Day-Roost Selection by Alberta Bats in an Urban Environment

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Abstract

Urbanized areas become unsuitable habitat for temperate-zone, tree-roosting bats. As urbanization increases, an alternative to natural roosts is required to provide habitat for the remaining populations. I sought to identify the box and habitat characteristics affecting occupation rates, as well as the reproductive success of the bats occupying those boxes. During the Spring and early Summer of 2017 various characteristics were recorded at each box within Central and Southern Alberta and their occupation status was determined by the end of that Summer by performing multiple exit counts (n= 45 boxes). Variables that significantly affected the temperature of the bat boxes were first identified with linear mixed-effects models. Boxes within the Calgary city limits had significantly warmer minimum temperatures than those outside of the city, and boxes with more chambers had significantly cooler maximum temperatures. No rocket style boxes within the study were occupied (n= 8 boxes). They were not included in further analyses due to an apparent aversion of the style by bats. Finally, generalized linear models with a binomial distribution were created to determine that occupation rates were increased when boxes were attached to buildings as opposed to trees or poles. These results can be used to give suggestions for future bat box design to increase general occupation or to specifically attract subsets of the urban bat population (e.g. reproductive females). If enough suitable bat boxes are placed within urban areas then urban bat populations can be assisted during the summer in their attempt to store enough energy to survive the winter.

Introduction

Small mammals are vulnerable to their environment as well as to aerial and terrestrial predators. Many of these organisms have found success in the use of a resting microhabitat to protect them from predation and harsh conditions, as well as to lower their energetic costs. These habitats serve a purpose by having insulating boundaries that provide conditions that vary less to extremes (Chappell 1980). Small mammals use various resting microclimates to serve particular functions over the changing seasons.

Hibernacula are used by some temperate-zone bats and other mammals that choose to remain near their summer distribution and hibernate to survive the winter (Nuebalm et al. 2006). Other bat and mammal groups continue using day-roosts in the Winter by migrating to warmer climates (Barclay et al. 1988). All temperate-zone bats, though, use summer day-roosts to rest in during the day and recover from a costly night of flying. Many processes involving food availability, thermoregulation, and predation avoidance create the large significance of roost selection in bat ecology (Vonhof and Barclay 1996). Being most active in the summer, a bat's success both short term (the energy available for the following night of foraging) and long term (the amount of stored energy in the form of fat that a bat needs to survive migration or hibernation) depends on their ability to choose suitable summer day-roosts. Due to the inability of temperate-zone bats to create their own roost sites, they are entirely reliant on the presence of existing roosts (Kunz and Lumsden 2003).

Summer day-roosts require a vigorous selection process as their microclimate determines the energetic costs for that day and evening. A warm roost reduces the need to use torpor (a reduction of metabolic rate causing a subsequent reduction in body temperature) by reducing the cost of thermoregulation and of passively rewarming (Kerth et al. 2001; Lewis 1993). A cool roost increases the energetic savings of going into torpor (Lausen and Barclay 2006). A single population of bats will adopt multiple thermoregulatory strategies and so multiple roosts with varied microclimates must be available to support the group (Grinevitch et al. 1995; Lewis 1993).

Canadian bats are primarily tree-roosting during the summer. These bats roost in old, dying trees once cavities are made accessible to them by pests, disease, and severe weather (Barclay and Brigham 1996; Vesk et al. 2008). Human development has led to a decline in suitable tree roosts within Canada. As urbanization increases (UNPD 2012) the complete deforestation of city and surrounding areas (e.g. farmland) creates a lack of natural roosts (Villaseñor et al. 2014). Some species, notably *Myotis lucifigus* and *Eptesicus fuscus*, have adapted to this loss by entering urban areas and roosting in human-made structures such as bridges and buildings (Coleman and Barclay 2012). To provide urban bat populations with suitable roosts and to avoid any potential, negative human-animal interactions, bat boxes can be placed in urban areas with low roost availability. Although these boxes may increase the overall abundance of roosts, they cannot maintain successful populations without being suitable for reproductive females, specifically.

Sub-groups of bat populations use different thermoregulatory strategies. Maternity colonies prefer to roost in warm microclimates and avoid torpor by passively rewarming as a group (Grinevitch et al. 1995). In doing this, reproductive females avoid the delay in parturition and reduced lactation associated with the reduction in metabolic rate due to being in torpor (Lewis 1993). Because of this, maternity colonies are more often found in both natural and artificial roosts that are warmer and large enough for colony formation (Kerth et al. 2001). Existing literature on bat-box selection by maternity colonies is currently lacking. Most urban maternity colonies in research are found in residential attics or building cavities (Lausen and Barclay 2006). There are contradicting opinions on whether it is best for bat boxes to mimic the most preferred natural tree roosts or the attic roosts of urban colonies (Doty et al. 2016; Kerth et al. 2001).

Though bat boxes are supporting urban populations by providing available roosts, their suitability for reproductive success has not been tested. If artificial roosts are the only available resting habitat in an area, they will eventually be occupied by any bats in the area. If those boxes provide unsuitable conditions, the fitness of individuals or entire colonies may decline. Most research chooses to focus on bat abundance as a measure of the preference of bat boxes by bats (Doty et al. 2016; Brittingham and Williams 2000). While the use of bat boxes by a population may be promising, the group may not be successful (At reproducing and/or storing energy). This may lead to increased mortality rates of these urban bats over the Winter and decreased rates of fertility in the subsequent Spring. Future research into bat box success cannot focus entirely on occupation rates, but on the fitness of the individuals occupying the boxes. If bat boxes can become a part of any effective conservation strategy, it must first be determined if bat boxes in urban areas have the potential to create population sinks.

With this study, I aimed to better estimate the suitability of bat boxes for urban bat populations. I planned to determine if specific artificial roost characteristics or those of their surrounding habitat were preferred by bats, as determined by occupation rates. The study area for this project included various urban centres and the surrounding rural areas of Central Alberta. A focus was made on Calgary and its surrounding areas, but boxes farther North in Alberta (e.g. Lacombe, Nanton, Red Deer) were also included. Initially, a priority was placed on identifying maternity colonies within bat boxes. However, the study boxes were continuously monitored for any occupation event, even individuals.

To test the suitability of bat boxes for urban bat populations, I originally focussed on the bat box characteristics that would best support maternity colonies based on the ecological constraints unique to reproductive female bats. I recorded bat box and habitat characteristics and determined the occupation status for each box to test the hypothesis that those characteristics would influence occupation rates of the bat boxes by making them more or less preferable to bats. I had three predictions to test: 1) That box characteristics would influence the temperature range in bat boxes (Lourenco and Palmeirim 2004); 2) That characteristics creating warmer bat box microclimates would result in higher occupation rates (Webber and Willis 2018); 3) That bat boxes closer to resources (e.g. Water source) would have higher occupation rates (Nuebaum et al. 2007); and 4) That bats would show preference for boxes with characteristics of increased protection from predation and human disturbance (Lausen and Barclay 2006; Nuebaum et al. 2007).

Methods

Study Area

The boxes in the sample include those on private, industrial, and public land sites. The bat boxes in the study can be grouped into those in the Calgary and immediately surrounding area (e.g. Okotoks, Priddis, etc.) for which I personally collected information, and then those further North in the greater central Alberta area (Red Deer, Lacombe, Nanton) that were observed by the owners as a 'Citizen Science' aspect of the research. All roost characteristics and the occupation status were collected by the owners at these sites.

Roost and Habitat Characteristics

Initial observations and measurements were collected at all bat boxes in April and May 2017 (Table 1). I measured height using a Clinometer or measuring tape when possible. I determined aspect with a compass. The box dimensions (exterior length, width, and depth) were collected with a standard measuring tape in the Spring for those boxes with temperature loggers installed. The other box dimensions were collected in January 2018 with a measuring stick and pole to take scale photos. After collecting GPS locations with a handheld GPS for each box, I determined habitat characteristics (e.g. nearest water body and tree cover) with Google Maps. The location for each bat box was separated into 'within city' and 'outside city' designations based on location with respect to Calgary to match the level of urbanization surrounding the boxes. The box style variable divided the boxes into rocket boxes and standard boxes (Fig. 1).

Information from the owners on previous occupation rates (where applicable) was used to determine the placement of temperature data loggers to attempt a balanced study. From May to June, 4 Onset HOBO (E348U23-002) and 6 Onset Boxcar loggers (H08-001-02) were placed in an equal number of expected occupied and unoccupied boxes and they subsequently collected temperature recordings every half hour. The loggers were attached to flat wooden sticks, which were then attached to wooden dowels by zip ties. The loggers were placed halfway up the box interior, with the dowels attached to the box entrance with staples or clamps. The loggers were placed in the inner chamber when applicable and were placed in the South chamber in rocket boxes. Hourly atmospheric temperature data were collected from the COP Calgary observatory by Environment Canada (Fig. 2).

Occupation status was determined by performing at least three exit counts at each box throughout the Summer of 2017. To identify boxes with maternity colonies, these were specifically timed to occur before parturition, after parturition, and after fledging. The exit counts were performed by arriving on site at least 30 minutes before sunset. At least one researcher was placed at each box if there were multiple boxes on site. Each individual exit was counted until at least 30 minutes after sunset, after which we would shine a flashlight up the opening of each box to ensure that they were empty. Maternity colonies were identified during exit counts that occurred between estimated times of parturition and fledging by confirming the presence or absence of pups remaining in the roost after post-sunset exit. To be considered occupied, a box required at least one occupation event during the summer.

Statistical Analyses

All figures and descriptive statistics were created using Microsoft Excel 2016. The model analyses were performed using the statistical program R, version 3. 4. 1. The results for all statistical analyses were interpreted using a significance value of $p < 0.05$.

Due to the expected impact of temperature on roost occupation, I generated linear mixed-effect models for maximum and minimum daily temperature. Sixty-six days of temperature data were used for the analysis of ten boxes within the study. The random effect of the grouping of temperature by box was first selected. Model selection of reduced maximum likelihood linear mixed models was performed with AIC to determine this random effect. Once the optimal random effect was selected, model selection occurred by testing maximum likelihood linear mixed models with varied fixed effects using AIC. All models included ambient temperature as a covariate.

Once the variables that significantly predicted the variance in temperature were determined, they were added (with other ecologically important variables) to occupation models. Variables were considered ecologically significant based on prior knowledge of bat biology as well as by comparing the median/average values of the variables between occupied and unoccupied boxes. Numeric variables were tested for normality by observing their qqplots and histograms. Variables determined to be non-normal were log-transformed.

Multicollinearity was tested with VIF values, any collinear variables were identified and redundant variables were removed from the models. Generalized linear models, fitted to a binomial distribution with the logit link function, were produced. Model selection was performed with AIC with a dAIC value < 2 used as the criteria to determine the best fitting models.

Results

A total of forty-nine bat boxes were measured/observed and their occupation status recorded. Four of those boxes were destroyed beyond the potential for occupation and thus were not included in further analyses. Two box styles were observed with 8 rocket style boxes and 37 standard style boxes (Fig. 1). The age of the boxes ranged from newly placed the summer of the study (0 months) to 25 years old. There were 26 single-chambered and 18 multi-chambered boxes. The structures to which boxes were attached included 17 buildings, 22 poles, and 6 trees. Eleven boxes were identified as within the Calgary city limits while 34 boxes were in the surrounding municipalities of central Alberta.

Two bat species were identified by sight from the boxes *Eptesicus fuscus* and *Myotis lucifigus*, although not all bats were identified at each box. Bats occupied 20 boxes, while 25 remained unoccupied throughout the summer. The number of individuals in occupied boxes ranged from 1 to 276 bats with an average of 6 bats (s = 14.4). No rocket boxes were occupied (n= 8 boxes), only standard boxes (n= 37 boxes). Two maternity colonies were identified by the presence of infants left in the boxes after the post-sunset exit.

The temperature range for unoccupied boxes was -0.6ºC to 53.5ºC and for occupied boxes was 1.2ºC to 47.4ºC. Four boxes surpassed the maximum tolerable threshold of 42℃ for the two known ‘urban’ species *M. lucifigus* and *E. fuscus* (Davis et al. 1968). Two of these boxes were consistently unoccupied all summer while the other two were abandoned halfway through the summer (Fig. 3). The average maximum daily temperature of occupied boxes, $\bar{x}$ = 35.36 ℃ (s = 8.28 ℃), was higher on average than unoccupied boxes $\bar{x}$ = 31.90 ℃ (s = 7.73 ℃); this was also seen in the minimum daily temperature of occupied and unoccupied boxes ($\bar{x}$ = 10.16 ℃ (s = 3.66 ℃); $\bar{x}$ = 9.28 ℃ (s = 3.85 ℃) respectively). Specific boxes were consistently cooler or warmer than both ambient temperature and the temperature of other boxes throughout the summer season (Fig. 2). There was more variation in maximum temperature (approximately 25 ℃ on average) than minimum temperature (approximately 10 ℃ on average) (Fig. 2).

AIC determined two best-fitting linear mixed-effects models for minimum temperature (Table 2). Both models included the random intercept effect of box ID (Fig. 4), the covariant of minimum ambient temperature, and the fixed binary option of the location within or outside of the city. The first model also included the binary option of the box attached to a building or not. Building did not have a significant effect (p-value > 0.05), while location within the city had a significant, positive effect on minimum temperature (Table 3; Fig. 5). Due to the nested nature of model m1 within model m2, I selected model m1 as the best fitting. These results are consistent with my first prediction due to the habitat characteristic of the location influencing the lower end of the box temperature range.

Three models were selected by AIC as best-fitting linear mixed-effects model for maximum temperature (Table 4). All models included the random intercept and slope effect of box ID (Fig. 6), the covariate of maximum ambient temperature, and the fixed effect number of chambers. A second model also included the binary variable Shade. Shade did not have a significant effect on maximum temperature (p-value > 0.05). A third model had the binary variable Colour, which was also insignificant (p-value > 0.05) (Table 5). Maximum temperature significantly declined with increasing number of chambers (Table 4; Fig. 7). Due to the nested nature of model m1 within models m2 and m3, I selected model m1 as the best fitting. These results are consistent with my first prediction due to the box characteristic of the number of chambers influencing the upper end of the box temperature range.

Due to all rocket-style boxes being unoccupied, they were removed from the sample for the occupation models. The sample size was thus decreased to 37 boxes. With the variables most influential to box temperature determined, other ecologically significant variables were identified for an analysis of occupation. By comparing average values, median values, and variable ranges, variables were identified as having different distributions by occupation status. The box age (in months) as well as the distance to water (meters) variables were both heavily skewed to the right and so they were both log-transformed (Fig. 8; Fig. 9).

In total, the number of chambers, the location relative to the City of Calgary, the attached structure, the level of shade, the log-transformed age, and the log-transformed distance to water were investigated for their effect on occupation using generalized linear models. Three models were selected by AIC as the best-fitting binomial generalized linear models for occupation (Table 6). All models included the variable Structure, which was significant in all cases (Fig. 9). Boxes in buildings were more often occupied than those on poles or trees (Fig. 10). The first model also included the variable number of chambers, which was not significant (p-value > 0.05). The second model included the log-transformed distance to water (meters), which was also not significant (p-value > 0.05) (Table 7). Due to the nested nature of model m1 within models m2 and m3, I selected model m1 as the best fitting. These results were not consistent with my second prediction due to the temperature-related variables not affecting the occupation rate. My third and fourth predictions were also unsupported due to habitat characteristics related to resource availability and characteristics related to protection both not affecting occupation rates.

Discussion

As urbanization increases and human development leads to urban expansion, it is becoming more important to not only focus on maintaining ‘pristine’ wilderness, but on making urbanized areas more wildlife-friendly. Bat boxes provide habitat for two of the nine Alberta bat species (Coleman and Barclay 2012); one of those species, *M. lucifigus* has recently been listed as an endangered species in Canada (Frick et al. 2010). Bats, specifically, are severely affected by urbanization due to the long recruitment time (greater than 100 years) of natural roost sites in trees (Kerth et al. 2001; Vesk et al. 2008). The development of urban centres and their surrounding farm/resource land use leads to large-scale, unsustainable deforestation of old-growth forests. Bat boxes can provide the remaining bats in those areas with artificial roost sites to replace the lost natural tree roosts.

While bat boxes can provide potential habitat when they are the only available roost sites in an area, they will only be occupied if they can actually attract the bats. I sought to determine what characteristics of the bat boxes themselves and of their surrounding habitat would make them most preferable to bats; thereby increasing occupation rates. I collected measurements and observations at each bat box as well as determined their occupation status during the summer of 2017.

An initial focus was placed on the variables that would affect minimum and maximum temperature: as small-bodied heterotherms, temperature is highly influential to a bat's energetic output. Minimum temperature has a large effect on the energetic costs of thermoregulation and determines the most efficient thermoregulatory strategy (torpor or colonial warming). This will also determine the population demographics who will more prefer each box with nonreproductive males preferring cooler boxes and maternity colonies preferring warmer boxes (Grinevitch et al. 1995; Lausen and Barclay 2006). I determined that the location of the box (whether within the Calgary city limits or outside of them) significantly affected the minimum box temperature with boxes located within the city being significantly warmer. The coolest box temperature most often occurred in the early morning. The heat island effect of the city appeared to have increased the thermal radiation throughout the night, preventing the coolest temperatures seen when bats returned to their roosts in the early morning (Zhao et al. 2006).

The maximum box temperature affects occupation mainly when the temperature nears the maximum tolerable threshold (42℃). Though this was not an initial objective of this research, it was interesting to note that there was some evidence over the summer that a high (greater than 42℃) maximum temperature led to decreased occupation the following nights (Fig. 3). The number of chambers significantly affected maximum temperature, with the number of chambers negatively related to maximum box temperature. With all loggers placed on the inner chamber, this demonstrated that the presence of insulating chambers of air significantly reduced the maximum temperature in the inner chamber and provided a larger temperature range within a single box as well as a cooler temperature range within the inner chamber for hotter than average summer days. More chambers provide a greater choice of temperature for bats.

Due to the pervasive lack of occupation in rocket boxes, they were removed from the formal occupation analysis. The eight rocket boxes from the sample were sufficiently distributed among the levels of the other variables to the extent that it was speculated that something about them specifically led to an aversion by bats (see below). Through observations made during the summer of 2017 as well as the results of the occupation model, I believe that the necessity of a pole as the attached structure may be a key factor in this lower preference. As well, the lack of a landing pad on all single-chamber boxes and the inner chambers of multi-chamber boxes may be contributing to the inability of the boxes to attract bats. This would require further analysis with varied rocket box designs and matching standard designs to determine what caused the avoidance of these boxes by urban Alberta bats.

Occupation rate was highest in boxes attached to buildings and lowest in those on poles. Based on 2017 summer observations alone, this is not a surprise: many boxes on poles were observed to sway on windy days. The lower stability, protection from weather, and thermal radiation associated with poles (as opposed to trees or buildings) could all have an affect on occupation rates and be causing the apparent preference for building-attached boxes.

The final models produced in this research determined the box and habitat characteristics that increased occupation rate. A box was considered occupied if it had at least one bat for at least one exit count throughout the summer. This research also found the characteristics that were determined to significantly impact the temperature of boxes through modeling. A single population of bats will practice varied roost selection strategies to fit the unique ecological requirements of their demographic. Depending on the bat deciding whether to occupy a box, the same temperature-related variable could create a preference or an aversion. This is why, I believe, that neither of the variables that significantly impacted temperature, location or number of chambers, were also significant in the occupation models. The temperature model results cannot be used to predict general occupation rate, but instead can be used to determine box suitability for specific groups within a population (e.g. reproductive females). This can have important applications for bat box owners who wish to specifically attract/support certain groups.

The results from the occupation models showed that when general occupation rate was to be predicted, the structure the box was attached to was the only significant variable. This means that for all groups within a population, bats prefer to roost in boxes attached to buildings over poles. There was no apparent preference or aversion with trees. However, they contributed less to the sample (6 of 37 boxes). I suggest that the stability and permanence of buildings makes them more attractive to bats. For a bat box owner looking to attract bats in general, I suggest that they attach the box to a building.

One of the initial objectives of this research included the desire to estimate the reproductive success of urban bats roosting in bat boxes. This information was obtained by performing exit counts around the times of parturition/lactation and fledging to determine the average pup/female count. It could then have been determined if all or most of the females of the colony were having pups and when and how quickly those pups were developing. This would provide information as to whether fetal and pup development was occurring quickly enough for both the pups and mothers to have a high chance of surviving the winter from their energetic reserves. Unfortunately, only two of the forty-five boxes were confirmed as housing maternity colonies throughout the summer. No formal analyses could be performed based on this small sample size.

Conclusions

Due to the large variation in bat boxes and the relatively small sample size compared to the number of measurements and observations, only one variable could consistently predict increased occupation rates. A box attached to a building (e.g. House, garage, barn) had a significantly higher chance of being occupied than a box attached to a pole or tree.

Two variables were identified as significantly impacting the temperature within the bat boxes. The location relative to Calgary significantly affected the minimum box temperature. The heat island effect of the city led to warmer minimum temperatures in the early morning when bats would be returning to the box. The number of chambers significantly affected the maximum box temperature. The insulation of outer chambers led to significantly lower maximum temperatures in the inner chamber of boxes. This can aid in preventing the severely hot temperatures (> 42 °C) seen in some of the studied boxes. Although temperature has a large impact on bat ecology and thus their roost selection, subsets within a population have unique preferences for roost temperature. Because of this, temperature-related variables could not significantly predict the occupation rates for all groups within a population combined.

With this research, I attempted to identify the box and habitat characteristics that were preferred by bats. Placing boxes within the urbanized areas of central Alberta provides bat populations with habitat in areas otherwise lacking in roosts. Increased roost availability reduces the energetic costs of searching for roosts and increases the variation in available microclimates for subsets of populations. The resulting energetic savings provide central Alberta urban-bats with increased survival rates in the winter. For *M. lucifigus*, this is especially important as a strategy to aid in their overwintering survival in areas with White-Nose Syndrome

(*Pseudogymnoascus destructans*). This research can also be applied to anyone, academic or bat-lover alike, interested in providing bats with more habitat.

Table 1. Summary of box and habitat characteristics measured in Summer 2017.

Variable	Data Type	Levels (if applicable)
Location	Nominal	Within City, Outside City
Age (months)	Ratio	n/a
Style	Nominal	Rocket, Standard
Number of Chambers	Ordinal	one, two, more than two
Colour	Nominal	Natural, Painted
Shade	Nominal	Shaded, No Shade
Height (meters)	Ratio	n/a
Structure	Nominal	Building, Pole, Tree
Aspect	Nominal	North, East, South, West
Distance to Water (meters)	Ratio	n/a
Distance to Cover (meters)	Ratio	n/a
Volume (meters^3)	Ratio	n/a

Table 2. AIC selection for linear mixed effects models of minimum box temperature, testing the random effect of individual box first and then the fixed effects second.

Random Effects Models	Predictor Variables	df	AIC	dAIC
intercept	random= ~1|BoxID	4	2518.66	0
slope and intercept	random=~1+MinTa|BoxID	6	2522.66	4
slope	random=~-1+MinTa|BoxID	4	2621.05	102.39
Fixed Effects Models	**Predictor Variables**	**df**	**AIC**	**dAIC**
m1	City+MinTa	5	2513.88	0
m2	Building+City+MinTa	6	2514.5	0.63
m3	MinTa	4	2516.78	2.9
m4	Building+MinTa	5	2516.94	3.07

Table 3. Output for the two best-fitting linear mixed-effects models for minimum temperature as determined by AIC.

Model m1	Num df	Den df	F-stat	p-value
Intercept	1	649	265.63	<0.0001
Building	1	7	3.12	0.1207
City	1	7	5.55	0.0506
MinTa	1	649	1418.84	<0.0001
Model m2	**Num df**	**Den df**	**F-stat**	**p-value**
intercept	1	649	231.9	<0.0001
City	1	8	6.296	0.0364
MinTa	1	649	1421	<0.0001

Table 4. AIC selection for linear mixed effects models of maximum box temperature, testing the random effect of individual box first and then the fixed effects second.

Random Effects Models	Predictor Variables	df	AIC	dAIC
slope and intercept	random=~1+MaxTa|BoxID	10	3416.6	0
intercept	random= ~1|BoxID	8	3418.27	1.67
slope	random=~-1+MaxTa|BoxID	8	3461.37	44.77
Fixed Effects Models	**Predictor Variables**	**df**	**AIC**	**dAIC**
m1	nChamber + MaxTa	7	3432.47	0
m2	Colour + nChamber + MaxTa	8	3433.76	1.3
m3	Shade + nChamber + MaxTa	8	3434.41	1.94
m4	Shade + Colour + nChamber + MaxTa	9	3434.66	2.19
m5	MaxTa	6	3435.23	2.76
m6	Shade + Colour + nChamber + Shade:Colour + MaxTa	10	3436.47	4
m7	Shade + Colour + nChamber + Volume+Shade:Colour + MaxTa	11	3438.34	5.87

Table 5. Output for the three best-fitting linear mixed-effects models for maximum temperature as determined by AIC.

Model m1	Num df	Den df	F-stat	p-value
Intercept	1	649	834.02	<0.0001
nchamber	1	7	7.2	0.0314
Colour	1	7	1.37	0.2806
MaxTa	1	649	339.82	<0.0001
Model m2	**Num df**	**Den df**	**F-stat**	**p-value**
intercept	1	649	1274.05	<0.0001
nchamber	1	7	12.03	0.0104
Shade	1	7	0.1	0.7568
MaxTa	1	649	339.82	<0.0001
Model m3	**Num df**	**Den df**	**F-stat**	**p-value**
intercept	1	649	1131.17	<0.0001
nchamber	1	8	10.49	0.0119
MaxTa	1	649	338.73	<0.0001

Table 6. AIC selection for generalized linear models with a binomial distributed occupation status response variable.

Model	Predictor Variables	df	AIC	dAIC
m1	Structure	3	33.16	0
m2	Structure+ log(dWater)	4	34.76	1.6
m3	nChamber+Structure	4	35.04	1.88
m4	nChamber+Structure+log(dWater)	5	36.69	3.53
m5	nChamber+log(Age)+Structure+log(dWater)	6	36.91	3.75
m6	nChamber+City+log(Age)+Structure+log(dWater)	7	37.72	4.57
m7	nChamber+City+log(Age)+Structure+Shade+log(dWater)	8	39.64	6.48

Table 7. Output for the three best-fitting generalized linear models for occupation rate as determined by AIC.

Model m1	df	LR Chisq	p-value
nChamber	1	0.12	0.7257
Structure	2	18.73	<0.0001
Model m2	df	LR Chisq	p-value
Log(dWater)	1	0.4	0.5252
Structure	2	17.33	0.000172
Model m3	df	LR Chisq	p-value
Structure	2	23.89	<0.0001

Figure 1. Photos taken of the two box styles from the study with the standard style (left) demonstrating the single aspect that the chambers face as well as the attachment of the back of the box to various structures, in this case a tree. The rocket box style (right) is conversely attached to a pole at the bottom and has chambers facing all four aspects.

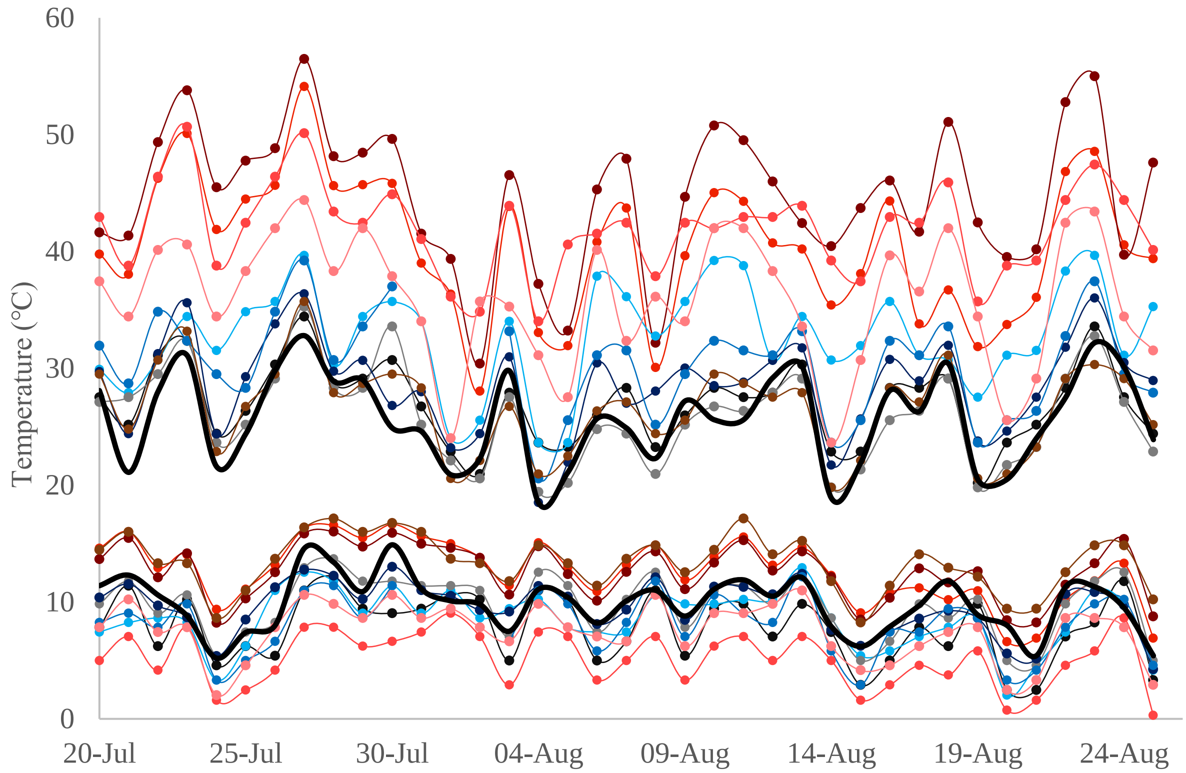

Figure 2. Sample graph of the daily maximum and minimum temperatures recorded for 10 bat boxes in the Southern Alberta area from June 20th to August 28th 2017. The black line is the ambient temperature recorded at the COP Calgary observatory by Environment Canada. The plot shows the presence of more variation in maximum temperatures than in minimum temperatures, as well as consistent relative temperatures between boxes throughout the summer.

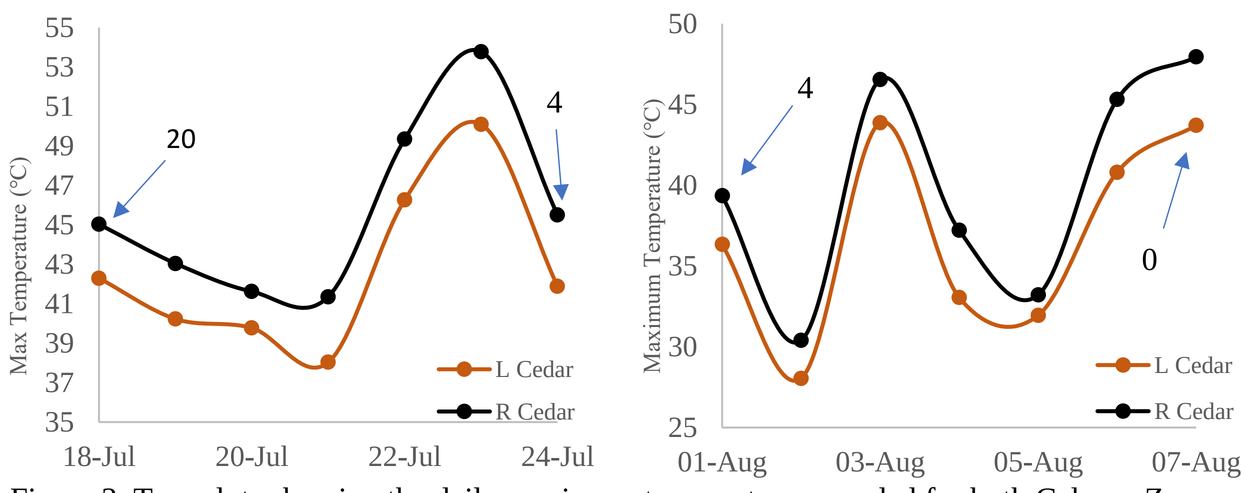

Figure 3. Two plots showing the daily maximum temperature recorded for both Calgary Zoo 'Cedar Barn' boxes (Left and Right) leading up to two separate exit counts on July 24th (left) and Aug 7th (right). The respective exit counts are demonstrated by the arrows. The occurrence of multiple days surpassing the maximum tolerated threshold for Alberta urban bats is paired with the decreased occupation (left) or abandonment of the roosts (right).

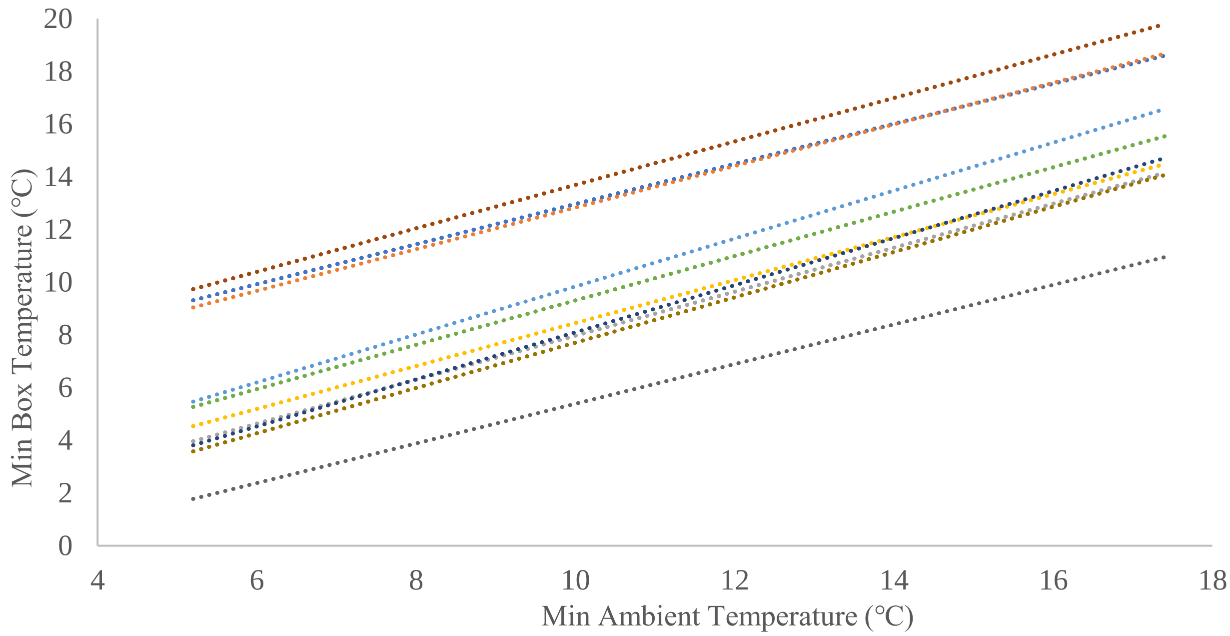

Figure 4. The effect of minimum ambient temperature on minimum box temperature from daily minimum temperatures recorded between June 20th to August 28th 2017. This plot demonstrates the random effect of individual box on minimum box temperature. The parallel slopes with different intercepts for each box shows a random intercept effect (n= 10 boxes).

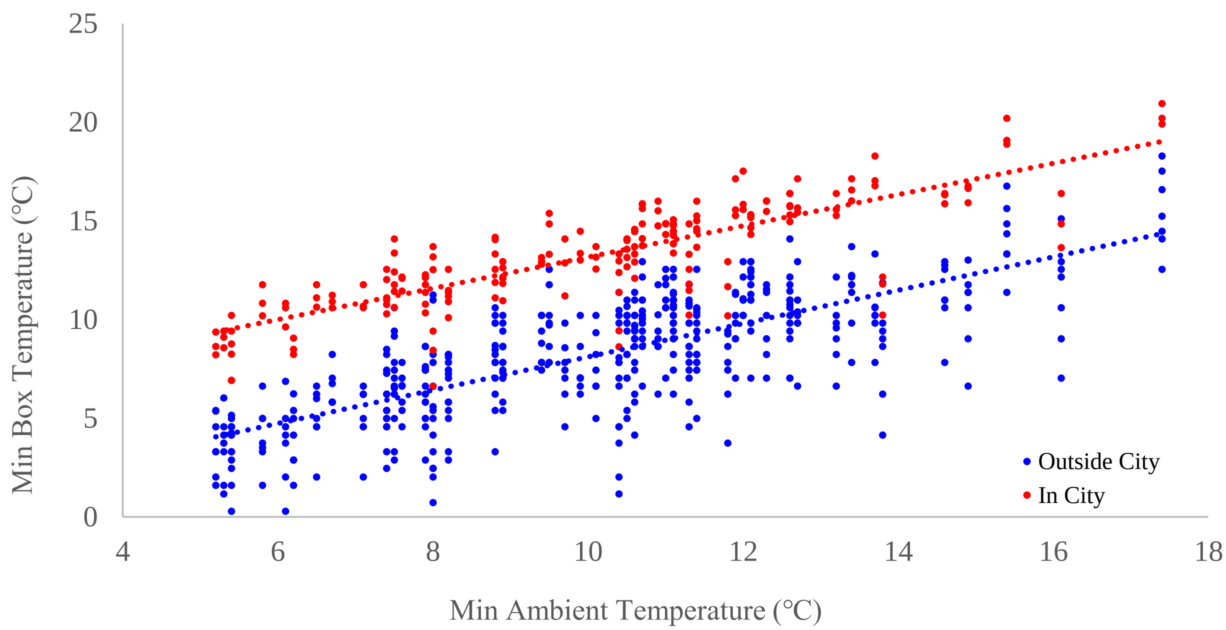

Figure 5. The effect of minimum ambient temperature on minimum box temperature with the added fixed effect of location. Comparison of the box temperature of 10 bat boxes in Southern Alberta shows an apparent warming effect of being within the city on the minimum box temperature (°C).

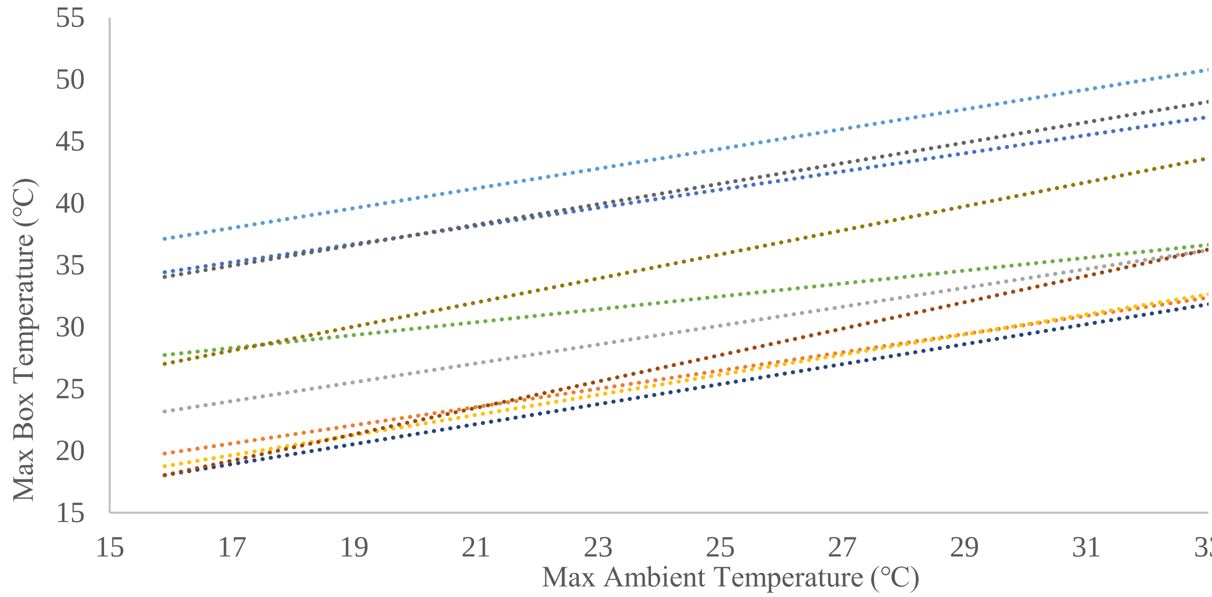

Figure 6. The effect of maximum ambient temperature on maximum box temperature from daily maximum temperatures recorded between June 20th to August 28th 2017. This plot demonstrates the random effect of individual box on maximum box temperature. The different slopes with different intercepts for each box shows both random slope and intercept effects (n= 10 boxes).

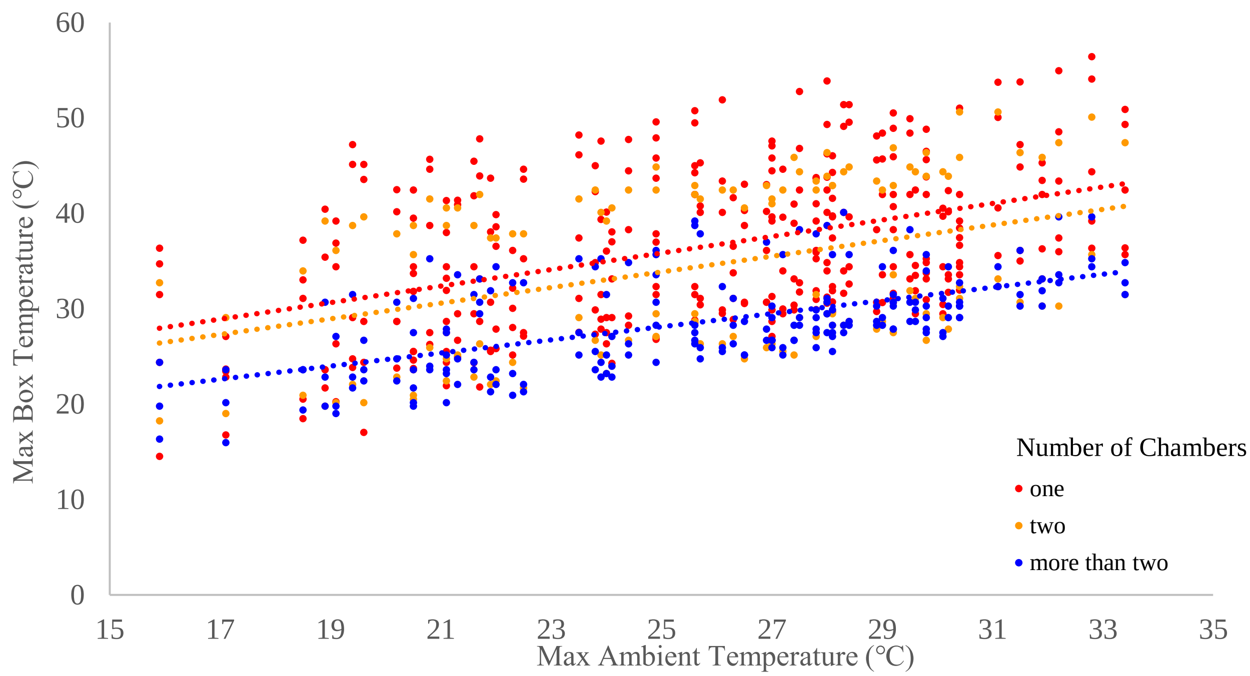

Figure 7. The effect of maximum ambient temperature on maximum box temperature with the added fixed effect of number of chambers. Comparison of the box temperature of 10 bat boxes in Southern Alberta shows an apparent cooling effect of increasing the number of chambers on the maximum box temperature (°C).

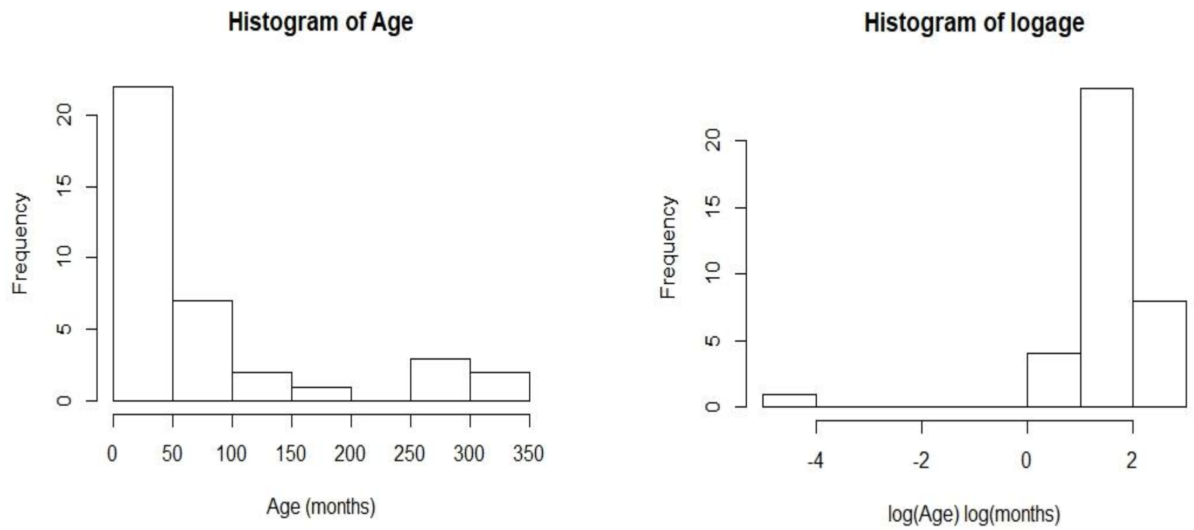

Figure 8. Histogram of age (months) (left) and of the log-transformed age log(months) (right). The right skew was corrected, but the log-transformed age appears to have an outlier (n= 37 boxes). Ages recorded from the Southern Alberta study bat boxes from owner knowledge.

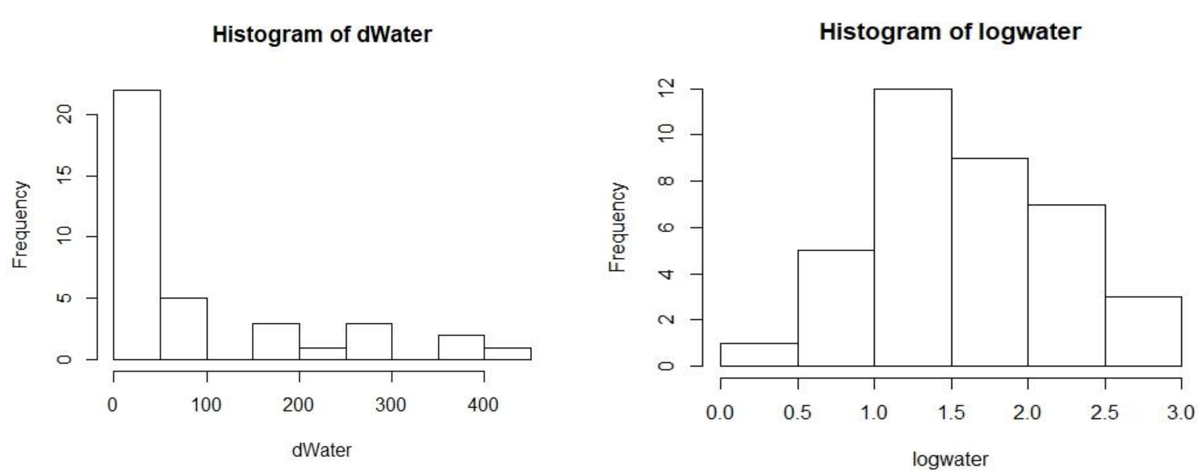

Figure 9. Histogram of distance to water (meters) (left) and of the log-transformed distance to water log(meters) (right). The right skew was corrected and the log-transformed variable is normally distributed (n= 37 boxes). Distance to water was recorded from the Southern Alberta study bat boxes through measurements made in Google Maps using GPS coordinates.

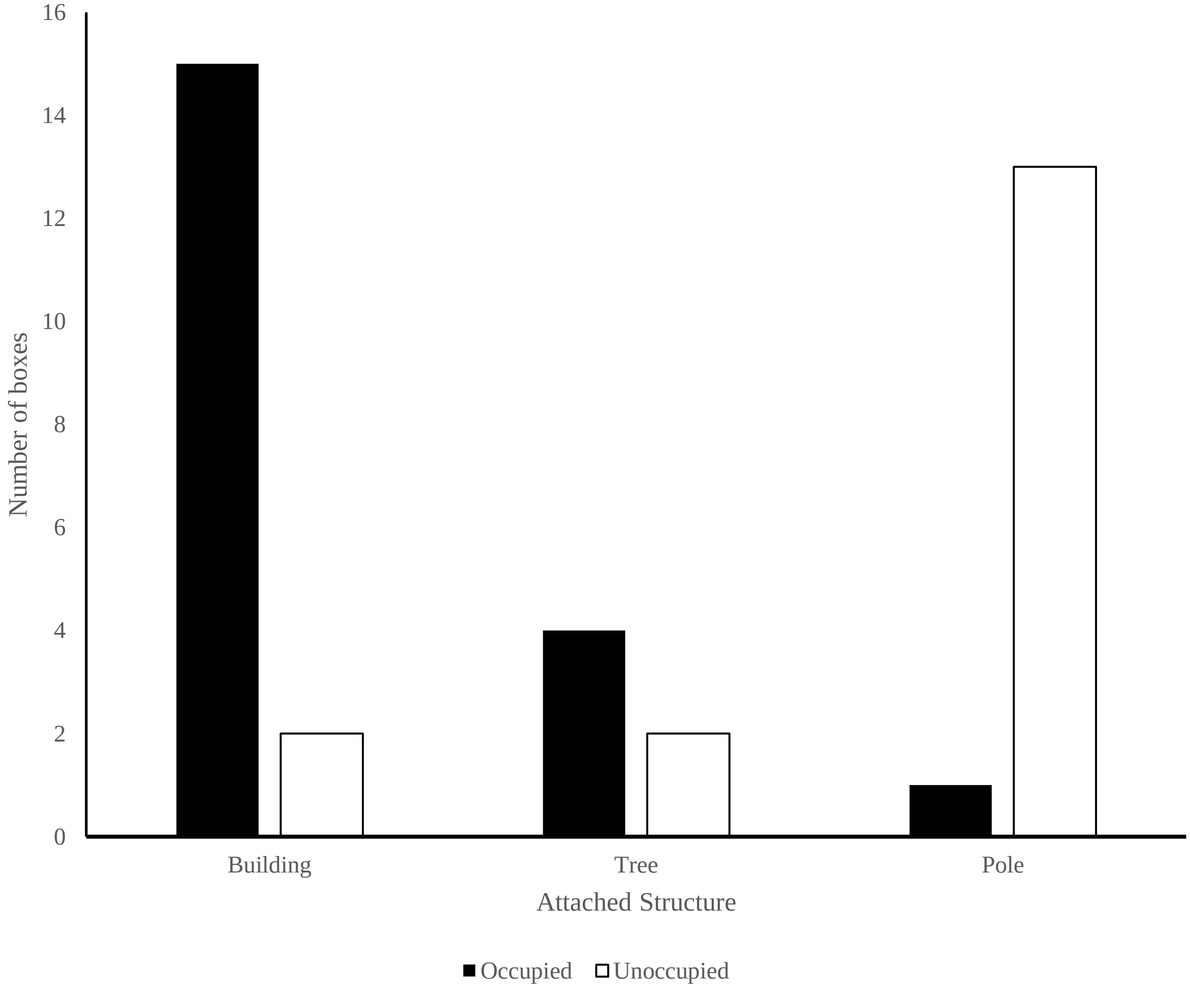

Figure 10. The effect of the attached structure type on bat box occupation rate demonstrated in a bar graph. Occupation status determined by the end of the Summer of 2017 as having at least one occupation event during an exit count. Comparison of the occupation rate of the 37 bat boxes in Southern Alberta shows an apparent preference for buildings and a noticeable aversion to poles.

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