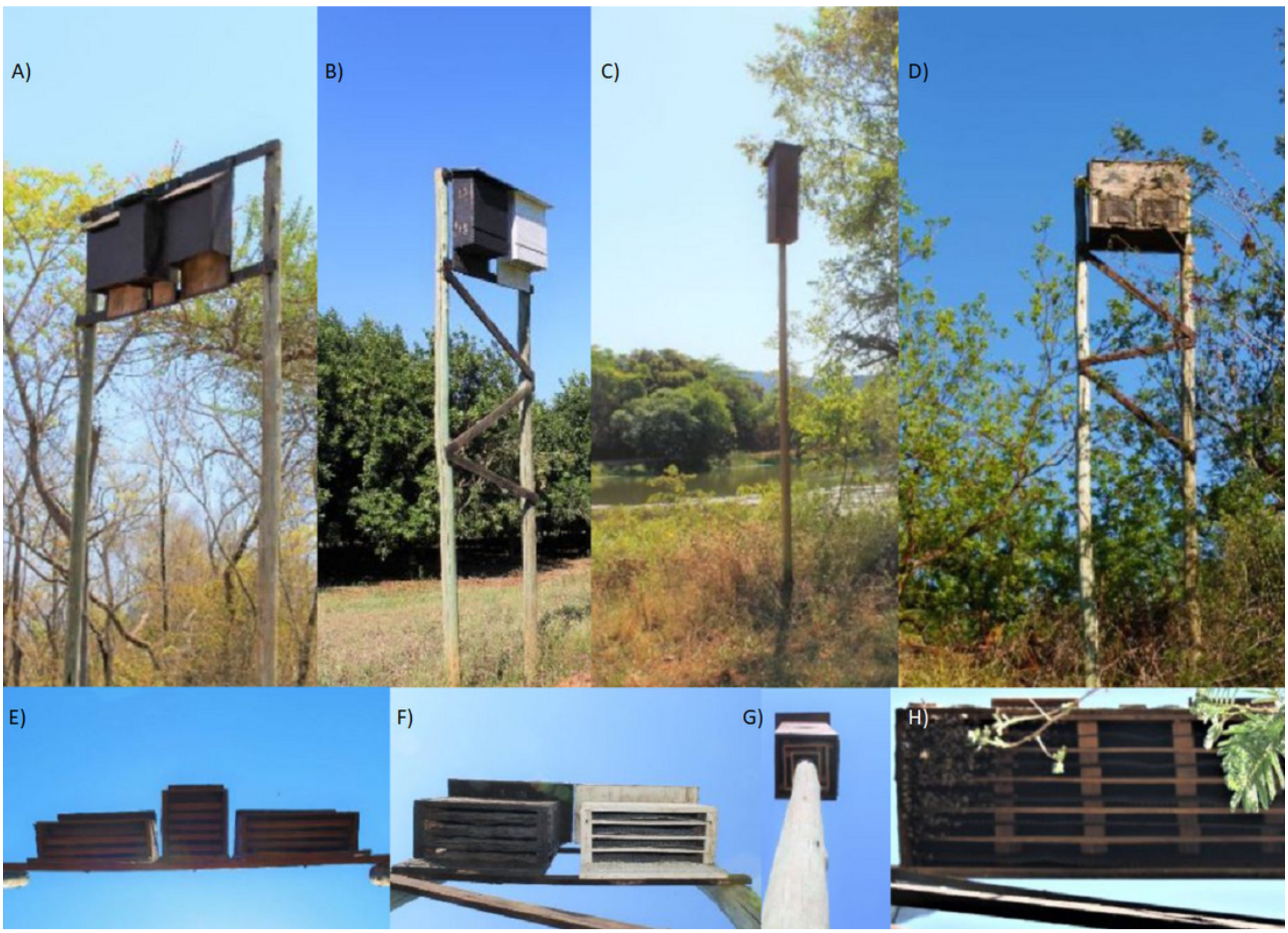

Figure 3 (on next page)

Figure 3 Showing the probability (Confidence intervals of 95%) of a certain type of bat house being occupied with in the study area Levubu, Limpopo, South Africa.

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

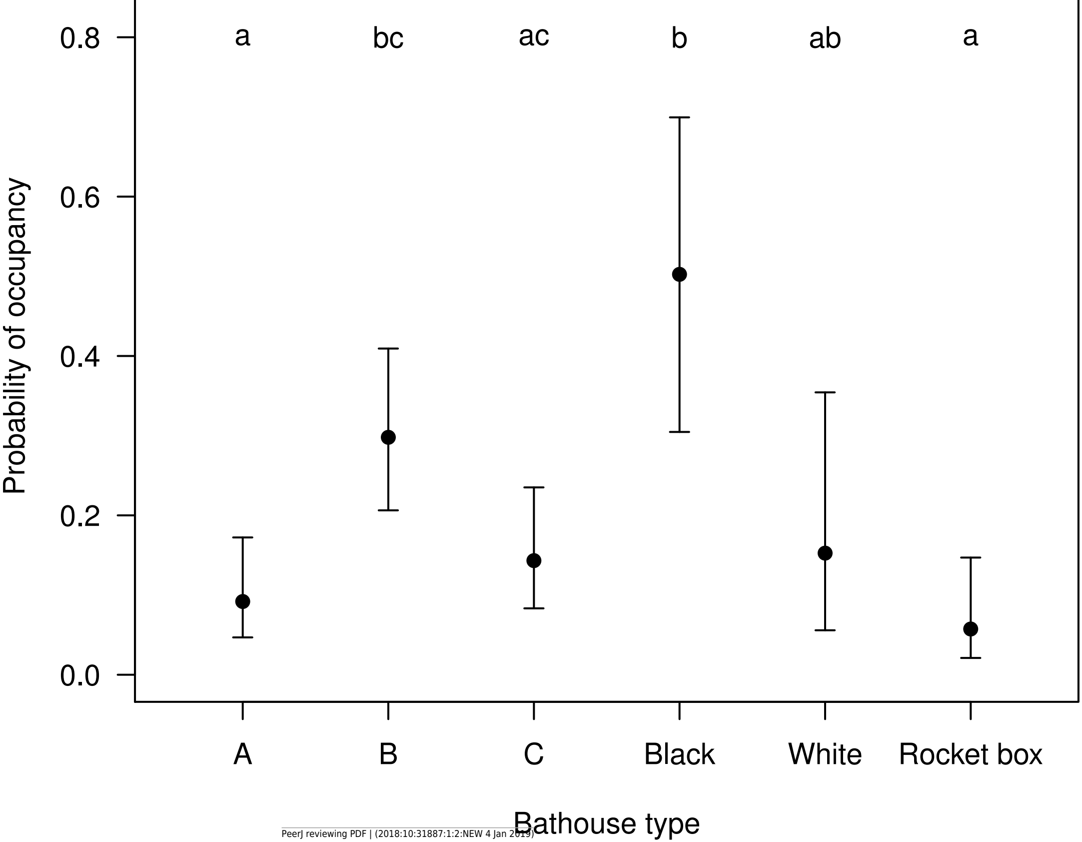
0.8
0.6
0.4
0.2
0.0
Probability of occupancy
a
bc
ac
b
ab
a
A
B
C
Black
White
Rocket box
Bathouse type

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.