ABSTRACT

Characteristics of Urban Constructions Occupied by Bats

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Certain bat species like *Myotis velifer* (cave myotis), *Pipistrellus subflavus* (eastern pipistrelle), and *Tadarida brasiliensis* (Mexican free-tailed) of Waco, Texas roost in buildings, sometimes even when more natural roosting structures are available. However, not much research has been done looking into the features of these chosen buildings that attracts bats. The purpose of this study is to identify some of these unknown characteristics. We surveyed and identified 62 buildings, in downtown Waco as roosts using external marks such as guano deposits and bat vocalizations to find their exact positions. 41 were day roosts and 21 were night roosts, used only as resting positions during the night. Using observation and GIS software we gathered characteristics about these buildings such as human occupancy and building footprint area in order to find common characteristics. We found construction type was a factor in day vs. night roost selection and human occupancy was a major factor in day vs. non-roost selection. Knowing these features will aid in conservation.

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CHARACTERISTICS OF URBAN CONSTRUCTIONS OCCUPIED BY BATS

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By

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CHAPTER ONE

Introduction

With the recent increases in urbanization, urban ecology has become a popular and redefined field; its theories have changed much over the years from an urban area being thought of as a single "animated spirit" to a "reflection of static harmony" to an "evolving organism" (Young 2009). Cities are growing and spreading outwardly, increasing their contact with the natural environment. Not only does this entail the addition of roads and buildings but also warmer temperatures, greater humidity, new and changed soils, exotic flora, different fauna, and adjusted light cycles (Pickett et al. 2001). By studying urban ecology we can discover how all of these things interact and affect the lives of humans and other species (Pickett et al. 2001; Young 2009). The newest theory of urban ecology accepts that these ecosystems are not materially closed (no influx or loss of resources) and thus interactions between ecosystems and roles of particular species come to light (Pickett et al. 2001). For years the impact of cities was generally thought to be harmful. However, more recently studies have shown that many of these changes brought about by humans are creating a resource-rich environment for some highly adaptable species such as raccoons, deer, birds, and bats (Dow 2000; Pickett et al. 2001; Shochat et al. 2006; Young 2009).

Yet many species suffer from urbanization. They not only lose their habitat but through adaptation, their very behavior is changed (Ditchkoff et al. 2006). With urbanization comes a completely new array of stresses for species to deal with: human activity occurring mostly during the day, high fragmentation of landscapes, different available foods, increased background noise, predatory pets, increased disease due to compact populations, and contamination of the environment (Ditchkoff et al. 2006). Because of this, urbanization has been blamed for causing declines in almost half of the threatened or endangered species under the U.S. Endangered Species Act (Miller and Hobbs 2002). This is why conservation efforts are needed. Different species have different tolerances to human presence; some live successfully alongside humans whereas others need protected, undeveloped areas to flourish (Miller and Hobbs 2002). A major challenge in conservation, however, is getting support. The success or failure of conservation efforts depends on public support and understanding (Fenton 1997). Community-based conservation is needed so the populace can better understand and appreciate the ecological processes that may very well be occurring in their back yards (Miller and Hobbs 2002).

The relationship between bats and urbanization is probably very complex (Gehrt and Chelsvig 2004). The effects of urbanization, and thus the conservation needs, depend greatly on the species of bats present. Some species can exploit urbanized areas as foraging and roosting sites, others are more sensitive and do not thrive (Johnson et al. 2008; Gehrt and Chelsvig 2004). Many species need conservation at different levels and in different places and unfortunately for most species, not enough is known of their basic natural history to establish a conservation area (Fenton 1997). Also, studies differ between cities; most cities show a decrease in overall bat activity in fragmented urbanized areas while in others, like Chicago, there is an increase (Johnson et al. 2008). Johnson et al. (2008) found that fragmentation of habitat had a large effect on foraging of big brown bats (*Eptesicus fuscus*), eastern red bats (*Lasiurus borealis*), little brown myotis (*Myotis lucifugus*), and northern myotis (*Myotis septentrionalis*). Fragmentation did not seem to affect hoary bats (*Lasiurus cinereus*) or eastern pipistrelles (*Pipistrellus subflavus*). For those species not negatively influenced, these environments offer good roosting sites in the form of human constructions and rich foraging due to the attraction of insects to lights (Fenton 1997). Additionally, their ability to fly could help bats overcome the effects of fragmentation (Gehrt and Chelsvig 2004).

Roosting behavior for bats is also very complex. Multiple studies have shown that while many bat species return to the same site each night (roost fidelity), others do not (roost lability; Lewis 1995, Scales and Wilkins 2007, Sgro and Wilkins 2003). Whether a bat species exhibits fidelity to a site relates to the kinds of roosts it chooses. A large number of semi- or non-reliable roosts may lead to lability (Lewis 1995). Other reasons for bats to change roosts could be due to disturbance, commuting distance, avoiding parasites, need to follow a food source, increased predation, micro-climate changes in the roost, or seasonality in general (Lewis 1995; Scales and Wilkins 2007). Reasons for maintaining the same roost could be familiarity, high quality of the roosts, increased value due to occupation, and a local food source (Lewis 1995; Sgro and Wilkins 2003). A common pattern is bats’ use of several roosts within the same general area (Lewis 1995; Neubaum et al. 2007; Scales and Wilkins 2003). This may be a behavior meant to maintain replacement roosts in case of disturbance (Lewis 1995;

Neubaum et al. 2007; Mager and Nelson 2001) or simply convenience of location. There may also be social and, by extension, gender aspects as well. Pregnant females of the species *Tadarida brasiliensis* (Mexican free-tailed bat*)* are known to relocate to large maternity roosts (Sgro and Wilkins 2003). This may be due to the need for certain conditions for the young, overcrowding of the original roost, or energy constraints of carrying the young (Lewis 1995; Sgro and Wilkins 2003). Other roost categories include roosts used during migration, mating, bachelor sites, and hibernation (Rhodes and Wardel-Johnson 2006). Within general roosts there is evidence of social structure as well, seen through segregation by gender and age. Some studies showed that some bats that return to the same roost utilized a different location within that roost while the rest returned to the same place (Sgro and Wilkins 2003; Neubaum et al. 2007), supporting the idea that social structure exists within the roosting colony. Maintaining these social structures and relationships or even territoriality in some bats could be a reason for fidelity (Lewis 1995).

Insectivorous bats, such as those studied in this project, consume vast quantities of insects each night (Fenton 1997), so they are actually very important species in the food chain and in agriculture. Conservation efforts are important for both the adaptive and the sensitive species to help them survive. Learning as much as possible about bats and their behavior in urbanized areas is important for this (Ghert and Chelsvig 2004). A few things must be taken into account in conservation efforts: food supply, habitat, roost, and the colony's inhabitants (Fenton 1997). Unfortunately, except for a few frugivorous bat species, protecting the food supply is very difficult. As for habitat, protecting a certain area of forest is probably the best tactic for sensitive species. A minimum forest size requirement needs to be established to put this into effect (Johnson et al. 2008). Otherwise, the most feasible conservation efforts should be conducted at the local level; bats are seasonal and some species regularly switch roosts as a colony or individually (Fenton 1997). This refers to preserving certain roosts or stretches of habitat known to be frequented. Knowing exactly what a bat requires in its roost is invaluable for conservation; we could preserve the appropriate buildings or design a small number of structures specifically for bats (Mazurska and Ruczynski 2008).

Ecologically speaking, the costs of having a behavior is unlikely to outweigh the benefits (Lewis 1995); the bats therefore must be gaining something from such buildings and other anthropogenic roosts that helps them to survive. There must be something specific about the roost sites that bats choose over others that gives them at least some survival advantage. It was shown in Europe that some bat species even regularly choose human constructions over available tree roosting sites (Mazurska and Ruczynski 2008). Unfortunately, not much is known about the specific characteristics that attract bats to a particular site (Neubaum et al. 2007; Rhodes and Johnson 2006; Mager and Nelson 2001; Mazurska and Ruczynski 2008). While some bats do still roost in natural structures like caves, trees and rock crevices, others have adapted to live in attics, bridges, culverts, cellars, spaces in concrete, and overpasses (Mazurska and Ruczynski 2008; Scales and Wilkins 2007; Sgro and Wilkins 2003).

In the few studies that have been performed, both trees and buildings have been examined. The two may seem to have little in common at first, but the important characteristics discovered in the tree research also pertain to buildings. The tree studies show that the most important or influential characteristics are height, size, and entrance types the species *Tadarida australis* (white-striped freetail) and *Lasiurus borealis* (red bats) preferred taller, and larger structures of and with entrances from which they could drop as they take flight (Mager and Nelson 2001; Rhodes and Johnson 2006). They also seemed to choose certain species of tree (depending on the species of bat) and provide overhead, protective cover (Mager and Nelson 2001; Rhodes and Johnson 2006). The characteristics most frequently identified in studies on buildings were height, size of building, temperature, and the roof lining. Other attributes of preferred roost buildings and locations for the species *Eptesicus fuscus* (big brown), *Vespertilio murinus, Eptesicus* serotinus, or *Pipistrellus pygmaeus* were sheet iron roofs, distance to woodlands, public use compared to private, lower building density, and less traffic noise (Mazurska and Ruczynski 2008; Neubaum et al. 2007). For roosts in general, factors like distance to food, water and an urban center could also play a role (Johnson et al. 2008).

In this study we examined buildings in Waco, Texas, and located those that bats use for day or night roosts and some buildings that were used for neither purpose. We noted the human occupancy, construction type, construction height, building foot print, building material, roost exit height, illumination condition, vegetation coverage, road level, presence of birds, condition of roost surroundings, land use, distance to forest, and distance to water at each site. From this we sought to identify common characteristics that make certain buildings attractive to bats as a roost in general and additionally, any characteristics that may lead to the roost becoming either a day roost or a night roost. With this information, bat conservation, in the form of preserving or creating appropriate buildings for bat roosting, can be furthered.

CHAPTER TWO

Methods

The study area included most of Waco, McLennan County, Texas though most of the roosts are mainly located in the downtown. In the Waco vicinity there are 9 known species of bats (Smithsonian 2012). Of those, *Lasiurus intermedius* (northern yellow bat), *Lasiurus borealis* (eastern red bat), and *Lasiurus cinereus* (hoary bat) are all specialized tree dwellers and are not known for using buildings. *Lasionyceris noctivagans* (silver-haired bat), *Eptesicus fuscus* (big brown bat), and *Nycticeius humeralis* (evening bat) may roost in buildings but prefer trees when available. The most likely bats roosting in the buildings of Waco are *Myotis velifer* (cave myotis), *Pipistrellus subflavus* (eastern pipistrelle), and *Tadarida brasiliensis* (Mexican free-tailed bat), which all prefer caves and human constructions to trees (Smithsonian 2012). *Tadarida brasiliensis* is the most common, but any of these latter three could be present in the roosts we find.

To locate areas with roosts we conducted broad surveys that we called “driving surveys.” These consisted of a group of interested students driving a specified route beginning around sunset with an Anabat SD1 bat call detector (Titley Scientific, Australia). The car was driven through different parts of Waco with the windows down and the microphone of the detector held close to the open window, allowing the detector to pick up any bat calls. The calls were then noted on the detector and frequency of calls and location were recorded for further examination later. This was a way to efficiently cover a large area and narrow down the area that would be later searched on foot. Areas with frequent bat calls, especially around sunset when the bats have yet to travel far, suggest a nearby roost.

Another method we employed to locate bat populated areas was by asking the public. A newspaper article was published in the local news paper asking for information about possible roosts and a Facebook group was created for the same purpose. People with information were able to contact us at any time.

Investigators returned to areas where bat detectors revealed activity or where people suspected a roost might be located and searched nearby buildings. The presence of guano, smudging, and detection of audible bat calls signified the past or present occupation of bats. Two types of roosts were found: night roosts and day roosts. Day roosts are those roosts in which bats spend the daylight hours and are typically well hidden. Night roosts are places where bats only stop temporarily to digest and wait for their weight to return to normal (Hirshfeld et al. 1977). For night roosts there was less guano and no actual entrances into a structure, only a covered and partly protected place to hang. These usually had one or two pieces of guano on the wall to identify them. Day roosts were sometimes harder to identify as the guano does not always fall outside (Fig. 1), but they were recognized in essentially the same manner as the night roosts with, rarely, the addition of audible bat calls from within the roost, sensed with the Anabat detector.

Fig. 1. Guano under a day roost.

Occasionally, when the roost was physically on the outside of a structure, large deposits of guano could be located beneath it, but usually there were only a few pellets stuck to the wall under the entrance. Black smudges directly around or below the roost exit were only evident on frequently used roosts in light colored buildings. An example of this is shown in figure 2. Bat calls were not used to identify roosts very often. Multiple photographs were taken at each site to document the roost evidence and indicate where on the building it was found.

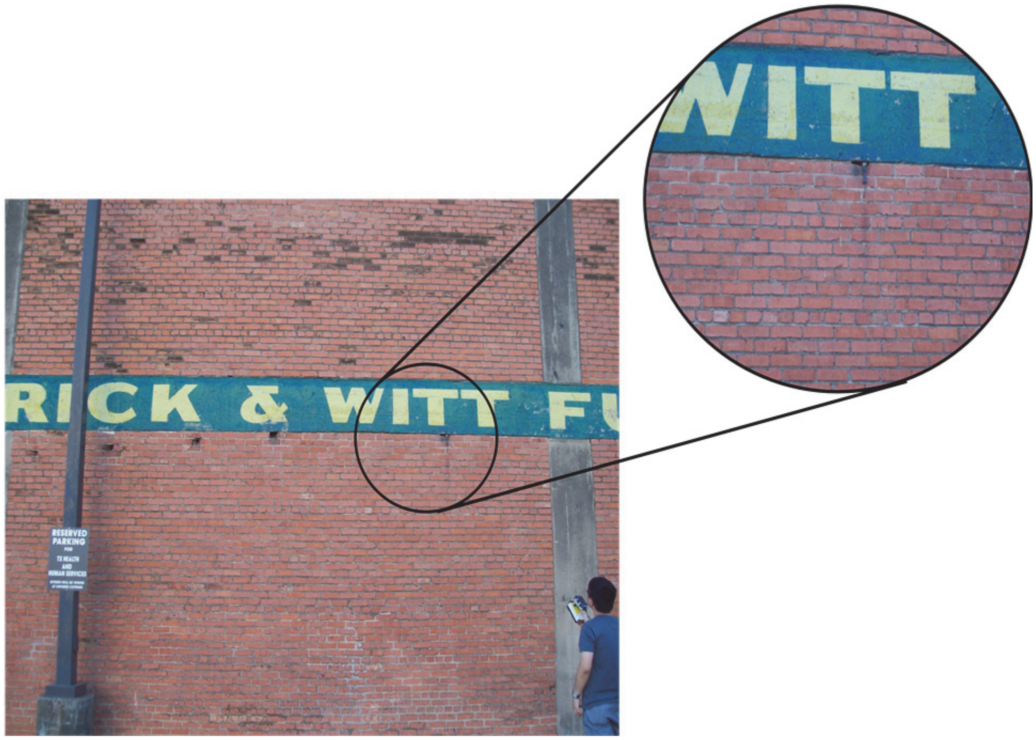

Fig. 2. Smearing outside a roost entrance.

After a roost site was identified, its location and the location of the entrance were recorded. Later the City of Waco Mapping Service (gisms.ci.waco.tx.us/Waco/) was used to determine several characteristics of the roost. The map offers land usage and road volume options that allowed for easy access to this information.

The land usage categories are low density residential, medium density residential, high density residential, mixed use, office only, commercial and office, service commercial, high quality office and industrial, high quality very light industrial, general industrial, public semi-public, and planned unit development. The range of residential land use is high for a building with multiple units in an urban core and low for houses that are on lots over an acre in size. Mixed usage refers to commercial areas where the area of non-commercial buildings exceed one third of the total. Office only contains only office buildings and commercial and office contains a mixture of the two. Service commercial or commercial use refers to an area where the land is used primarily for the sale of services and products. All of these described categories are from Anderson et al. 1976, the rest are categories listed on the GIS web site we used (gisms.ci.waco.tx.us/Waco/). The road-volume categories were primary arterial, arterial, collector, local, and semi-public.

The areal outline or footprint of each structure was taken with the polygonal measurement tool, outlining each of the buildings and noting the area. The locations were then grouped into categories: less than 100 m^2, 100-1000 m^2, 1000-2000 m^2, and greater than 2000 m^2. The Mapping service was also used to determine the distance of the roost to the nearest forest edge and body of water. These distances were determined by using the measurement tool in “line mode.” Each end of the line was placed just inside of the border of the building, forest, or water feature and then the distance was noted.

Each location was also briefly revisited to determine human occupancy (abandoned or occupied), construction type, the height (by number of stories), the construction materials (what the building was constructed of), roost exit height (also by stories), the level of illumination, the level of surrounding vegetation, the presence of birds, and the condition of the surroundings.

Construction type categories were residential, office, retail, industrial, public service, and open concrete structures. Residential included houses and apartments.

Office entailed buildings that were strictly offices. Buildings that had stores, restaurants or sold services on the first floor were considered retail. Industrial buildings included those that were used for agriculture, design, assembly, or storage. Open concrete constructions included bridges and parking structures.

Illumination was given four levels: low, medium, high or none. Low illumination had only distant lamps to shine by the roosts. Medium had a few street lamps or lights on the building. High illumination meant the roost was near a parking lot that would be very brightly lit at night. This was subjectively estimated by the proximity of lights around the roost.

The surrounding vegetation was placed in the categories of completely covered, half covered, scattered, or none. “Completely covered” referred to buildings that were almost completely obscured by trees in aerial photos. “Half covered” buildings had one or two trees and some bushes around the roost entrance. Scattered vegetation lacked nearby trees and there were few, if any bushed significantly near the roost. Buildings with no vegetation had no trees or bushes.

For presence of birds we looked for evidence that birds were spending a large amount of time at a building which was usually evident by the amount of droppings present. The birds we looked for were those that used buildings to nest in. For our study birds were either present or absent.

Roost surroundings were either open or enclosed. “Open roosts” bordered a parking lot or street or had a greater height than their surroundings while “enclosed roosts” were next to other buildings or were obscured in some way.

Information on 60 randomly selected buildings was also collected for a comparison of day roosts vs. buildings that had no evidence of bat occupation. At these sites we recorded human occupancy, construction type, construction height, building footprint, construction material, illumination, vegetation coverage, road level, presence of birds, land use, and distance to forest and water using the same categories.

This information was then compiled into the SPSS Statistics 17 software for analysis. The Backward Wald method of logistic regression was used to determine significance. Additionally, chi-square tests and additional logistic regressions were run on the following day vs. night roost characteristics: human occupancy, construction type, construction material, illumination, vegetation coverage, presence of birds, and land use. An additional logistic regression was run on the day vs. night categories of building footprint, distance to forest and distance to water. Between the various methods significant characteristics were more likely to be identified.

CHAPTER THREE

Results

On weekends from August through November 2011, we searched for bat roosts in Waco. Seven days of field searching resulted in the location of 44 roosts. The majority of these were located within the downtown area and were identified solely based on the signs of bat activity. We had an additional 18 roosts known from other sources. Twelve were known from earlier studies performed in the area. The last 6 roosts were brought to our attention by the public in response to our inquiries, which included responses to both the newspaper article and the Facebook group. These sites included most of those outside the immediate downtown area. Fig 3. shows a layout of the roosts in the immediate downtown area. An additional 8 roosts from much farther out in Waco are not shown. The majority of the roosts we found, however, were in downtown.

Fig. 3. Map of Waco with day (green) and night (red) roosts highlighted.

Distinguishing Day Roosts from Night Roosts:

A typical day roost had multiple pellets of moist, soft guano which hinted that it was fresh. These were either stuck to a wall under an identifiable hole or were found in a pile under an overhang that contained a gap. Occasionally, a few bat calls could also be heard from inside a roost, showing that the roost was currently occupied.

Fig. 4. Day roost through gaps left by warping door.

The typical night roost had no opening. Guano pellets, not always fresh, were found adhering to walls. However, locations where we found these pellets were typically slightly enclosed in some way. They were in places where a pellet dropped by a bat flying normally could not have fallen. This was typically a place like the upper corner of a window or underneath an overhang without openings.

Fig. 5. Night roost in windows.

Day Roosts vs. Night Roosts:

For human occupancy, 15 day roost buildings were abandoned and 26 occupied by humans. This was a larger percentage of unoccupied roosts than appears night roosts which had only 6 abandoned and the remaining 15 all still in use. The concrete structures (bridges, parking garages, etc.) were considered to be occupied based on their constant usage by vehicles.

Roosts in general tended to be in buildings used for offices, public service, retail, industrial and cement structures like bridges and parking garages. The public service structures we found were usually various churches but we also located a few roosts in museums, banks, and a few school buildings. Retail buildings included many shops, garages, and restaurants. The industrial buildings included storage buildings, two empty packaging facilities, a furniture assembly facility, and a graphics design building. Only three residential structures were found to be used by bats: 2 day roosts and 1 night. Though office, retail and public service building were common to both day and night roosts, only day roosts were found in industrial buildings and concrete structures.

Only one roost, a day roost, was under a level bridge and it was given a height of 0. The majority (80.5%) of the day roost buildings were 1-3 stories high with only 7 being a few stories taller than that and 1 that was 19 stories tall. The night roosts had almost the same majority (81.0%) in 1-3 story height range (Fig. 6). There is little difference between day and night roost building heights.

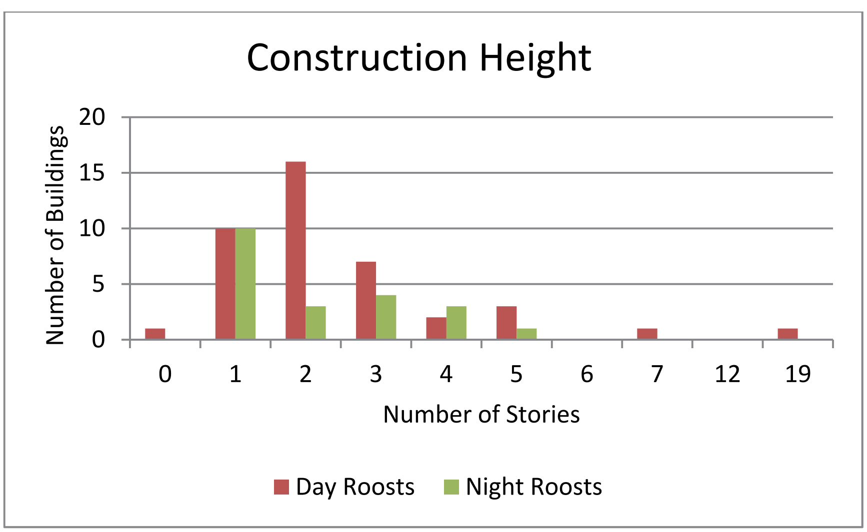

Fig. 6. Graph comparing construction height of day vs. night roosts.

In general the day roosts tended to occupy larger buildings than night roosts. While the majority (66.7%) of night roosts were of the size range 100-1000 m^2, more than half (68.3%) the day roosts are in the 1000-2000 m^2 and >2000 m^2 ranges. Whereas there were only 2 night roosts in the >2000 m^2 range, there were 12 day roosts.

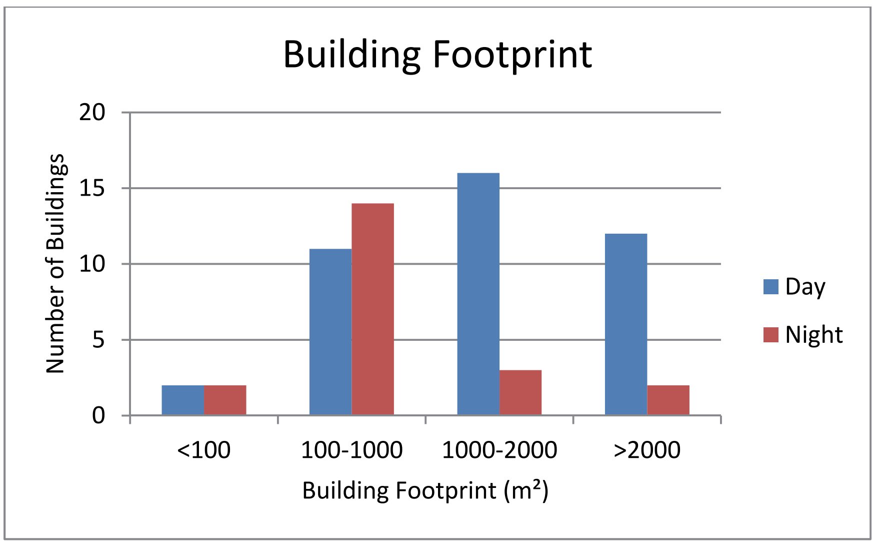

Fig. 7. Chart comparing building footprint of day vs. night roosts.

Buildings were made of stone, concrete, brick, metal, and occasionally a mixture of metal and stone. There was also a single day roost with wooden siding. The majority of buildings in the case of both day and night roosts were made of brick, stone or concrete. There is little variation between day and night roost materials.

The majority (87.8%) of the roost exits for day roosts were 1-2 stories high. This is different from the majority (76.2%) of night roosts residing only on the 1^{st} story.

Figure 8, displaying the data gathered from this category, suggests that day roosts are at least slightly taller.

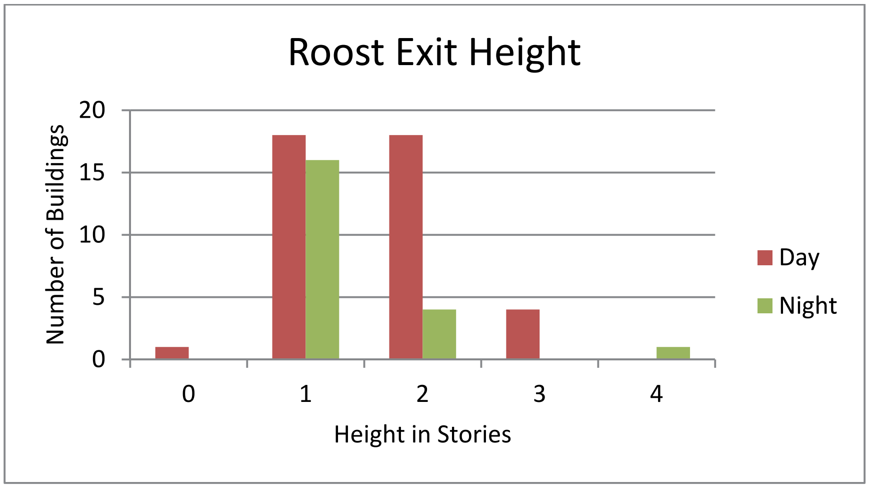

Fig. 8. Comparison of day vs. night roost exit heights.

Low level illumination was the most common in both day and night roosts with 48.8% of day roosts and a 71.4% majority in night roosts. The "none" category was found the least number of times with only 3 day roosts. There is no evident trend in illumination (Figure 9).

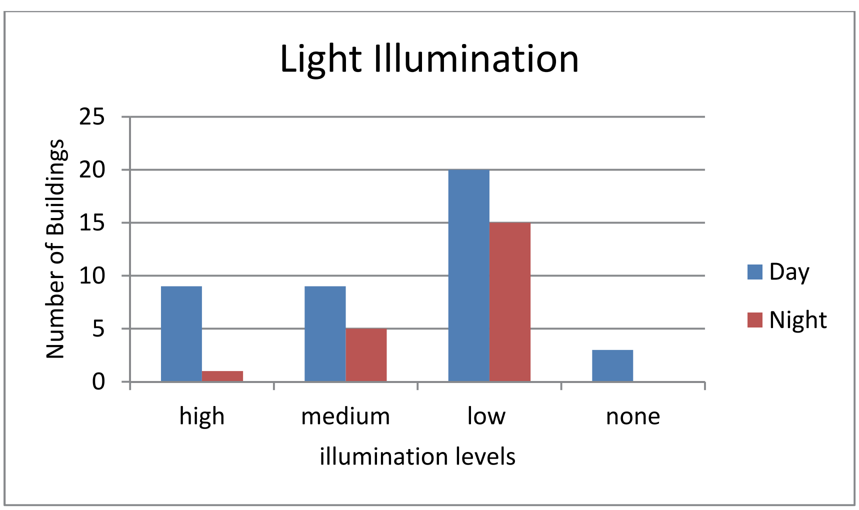

Fig. 9. Comparison of illumination levels in day vs. night roosts

Of the 41 day roosts, 27 were in areas with no vegetation. This is well over half the total and could be indicative of selection. Night roosts on the other hand are more evenly distributed with only 9 roosts with no vegetation, with 4 scattered and 8 areas that were half covered. Only 2 fully-covered sites were found: 1 day and 1 night. The trend seen towards no vegetation in day roosts is not repeated in night roosts (Fig. 10).

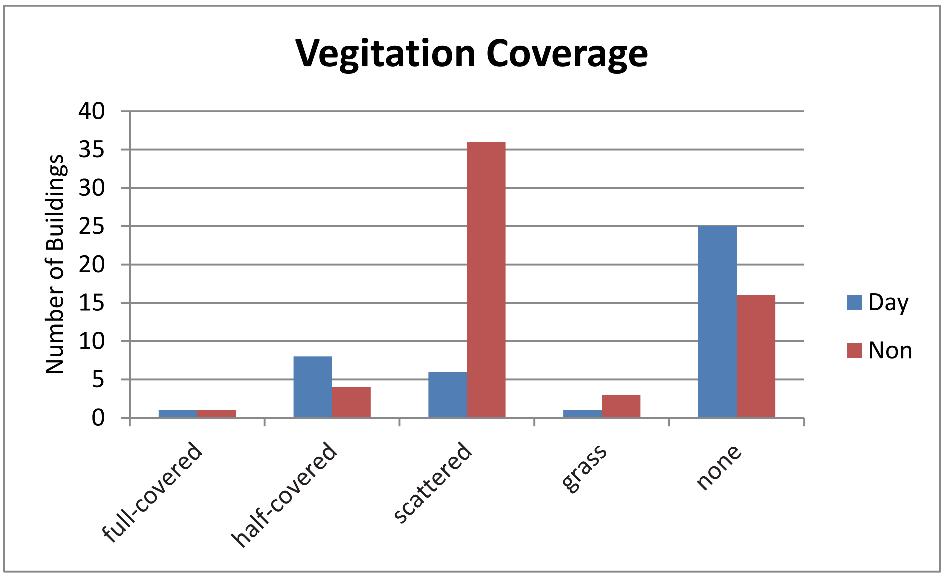

Fig. 10. Comparison of vegetation levels between day and night roosts

Road level, or traffic volume, varied greatly between roosts. In general, arterial roads were the most common around both roosts: 56.1% of day roosts and 42.9% of night roosts. Local streets were the second most common with 24.3% of day roosts and 28.6% of night. As these ratios are very similar, road level may not a very important factor in roost selection.

For both day and night roosts the majority of buildings were not shared with roosting birds. Very few buildings we visited actually had birds present at the time;

most were determined to have birds due to the presence of droppings. There were only 13 of 41 day roosts and 3 of 21 night roosts that also had birds living there.

The majority of both day (61.0%) and night (57.1%) roosts were in more open surroundings. This was usually because they bordered parking lots, wide streets or were taller than the buildings around them. Enclosed roosts were typically next to other buildings. There was little difference between the two in this category as well.

The overwhelming majority of both day roosts (85.4%) and night roosts (90.5%) were in mixed usage land zones. There were also a few day and night roosts in public semi-public, service commercial and high quality very light industrial. Once again, there was little difference between day and night roosts.

Except for one bridge located in Cameron Park, almost all roosts were 1-3 km from the edge of the park. Three other roosts that a much greater distance away and thus were not included in the analysis. As for distance to water, none were farther than 2.8 km from the Brazos River, with the exception of the previously mentioned three roosts. There was no difference between day and night roosts in these distances.

Statistical Analysis of Day Roosts vs. Night Roosts:

Initially we performed logistic regression using the software SPSS Statistics 17. The method used was the Backward Wald method by which one compiles all of the data and then extracts variables individually which do not contribute to discriminating the types of roosts from each other. None of the assessed variables was retained in the model (Table 1).

Table 1. Results of logistic regression comparing attributes of day and night roosts. Variables not in the equation

Variables	Wald	Df	P
usage	15.636	6	0.016
human occupancy	0.398	1	0.528
construction height	8.328	7	0.305
construction area	3.349	1	0.067
construction material	6.320	5	0.095
roost exit height	9.571	4	0.048
illumination condition	5.364	3	0.147
vegetation coverage	4.993	4	0.288
birds	3.892	2	0.143
distance to the closest forest edge	0.275	1	0.600
distance to the closest water body	1.638	1	0.201
road level	7.685	4	0.214
roost surrounding	4.253	1	0.356
land use	1.811	4	0.770

In efforts to identify features that distinguish day roosts from night roosts, we also ran a chi-squared test on several characteristics (Table 2). With this test, we found that construction usage is a significant characteristic ($P = 0.0366$). This result indicates that, if a roost was located in a concrete structure (bridge or parking garage) or a retail building, it is most likely a day roost.

Table 2. Results of χ^2 tests comparing day vs. night roosts.

Characteristics	χ^2	df	P
Human Occupancy	0.1178	1	0.7314
Construction Usage	11.8711	5	0.0366
Construction Material	7.233	4	0.1241
Illumination	1.63	3	0.6526
Vegetation coverage	2.864	3	0.4131
Presence of Birds	1.0688	1	0.3012
Land Usage	2.5132	4	0.6423

Day Roosts vs. Non-roosts

Our random, non-roost data shows that 30% of the buildings in downtown Waco are unoccupied. However, 63.4% of the day roosts were occupied, as compared to 70% of the non-roost buildings being occupied by humans (Figure 11).

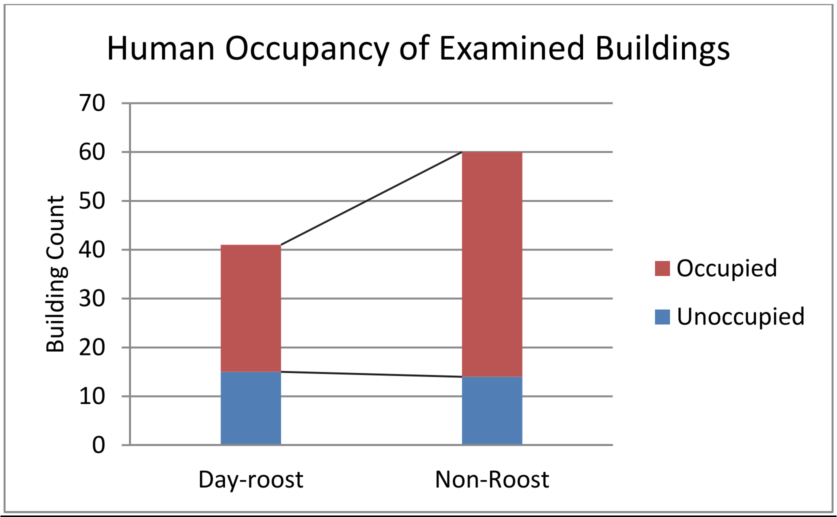

Fig. 11. Comparison of day roosts vs. non-roost buildings with regard to human occupancy of the buildings.

The construction type categories for random buildings were more evenly distributed than those of the day roosts (Figure 12). More of the day roosts were in retail (29.3%) than any other category; only 16.7% of the random buildings were retail. Also, residential buildings, while only being 4.9% of day roosts, comprised 26.7% of the random buildings sampled. This may be indicative of selection.

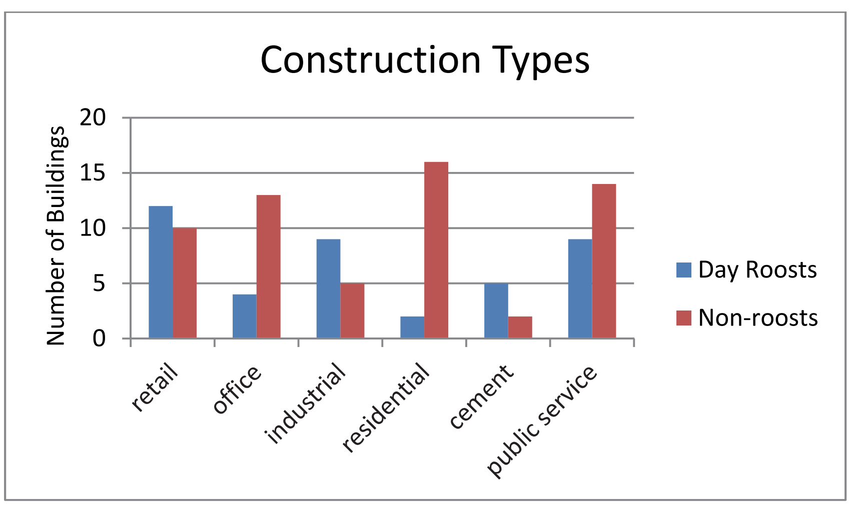

Fig. 12. Comparison of construction type data from day roosts and non-roost.

Building height ratios do not appear very different between day and night roosts (Fig 13). For day roosts, 80.5% of the buildings were 1-3 stories high and 93.3% of the random non-roosts were the same 1-3 stories.

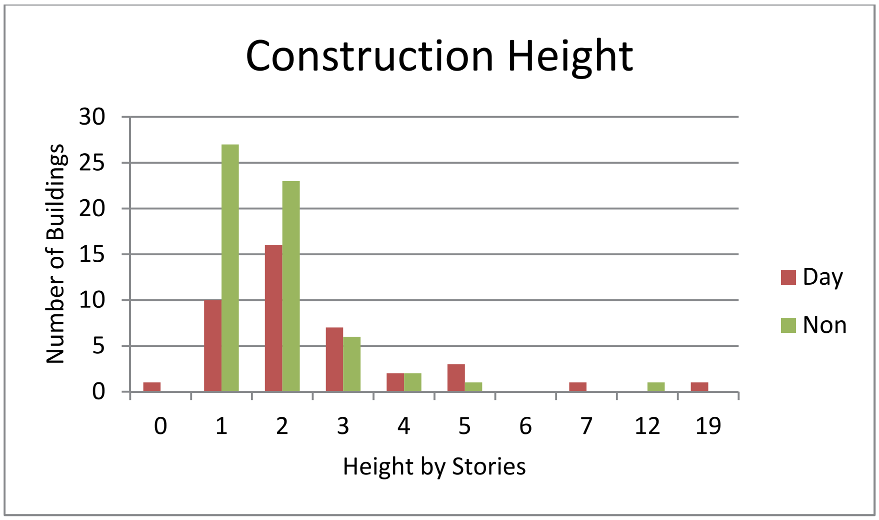

Fig. 13. Comparison of construction heights between day roosts and non-roosts

The majority (81.7%) of the non-roost buildings had footprints that were < 100 or 100-1000 m². However, the majority (68.3%) of day roosts are in the 1000-2000 m² or > 2000 m² categories. This appears to suggest selection of larger buildings for use as day roosts.

Of all the materials brick was the most common in both day roosts (46.3%) and night roosts (48.3%). The proportions for the rest of the materials were similar as well.

The level of nighttime illumination did not seem to distinguish day roosts from non-roosts. Low intensity light was present at nearly half (48.8%) of the day roosts and a majority (60%) of non-roosts. Only 4 non-roost buildings were highly illuminated as compared to 9 highly lit day roosts.

Scattered was the most common vegetation coverage category, with a majority of 60%, for the non-roost buildings was scattered vegetation. This differs greatly from day roosts which had a 61.0% majority in the no vegetation category (Figure 14).

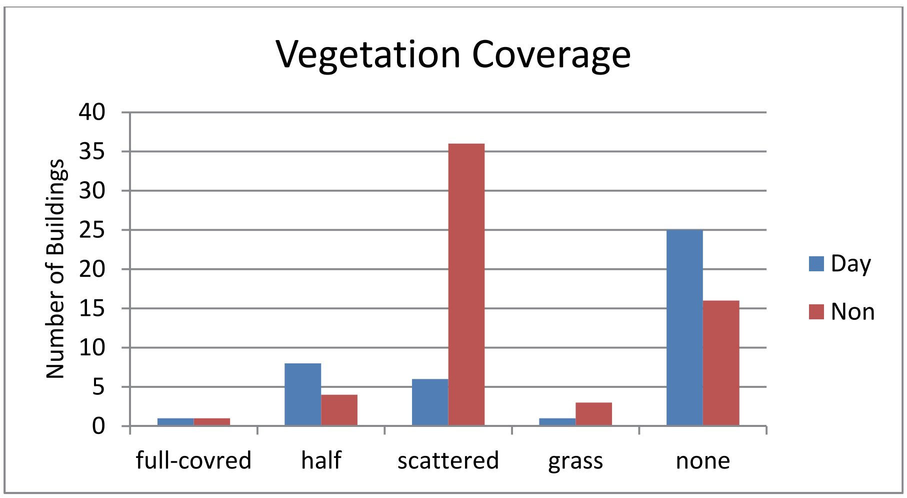

Fig. 14. Comparison of vegetation coverage surrounding buildings used day roosts vs. non-roosts.

Most day-roost buildings (561%) and a plurality of non-roost buildings (48.3%) fell into the arterial road-level category. As with both day and night roosts, local streets was the second most common level for non-roosts with (33.3%) of the buildings.

Birds were absent from 68.3% of the day roost buildings. This differs from non-roosts in which only 48.3% of buildings don't have birds. This may suggest bats choose roosts for the absence of birds.

Mixed usage was the majority for both the day roosts (85.4%) and the non-roosts (86.7%). The public semi-public, the next most common category, only had 4.9% of the day roosts and 5% of the non-roosts. These ratios were very similar.

All non-roosts were within 1-2 km of water and the nearest forest edge. This differed slightly from day roosts which had several roosts over 2 km away from water and the forest edge. This difference however was probably a result of our finding all of the non-roosts in the downtown area. A few of the day roosts were not in the downtown.

Statistical Analysis of Day Roosts vs. Non-roosts:

We used the Backward Wald method of logistical regression to determine which characteristics might be selected for in comparison to those that are not. Table 3 shows the results from this analysis. Using this method we determined that only human occupancy had significance ($P = 0.002$).

Table 3. Logistic regression for non-roosts vs. day roosts

Variables in the Equation

	Wald	df	Sig.
human occupancy	9.683	1	0.002
Constant	6.216	1	0.003

Variables not in the equation

Variables	Score	df	Sig.
usage	10.323	6	0.027
construction height	1.658	1	0.198
construction area	3.999	1	0.046
construction material	1.446	5	0.229
illumination condition	2.689	3	0.161
vegetation coverage	5.578	4	0.222
birds	1.118	2	0.029
distance to the closest forest edge	0.24	1	0.624
distance to the closest water body	1.763	1	0.240
road level	2.245	4	0.103
land use	1.059	4	0.304

CHAPTER FOUR

Discussion

The aim in this study was to determine what characteristics exist that may attract bats to roost in a building and what, if any, characteristics may signal the selection of day vs. night roosts. We found that construction type was significant for day vs. night roost selection and, human occupancy was found to be significant in determining whether a bat chooses a roost.

The use of abandoned buildings more often than occupied buildings could be due to several factors. Abandoned buildings tend to be less maintained and as a result have easier access to the interiors. Access to the interior of the building provides for bigger and more insulated roosts in which bats can roost. In addition, unoccupied buildings have little to no human disturbance, allowing the bats to roost with less interruption than they would if they roosted in the presence of humans. Disturbances such as loud noises and vibrations might make roosting difficult for bats, so they may avoid such locations. Though bats are known to live in very noisy locations, little research has been done as to its exact effects on roosting behavior. Noise is known to disrupt bat foraging, however, and insectivorous bats have been known to avoid nosier areas during the night (Schaub et al. 2008).

The human use of buildings occupied by bats was only found to be significant in the Chi Squared test for day roosts vs. night roosts. It showed that a retail building or concrete structure would more likely be a day roost than a night roost. This may be due to increased noise levels or disturbance at concrete structures or in areas around retail shops at night. This would disturb foraging bats (Schaub et al. 2008), making them less likely to night roost in these areas. Also, very few buildings were residential. This would appear to match earlier studies that stated bats favor public buildings for their greater size (Mazurska and Ruczynski 2008). Though size also was not found to have an influence in our own research, it was determined significant in other studies. It was suggested that bats prefer larger roosts for not only their increased shelter but also their increased heat retention (Rhodes and Johnson 2006; Mazurska and Ruczynski 2008). The temperature within a roost depends greatly on its internal construction; some areas may insulate bats more and others less (Entwistle et al. 1997).

Height was also found to be significant in other research, though not our own. (Mager and Nelson 2001; Neubaum et al. 2007). A study of *Eptesicus fuscus* (big brown bat) in Colorado found that the bats preferred buildings taller than their surroundings. The group suggested greater height may help bats to obtain more lift when leaving the roost (Neubaum et al. 2007). The apparent lack of significance in our study for this characteristic could be due to the inability to determine the exact height of the roosts and thus generalizing them by floors. The internal roosts may not necessarily have been at the very top of the building or at the same level as the exits. Also, as we did not identify the species in each roost, some species may prefer differing heights. One study showed that tree roosting species *Nyctophilus geoffroyi* (lesser long-eared bat) and *Chalinolobus gouldii* (Gould's wattled bat) roost in the same area but prefer trees with differing heights (Lumsden et al. 2006). This was attributed to a differing preference of trees and on which part of the trees to roost and flight ability. *Nyctophilus geoffroyi* prefers to roost under bark or in tree hollows and is agile in flight, making it possible to reach roosts closer to the ground. *Chalinolobus gouldii* prefers roosting in 'spouts' or openings left my dead branches in the canopy and is less agile in flight and may not be ble to reach some of the roosts that *N. geoffroyi* can (Lumsden et al. 2006). Similar interspecies difference could be occurring in our study. Identification of the species may be required to determine the exact differences.

Building material, though not shown as significant, was mostly various kinds of bricks. This may be because the majority of the buildings in the area are of these materials. Further research is required to determine whether there is actually selection for these materials or whether these are just the available buildings. Materials like brick and stone would conserve heat better but also be harder to access than something like metal siding. One group actually found that wall materials did not matter, but they thought it might be due to the bats of the area roosting in the attic (Mazurska and Ruczynski 2008). The only materials found to be of marginal importance in other studies was that of the roof and lining. Bats were found to favor metal roofs with wooden linings as this combination provides a better thermal advantage (Mazurska and Ruczynski 2008).

Though no significance was shown for illumination in our study, many other studies have shown is does, at least, have a significant effect on the foraging of insectivorous bats (Fenton 1997). Whether or not it actually has an impact on roosting behavior requires more a more detailed study. With a light intensity detector, it would be possible to improve the light intensity data set and possibly find a correlation. As bats tend to travel when roosting, they may not have a need for lights to attract bugs near the roosts.

Vegetation's impact was typically to obstruct the area around the roost. Regarding this, vegetation and roosts surroundings can be treated as similar or the same characteristic. The only research on these characteristics was performed on two different tree roosting species and differed in outcome. A study of *Lasiurus borealis* (eastern red bat) showed they preferred dense foliage for protection from the elements (Mager and Nelson 2001). The species *Tadarida australis* (white-striped freetail), on the other hand, preferred less clutter for a clearer flight path and possibly more energy conservation (Rhodes and Johnson 2006). As these characteristics obviously vary by species, identification of the specific species occupying each roost may be necessary for fuller understanding of the importance of these factors.

One study found that road level or road volume was lower on streets surrounding roosts (Neubaum et al). The study mentioned that this could be due to an 'urban tolerance level' in bats. This tolerance level could depend on any number of factors including noise and openness around the roost.

The presence of birds was not found to be significant. This could be due to the generality of the data set regarding birds. Observed bird droppings may have been from birds only resting at the roost. Extensive observation of each roost would be necessary to determine the actual presence of birds. Little or no research has been performed on the effects of the presence of birds on bats.

The land usage characteristic was not found to be significant because most of Waco is a single category: mixed usage. Research in a city with more varied categories is necessary to fully determine whether or not this characteristic is significant. Little or no research has been performed on the effects of land use on bats.

Regarding distance to forest edge and distance to nearest body of water, only the distance to forest edge was found to be important in other research. Roosts were located near forest edges to reduce the commuting distance (Mazurska and Ruczynski 2008). For our research we used one location, Cameron Park, as our forest edge. The presence of other smaller parks may account for the great variance in distance. In order to determine which of these smaller parks actually serve to feed bats, detectors would need to be placed around them to determine bat density. Then measurements could be made from these parks to better represent distance to forest edge. Also, bats' mobility may lessen their 'dependence' on a single setting (Fenton 1997). Distance to water on the other hand, may not be significant in urban areas. Water is almost always available in urban areas, so bats need not travel to the nearest body of water for a drink. The addition of man-made ponds, streams, gutters, and sprinklers ensures there is water available

In summary, our research and others have found that bats do select for a number of different characteristics when finding a roost including human occupancy, shown in our own data. Additionally, we found that there are some differences in what qualifies a building to be a day or night roost as a building that is a concrete structure or retail building is more likely to be a day roost than a night roost.

With this knowledge I propose that a large, abandoned building that is taller than surrounding structures and has a warm, stable internal temperature would make the ideal roost for conservation purposes. If this building is meant to be a night roost it would additionally not be a concrete structure (bridge or concrete), retail building, or residential structure. Building roosts like these, specifically designed for bat roosting, day and night, would not only cause fewer bats to choose to roost in buildings currently being used by humans, but also preserve the bat populations of the area. Both of these factors are very important to bat conservation.

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