Occupancy of *Myotis lucifugus* among various bat house designs and habitats in the Beaverhill Natural Area

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2021

Introduction

Bats are members of the highly diverse Order Chiroptera, which contains over 1400 species worldwide (Bat Conservation International, 2021). The province of Alberta is home to nine species of migratory and year-round resident bats (Alberta Community Bat Program, 2021a). The distribution ranges of six bat species extend into the Beaverhill Natural Area (BNA), including *Lasiurus cinereus* (Hoary Bat), *L. borealis* (Eastern Red Bat), *Lasionycteris noctivagans* (Silver-haired Bat), *Eptesicus fuscus* (Big Brown Bat), *Myotis lucifugus* (Little Brown Myotis), and *M. septentrionalis* (Northern Myotis). Alberta bats face many threats, and several species are listed as Endangered under the Species at Risk Act, including *M. lucifugus* and *M. septentrionalis* (Government of Canada, 2021). The Beaverhill Bird Observatory (BBO) is conducting long term monitoring of bat houses in the BNA to enhance the area for bats, and to determine how many bats are using the area and their roosting preferences (Beaverhill Bird Observatory, 2021).

All bats in Alberta are insectivorous, i.e. predators of nocturnal insects. Many eat different types of crop and forest pests and play an important role in suppression of pest insect populations (Boyles, Cryan, McCracken, & Kunz, 2011). The loss of bats in North America could lead to agricultural losses of a minimum of 3.7 billion dollars a year (Boyles et al., 2011). The loss of natural pest control methods will inevitably lead to an increased reliance on pesticides (Boyles et al., 2011).

In North America, bat populations are threatened by various factors: the rise in wind power facilities, loss of suitable roosts, and the spread of White-nose Syndrome (WNS) (Boyles et al., 2011; Entwistle, Racey & Speakman, 1997), all of which are contributing to the sudden, rapid, and unprecedented population declines (Boyles et al., 2011). WNS is caused by the fungal pathogen *Pseudogymnoascus destructans* (Pd) which spreads rapidly, especially in hibernacula, and has caused fatalities of over 6 million bats across North America (Bernard et al., 2020). WNS infects the face, ears, and wings of bats with fungal spores causing them to become frequently aroused during torpor and severely depleting fat reserves leading to starvation and mortality (Hoyt, Kilpatrick, & Langwig, 2021; Warnecke et al., 2012). The rapid decline of populations has led to regional extirpation of *M. lucifugus* populations in Canada and the United States (Boyles et al., 2011). Despite exposure to Pd, survival is possible and remnant populations may slowly aid in the recovery and recolonization of bat populations affected by WNS (Kurta et al., 2020; Russel et al., 2015). Although there is a focus on conservation management of bats, significant population decline and low reproductive rates makes recovery challenging (Boyles et al., 2011). However, while WNS has not yet been identified in Alberta early detection can be achieved through long term monitoring (Government of Alberta, 2021).

Roosts provide valuable environmental and predation protection and are a limiting factor to population size and distribution (Entwistle et al., 1997). Roosts are the primary location for social interaction and reproduction of colonial bat populations (Entwistle et al., 1997; Johnson, Treanor, Slusher, & Lacki, 2019). Increasingly, bats are found to roost in man-made structures and buildings, likely due to a loss of natural roost sites such as tree cavities or because man-made structures offer preferable conditions (Entwistle et al., 1997). However, man-made structures may be susceptible to disturbance by humans, posing a threat to bat populations (Entwistle et al., 1997; Griffiths et al., 2017). Commonly, bats are seen as pests and will be removed from human occupied buildings, which is especially threatening to maternity colonies (Johnson et al., 2019). Setting up structures designed specifically for bats such as bat houses provide an alternative roosting option to occupied buildings and can mitigate human-bat conflicts. A study found that *M. lucifugus* and *M. septentrionalis* prefer old forest stands when selecting natural roosts, which have become less abundant due to logging practices (Crampton & Barclay, 1998). It is important to consider that bat houses do not provide adequate shelter for all bat species as many tree dwelling species will not use those (Griffiths et al., 2017). Several Alberta species including *L. cinereus*, and *L. borealis* require the foliage of deciduous and coniferous trees for roosting habitat, while others, such as *L. noctivagans* and *M. septentrionalis* roost in the crevices and hollows of large decaying trees (Alberta Community Bat Program, 2021a). Evidently, artificial bat houses are not a strict alternative for habitat loss from human disturbance (Griffiths et al., 2017).

Nelson & Gillam (2017) found that female *M. lucifugus* selected for edge type habitats. In particular, *M. lucifugus* preferred edge habitat that was associated with water sources and open vegetation for roost selection (Nelson & Gillam, 2017). Broders et al. (2006) found male *M. lucifugus* primarily used water sites for foraging and would travel over 1500m from the roost to access these sites. Wooded areas provide shelter from aerial predators; in addition, wooded and riparian areas offer ideal feeding habitat (Entwistle et al., 1997). Roosting in proximity to foraging areas is beneficial to bats because it minimizes energy expenditures related to commuting and decreases the risk of predation (Broders et al., 2006). In addition, edge habitats may be selected for because access to linear landscape features offers navigational corridors that are less cluttered and provide easy access for foraging areas (Verboom & Huitema, 1997).

Of the species known to BNA, *M. lucifugus* & *E. fuscus* commonly roost in man-made structures such as buildings and bat houses (Alberta Community Bat Program, 2021a). A study by Johnson et al. (2019) found buildings to be essential summer habitat for hundreds of *M. lucifugus* in maternity roosts in Yellowstone National Park, making man-made structures a priority for conservation management of the Little Brown Myotis. To determine bat house preference, it is important to monitor and categorize traits of both occupied and unoccupied houses (Entwistle et al., 1997).The purpose of this study is to determine if there is correlation between bat occupancy and habitat type and bat house design through regular monitoring of bat houses in the BNA.

Methods

Study Area

The occupancy surveys took place within the Beaverhills Natural Area (BNA); for conservation considerations this area cannot be accessed by vehicles or ATV's as it is within the boundaries of the provincial protected BNA. The study area contains a variety of habitat types including aspen forest, wetland, and open grassland. Common vegetation found within the BNA include *Populus tremuloides* (Trembling Aspen), *P. balsamifera* (Balsam Poplar), understory shrubs and forbs, and cultivated and native grasses (Downing & Pettapiece, 2006).

The transect for the occupancy survey contained four habitat types: clearing, interior, edge, and open (Fig. 1). Weather data, consisting of temperature (°C), cloud cover (%), wind speed (Km/h) and direction, and precipitation (mm) were recorded at the beginning and end of each survey in order to control for potential confounding variables. We conducted weekly occupancy surveys on 33 bat houses (and later 38 as 5 new houses were added in August 2021). The houses were three different sizes: large (9 houses), medium (5 houses), and small (19 houses) in various locations along the transect (Appendix 1) from May 16 to October 1st. Surveys were completed at least half an hour before sunset to allow for accurate estimates of bat numbers before they began to leave the houses in the evening to begin foraging. We encountered some issues estimating occupancy numbers during peak times in midsummer after the maternity colonies grew in size, as bats would crowd around the entrance to the box, (specifically box M22, M24, and M41). This prevented us from counting bats further up inside the box. Rough estimations of bat occupancy numbers were collected quickly during these instances so as to not disturb the colonies by exposing them to longer periods of bright light while counting the large colonies.

To correct for this problem and to collect accurate counts the BBO had volunteers occasionally conduct emergence count surveys at these boxes. These emergence surveys consisted of counting the total number of bats as they emerged from the box around sunset which allowed us to collect a more accurate count of the number of individuals within the box.

We checked bat houses along the survey route (Fig. 2) by shining a light into the houses to determine the number and species of the bat(s) inside (Fig. 3). This was done quickly and without leaning on the trees to minimize the disturbance to the bats. Bat house number, count of bat(s) inside, and species were recorded at each bat house along with relevant comments.

Statistical Analysis

Mann-Whitney U-tests were performed using Microsoft Excel (version 2102) to determine if there was a significant difference between occupancy rates between small and medium houses, medium and large houses, and small and large houses. In addition, Mann-Whitney U-tests were conducted to determine if there was a significant difference between single chamber and multi-chamber houses. A Kruskal-Wallis test was conducted to analyze habitat preference in relation to occupancy rates. Linear regressions were used to determine if there was a correlation of occupancy to maximum daily temperatures and the air quality health index.

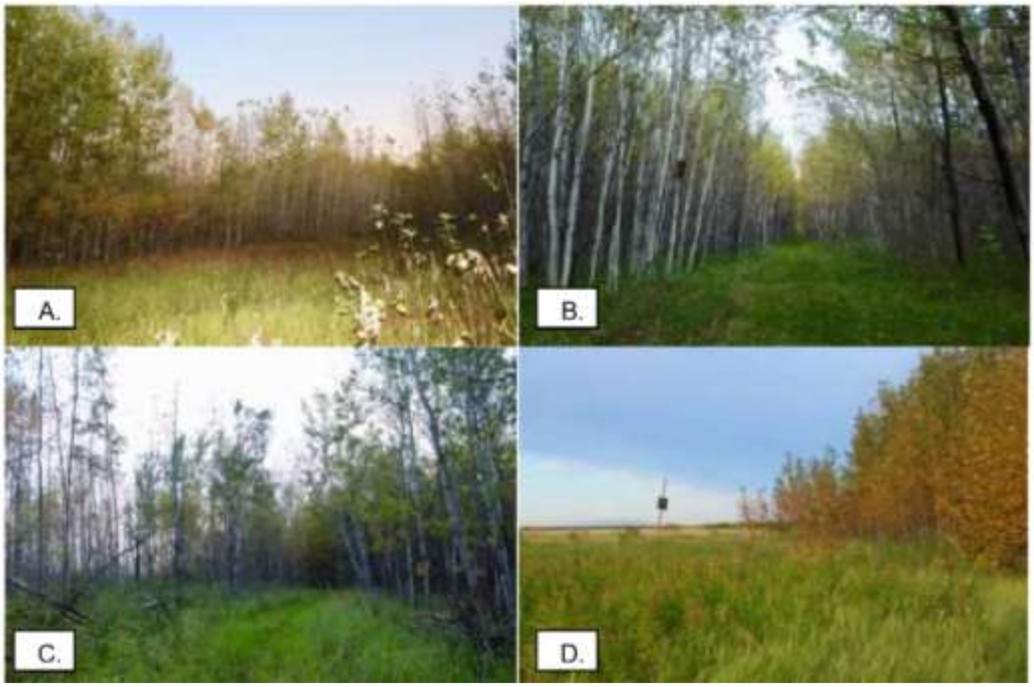

Figure 1. Four habitat types found along the occupancy survey transect. (A) Clearing: areas lacking trees but surrounded by forest. (B) Interior: forested areas. (C) Edge: open areas flanked by forest on one side. (D) Open: open habitat with few trees in the surrounding area (Low, 2021).

Figure 2. Map of the bat box locations and habitat types they occupy in the BNA (Low, 2021).

Figure 3. Method of occupancy data collection; done by briefly shining a light into the bat box interior, without leaning on the tree to minimize disturbance to the bats.

Results

Bat House Occupancy

Over the eighteen week study period *M. lucifugus* were visually observed roosting in the bat houses in the BNA; however, it is possible that *E. fuscus* and other *Myotis spp.* also used the houses but were not visually identified as such. In total 1475 bat-observations were counted in bat houses; however, this number is likely higher due to the inability to accurately count bats when crowded or huddled together. In comparison, at least 653 bat-observations were made in the 2020 study.

Of the 33 houses, 29 were occupied at least once (87.9% occupancy), and 4 were not occupied (12.1%) at any point during the study. The unoccupied houses included house numbers 10, 20, 23, and 27. Of the occupied houses, 10 were occupied 1-3 times, 13 were occupied 4-9 times, and 6 were occupied most frequently at 10 or more times. The most frequently occupied houses included #3, 11, 15, 16, 39 and M41. Houses with the most frequent occupancy consisted of small, medium, and large houses, with some painted exteriorly only, and some painted interiorly and exteriorly, and they were set up in clearing, interior and edge habitat types (Appendix 1). Bat house #16 had the highest occupancy of the single chamber bat houses (53 bats), and M41 had the highest occupancy of the multi-chamber houses, and all houses in general (302 bats) (Figure 4). Throughout the study, we found overall occupancy was higher in multi-chamber bat houses with a total of 1158 bat observations, compared to 317 bats observed in single chamber houses. Multi-chamber occupancy peaked in June and July but declined severely as no occupancy was observed in August or September (Figure 5). Single chamber houses peaked in July; however, bats were still observed in single chamber houses into September. (Figure 5). Large houses had the highest observed occupancy of the single chamber houses and peaked in late July (34 bats). Small and medium single chamber houses also peaked in late July (25, and 7 bats, respectively). (Figure 6). Overall, a total of 84 bats were observed roosting in small houses, 40 bats in medium houses and 193 bats in large houses.

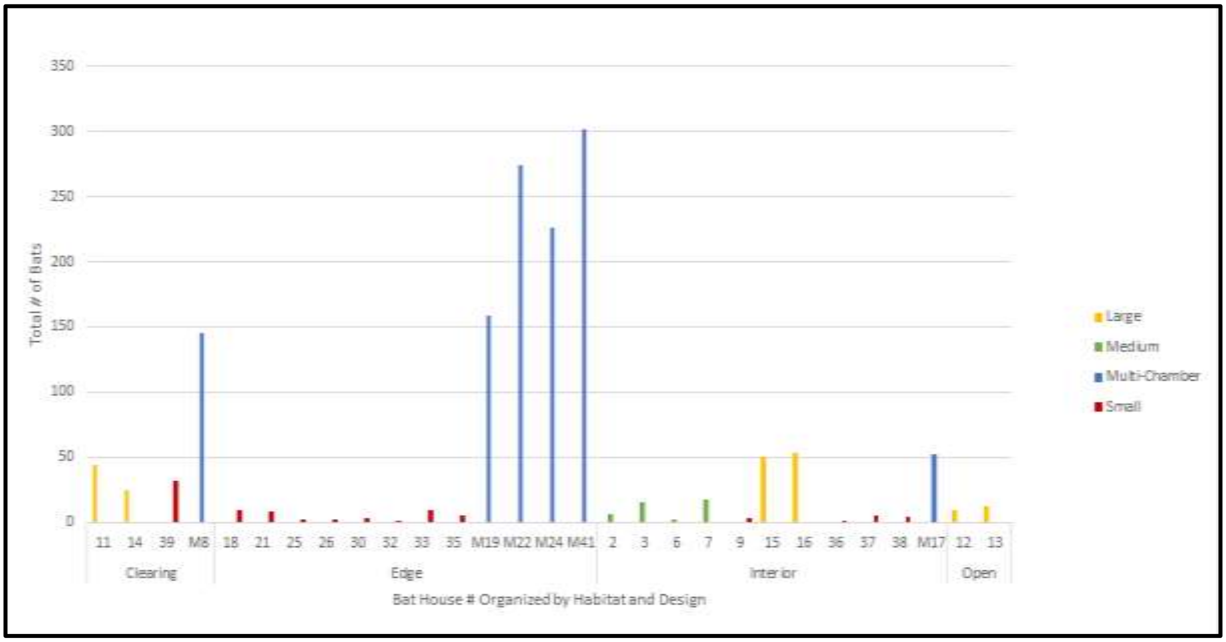

Figure 4. Total number of bats observed per house in each habitat type for the 18 week study period. House 16 had the highest total occupancy (53 bats) of the single chamber houses, and M41 had the highest total occupancy (302 bats) of the multi-chamber houses.

Occupancy was highest in edge habitats (1000 bat-observations) over the study period, especially from June - July (Figure 7). Clearing habitat had a total of 246 bat-observations, interior habitat had a total of 208 bat-observations, and open habitat had a total of 21 bat-observations. Bats were not observed roosting in houses in open habitat in May or September; in addition, only interior habitat houses were used in September. Observations were recorded for all habitat types from June - August. A total of 137 bats were observed roosting in bat houses during the month of May, 737 bats in June, 532 bats in July, 69 bats in August, and 3 bats in September. Reportedly, the overall highest occupancy occurred in June.

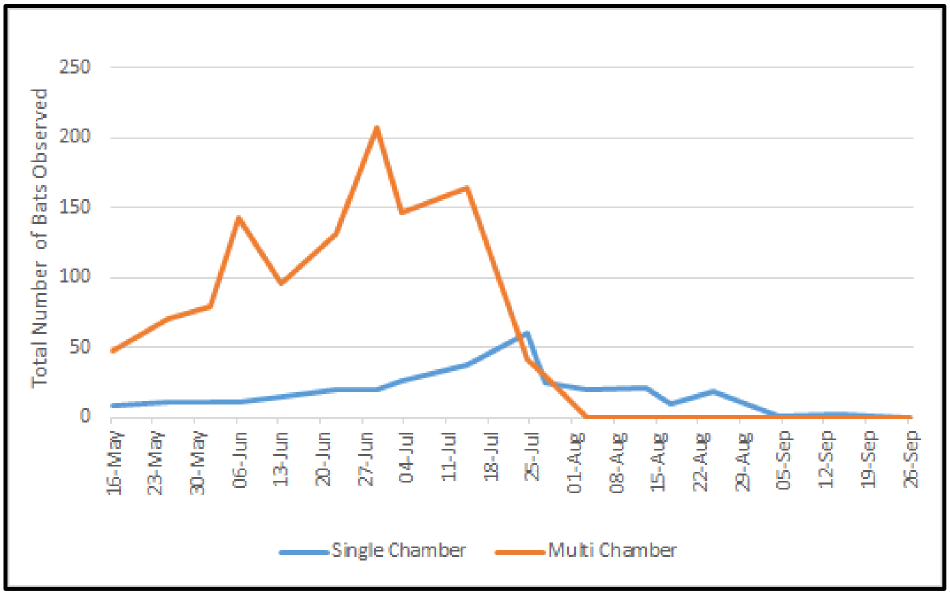

Figure 5. Number of bats observed in single chamber and multi-chamber bat houses by survey date. Multi-chamber occupancy was the highest on June 27 and then declined to no occupancy from August to July. Single chamber occupancy was drastically lower throughout the season. In contrast, single chamber occupancy peaked on July 25, but observations continued into September.

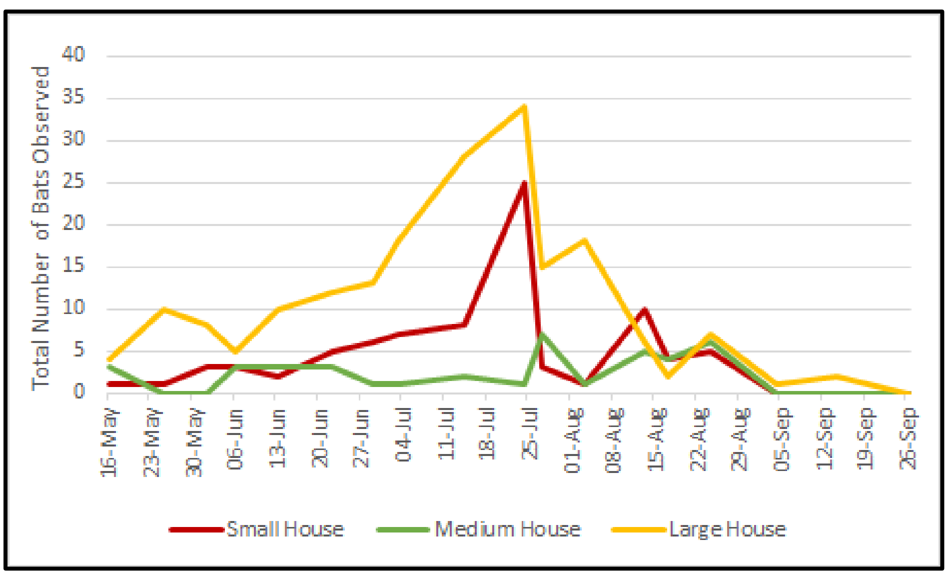

Figure 6. Occupancy among the small, medium and large single chamber bat houses at the Beaverhill Natural Area by week from May to September.

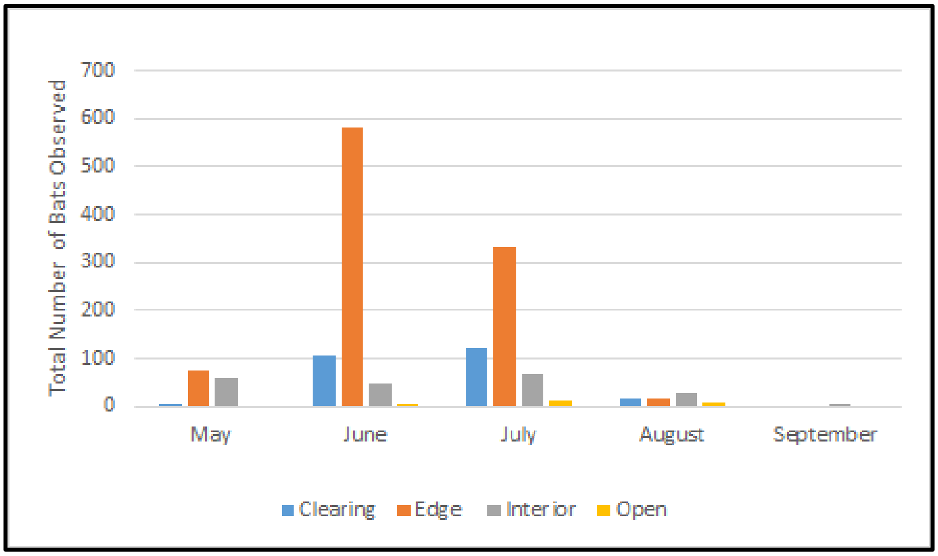

Figure 7. Number of bats observed roosting in bat houses by habitat type in the Beaverhill Natural Area from May-September 2021.

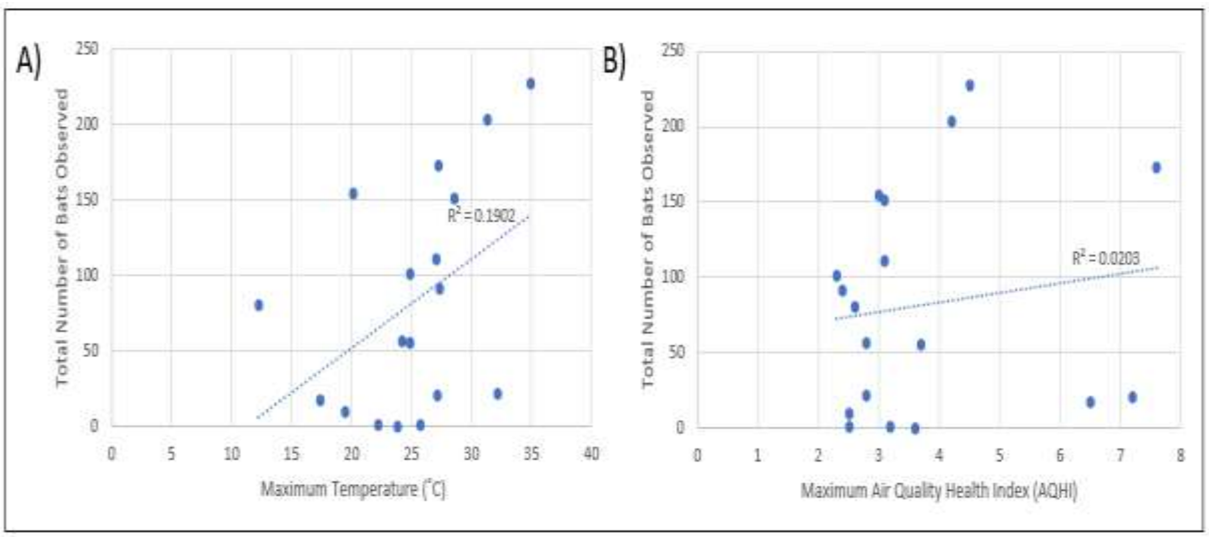

Figure 8. Number of bats observed plotted against A) maximum daily temperature, and B) the maximum air quality health index (AQHI) from May 16 to September 26, 2021.

Statistical Analysis

Confounding variables of interest to us in this study consisted of maximum daily temperature (°C) and the maximum daily air quality health index (AQHI). Air quality was considered because of high smoke levels in the area from wildfires in British Columbia, Alberta, and Saskatchewan occurred throughout this study. To determine if there was a correlation between these variables and occupancy rates, we plotted the total number of bats recorded per survey against each variable. Variations in occupancy were determined using the R^2 value and consist of 19.0% for maximum daily temperature (Figure 8a), and 2.0% for maximum air quality health index (Figure 8b). This suggests there is minimal to no correlation between these confounding variables and occupancy rates.

Non-parametric statistical tests were used to analyze our findings. Mann-Whitney U-Tests were conducted to determine if there was a difference between single chamber and multi-chamber bat houses. In addition, Mann-Whitney U-Tests were conducted to determine if there was a difference between small and medium houses, small and large houses, and medium and large houses. Furthermore, a Kruskal-Wallis test was used to see if there was a significant difference between occupancy and between interior, clearing, open and edge habitat types. Our null hypothesis is that there is no significant difference in occupancy between house chamber styles, houses sizes, and habitat types; our alternate hypothesis is that there is a significant difference in occupancy between house chamber styles, house sizes, and habitat types with larger boxes preferred.

For the statistical analysis of occupancy rates between single and multi-chamber bat houses the smaller U-test value (Mann-Whitney U-test; $U=126.5$; $p<0.05$) was larger than the critical value (Mann-Whitney U-test; U-critical=99; $p<0.05$). Therefore, we fail to reject the null and no significant difference was determined between medians of single chamber and multi-chamber bat houses. For the analysis of occupancy rates between small and medium houses, the smaller U-test value (Mann-Whitney U-test; $U=116.5$; $p<0.05$) was larger than the critical value (Mann-Whitney U-test; U-critical=99; $p<0.05$). Therefore, we fail to reject the null and no significant difference was determined between medians of small and medium size bat houses. For the analysis of occupancy rates between small and large houses, the smaller U-test value (Mann-Whitney U-test; $U=62$; $p<0.05$) was larger than the critical value (Mann-Whitney U-test; U-critical=99; $p<0.05$). Therefore, we reject the null and there is a significant difference between medians of small and large sized bat houses. Finally, for the analysis of occupancy rates between medium and large houses, the smaller U-test value (Mann-Whitney U-test; $U=45.5$; $p<0.05$) was larger than the critical value (Mann-Whitney U-test; U-critical=99; $p<0.05$). Therefore, we reject the null and there is a significant difference between medians of medium and large sized bat houses. These results suggest bats prefer large sized bat houses in comparison to small or medium sized bat houses, and no preference between single and multi-chamber bat houses.

For the statistical analysis of occupancy rates between habitat types the K value was larger (Kruskal-Wallis Test; $K=20.78$; $p<0.01$) than the critical value (Kruskal-Wallis Test; $\square^2$-critical=20.78; $p<0.01$); therefore, we reject the null and there is a significant difference between medians of the four different habitat types. There is a preference for edge habitat ($R=869$) in comparison to open habitat ($R=334.5$) as these habitats have the largest difference between sum of ranks. Although, it cannot be concluded from this analysis that edge habitat is selected over interior or clearing habitats.

In summary, we determined that there was preference for edge habitat when foraging and large size bat houses for maternity colonies.

Other Occupancy Observations

Five new multi-chamber bat houses of various sizes were donated to the Beaverhill Bird Observatory and installed on August 21, 2021 **(**Figure 9**)**. These houses were checked from September 4-26, 2021 on three separate occasions. During this time a single bat was observed in each M42, M43, and M44; 2 bats were observed in M46; and 3 bats were observed in M45. Therefore a total of 8 bats were observed from September 4-26, 2021. Cleanliness and quality of the new houses may be favorable factors to bats in future seasons. These observations were omitted from statistical analysis.

Figure 9. A new multi-chamber bat house (M42) installed in the Beaverhill Natural Area in August, 2021 (Waldron, 2021).

There were also several observations of *Myotis sp.* in house wren nest boxes around the BNA. Only single bats were observed in the nest boxes and the observations occurred on June 8, **(**Figure 10.), July 7, and July 21, 2021. These observations were also omitted in the statistical analysis.

Figure 10. *Myotis sp.* observed by house wren intern in nest box A4 on June 8, 2021 (Cruz, 2021).

Emergence counts of some multi-chamber houses were performed by volunteers through the month of July. A maximum total of 151 bats, presumably females, were using these three boxes with a maximum of 56 bats roosting in one box. Volunteer counts contribute to an additional 249 bat observations; however, these were omitted from the statistical analysis.

Table 1. Volunteer observations of multi-chamber bat houses in the Beaverhill Natural Area during July, 2021.

Date	**House Number**	**Number of Bats**
July 3, 2021	M22	47
July 4, 2021	M41	51
July 5, 2021	M24	48
July 11, 2021	M41	56
July 18, 2021	M41	22
July 24, 2021	M22	25
	Total	**249 (Ave = 41.5)**

Discussion

The results of this occupancy monitoring study clearly indicate an increase in the number of bats using houses in the BNA. Bat observations more than doubled between 2020 and 2021. Results of previous studies have led to the installation of more bat houses, and the addition of multi-chamber houses in 2019. The overall increase in bat observations in the BNA could be related to the increase and inclusion of more suitable and preferred roosting habitat. Multi-chamber houses had higher occupancy than single chamber houses; however, our statistical analysis did not suggest a preference between single and multi-chamber houses. However, raw data was used in the statistical tests opposed to the mean values of each house. The ambiguity of our statistical analysis may be a result of this and consideration should be made to using mean values in future studies as this may have impacted the results of our study. Despite the results of the statistical analysis the high occupancy of the multi-chamber houses throughout the study suggest a preference for multi-chamber houses (1158 bat-observations total) over single chamber houses (317 bat-observations total).

In accordance with past studies at the BBO, large houses had the highest occupancy of the single chamber bat houses (Low, 2017; Caron & Hlewka, 2018; Gualter & Halajian 2019; Abernathy & Pearce Meijerink, 2020). The results of our statistical analysis suggest that bats in the BNA prefer large sized bat houses, similar to results of these past studies. Occupancy was the highest in edge habitat followed by clearing, interior, and open. Habitat preferences have varied from year to year with open habitat most preferred in 2017, interior preferred in 2018, and clearing preferred in 2019 (Low, 2017; Caron & Hlewka, 2018; Gualter & Halajian 2019). Again, it should be considered that raw data values were used in our analysis, making it difficult to compare our results with previous studies.

In regards to preference of house style and size, many factors deem to make interpretation difficult. There is high variability in the design and installation of the bat houses in the BNA. Between the four house designs (single chamber small, single chamber medium, single chamber large, and multi-chamber large) color and painting varies, some being painted interiorly and exteriorly and some solely painted exteriorly; additionally, the houses are installed at various heights, receive differing amounts of sunlight and are located in different habitats (Appendix 1). Distribution among the habitat types, and the number of houses of each type are both unequal (Appendix 1). Several of the house styles and habitat types have smaller sample sizes in comparison to others, specifically, multi-chamber houses (6/33 houses), medium size (4/33 houses), open habitat (2/33), and clearing habitat (4/33).

Studies have shown that bats prefer large, multi-chamber boxes (Brittingham & Williams, 2000; Hoeh, Bakken, Mitchell & O'Keefe, 2018). Factors that might influence bats to select for large and multi-chamber houses include increased volume, surface and entrance area, and temperature variability (Hoeh et al., 2018). Providing roosting structures that offer variability in temperature give bats the ability to freely move to cooler or warmer areas within the roost depending on thermal needs (Hoeh et al., 2018). Hoeh et al. (2018) specifically determined that large houses with multiple temperature options are the primary factors in roost selection by bats in Indiana. This likely explains why we found large numbers of bats roosting in the large and multi-chamber houses in the BNA. In addition, our results determined a preference for edge habitat, which may be related to the majority of the multi-chamber houses being located in edge areas. A study in Ontario found edge habitat to have the most activity of five bat species, including *M. lucifugus* (Jantzen & Fenton, 2013). Linear landscapes have been found to be valuable to bats due to proximity to water and access to less clutter in the environment which eases navigation and increases insect availability (Entwistle et al., 1997; Verboom & Huitema, 1997).

Confounding variables considered in this study included maximum daily temperature and the air quality health index. Selection of these factors was based on lack of evidence found in past BBO studies by Low (2017), and Gualter & Halajian (2019) relating weather variables to occupancy rates. However, Alberta experienced record breaking temperatures amidst various heat waves this summer, and high smoke levels due to fires in BC, Alberta, and Saskatchewan. Analysis of these confounding variables did not show a correlation between maximum daily temperature or air quality and occupancy rates.

Occupancy of multi-chamber houses peaked from mid-June - late July, and quickly dropped down to no occupancy in August and September. Similarly, occupancy was highest in edge habitat from June-July and decreased drastically in August. This is likely due to 4 of 6 of the multi-chamber houses being located in edge habitat. In contrast, single chamber occupancy peaked in late July and continued into August and September. These results coincide with known reproductive and migratory behavior of the *M. lucifugus* (Lausen, 2007; Alberta Community Bat Program, 2021b). Multi-chamber bat houses can serve as a roosting option for maternity colonies of *M. lucifugus* (Brittingham & Williams, 2000). Consistent with our study, occupancy can be expected to increase from June to late July while pups are born and cared for in the maternity roost for several weeks following birth (Lausen, 2007). *M. lucifugus* fall migration usually begins in late July and may extend into October (Alberta Community Bat Program, 2021b). This is likely why we continued to observe bats in the single chamber houses into September as juvenile and transient bats are opportunistically selective when choosing roosts to rest in during migration (Riskin & Pybus, 1998).

Factors that may have impacted the results of our study include the inability to accurately count bats when huddled closely together in large quantities as well as frequent visitor traffic in the BNA. As many of the houses are located along trails in the natural area human presence may have influenced roost selectivity. In addition, great horned owls and a long eared owl were witnessed several times perching on the multi-chamber boxes by other student interns and BBO staff. Owl feathers and droppings were found on M22, and M17 throughout August and September. Therefore, it is possible that proximity to predators may have impacted occupancy rates during these months.

Conclusion

Between May 16 and September 26, 1475 *Myotis sp.*were observed roosting in bat houses in the BNA. Occupancy peaked in June and July, followed by a drastic decrease in August and September. We did not find a preference between single and multi-chamber houses, although we suggest further exploration of these design variables and reanalysis of the data to account for differences in sample sizes between the different bat house designs. We determined a preference for large bat houses compared to small and medium houses. Lastly, we found edge habitat to be preferred compared to open habitat, followed by clearing, interior and open. It is clear that bats are displaying selectivity of houses in the BNA so further investigation should be conducted in regards to box design and confounding variables in order to provide information for management decisions regarding bat conservation.

Recommendations for Future Studies

Future studies should consider addressing unequal distribution of house sizes and habitat types. We suggest considering increasing the number of houses in open and clearing habitats, as well as including multi-chamber houses in all habitat types. In addition, multi-chamber houses provide a multitude of benefits for bats and installation of new houses should consider this. Since a preference for edge habitat has not been found in past studies by the BBO we suggest further investigating habitat preference. Statistical analysis in future studies should use mean values to ensure data is comparable from year to year. Future comparisons should separate maternity colonies from other boxes to show any preferences for roosts that are not maternity colonies. Also interannual comparisons should use maximum numbers with the same survey effort for consistency.

Lastly, we recommend thorough cleaning and maintenance (clear spider webs, remove wasp nests, etc.) of the houses before the next season. Cleaning and maintenance should continue throughout each study season to ensure the houses stay accessible to bats.

Acknowledgements

We would like to thank the Beaverhill Bird Observatory for the opportunity to participate in the bat monitoring internships, Laurie Hunt for assisting in organizing the program, the biologists at BBO for all their kindness and support, including Geoff Holroyd and Sara Pearce Meijerink for editing our reports, and the volunteers and other interns that shared their bat observations with us. We thank Carole and Gary Dodd for funding our internship. We are especially grateful for our mentor, Erin Low, for the guidance and support she offered throughout the summer and the time she took to edit our papers.

Celina would also like to thank her husband, William Waldron, and her friend Justin Andrade, for keeping her company and assisting her during the late night surveys. She is incredibly grateful for her instructors from the NAIT Conservation Biology Program as they prepared her so well for opportunities like this. Lastly, she would like to thank Kayley Burke, her incredible internship partner, for all her hard work and sharing this experience with her.

Kayley would like to thank her phenomenal friends Toni Sparks, Breanna Haugen, Caitlin Morganson, and Gabrielle Bonin for venturing out with into the woods late at night to collect bat data, and for her University of Alberta instructors who have given her the knowledge and experience to participate in this opportunity. She would also like to extend thanks to her wonderful partner, Celina Gerlich for all her hard work and company on surveys.

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Appendix

Appendix 1a. Bat house metadata for houses installed at the Beaverhill Natural Area in 2021, including size, attachment, color, habitat type and sunlight exposure (Low, 2021).

Bat house ID	Size	Attachment	Colour	Inside Painted?	Habitat Type	Direction	Sunlight exposure	Height off ground	Distance to tree / obstacle	Nearest bat house	Distance to weir (m)
2**	medium	tree (balsam)	green	no	interior	southeast	partial sun (only morning or afternoon sun)	10'	2'	not sighted	890
3**	medium	tree (balsam)	green	no	interior	east	mostly shade (minor sun)	8.5'	3'	4’	740
4	medium	tree (aspen)	brown	yes	interior	south	full shade (no direct sun)	5'	1'	not sighted	210
6**	medium	tree (aspen)	green	no	interior	west	mostly sunny (minor shade)	5' plus 3' vegetation	5'	not sighted	695
7**	medium	tree (aspen)	green	no	interior	southwest	mostly shade (minor sun)	8'	3'	not sighted	700
9	small	tree (aspen)	red	yes	interior	south	partial sun (only morning or afternoon sun)	9.5'	5'	not sighted	675
10	small	tree (aspen)	red	yes	interior	south	partial sun (only morning or afternoon sun)	8'	5'	not sighted	654
11*	large	tree (aspen)	brown	no	clearing	south	mostly sunny (minor shade)	8'	10'	10’	840
12	large	post	brown	no	open	southwest	full sun (no shade)	10'	20'+	not sighted	835
13	large	post	brown	no	open	southwest	full sun (no shade)	10'	20'+	not sighted	980
14*	large	post	brown	no	clearing	southeast	mostly sunny (minor shade)	10'	28'	not sighted	720
15	large	tree (balsam)	brown	no	interior	southwest	partial sun (only morning or afternoon sun)	9'	4'	not sighted	775
16	large	tree (balsam)	brown	no	interior	southeast	partial sun (only morning or afternoon sun)	8'	4'	not sighted	890
18	small	tree (aspen)	red	yes	edge	south	partial sun (only morning or afternoon sun)	9' plus 1' to bush	5'	not sighted	550
20	small	tree (aspen)	red	yes	edge	southwest	partial sun (only morning or afternoon sun)	8' plus 1' bush	2'	not sighted	355
21	small	tree (aspen)	red	yes	edge	south	partial sun (only morning or afternoon sun)	10'	3'	not sighted	350
23	small	tree (aspen)	red	yes	edge	south	partial sun (only morning or afternoon sun)	9' plus 3' bush	5'	not sighted	340
25	small	tree (aspen)	red	yes	edge	southwest	partial sun (only morning or afternoon sun)	3' to obtruding branches	1.5'	not sighted	330
26	small	tree (aspen)	red	yes	edge	south	mostly shade (minor sun)	9'	3'	20’	340
27	small	tree (aspen)	red	yes	edge	southeast	partial sun (only morning or afternoon sun)	10'	3'	20’	350

30	small	tree (aspen)	red	yes	edge	southeast	mostly shade (minor sun)	9' plus 1' bush	3'	not sighted	475
32	small	tree (aspen)	red	no	edge	southeast	partial sun (only morning or afternoon sun)	10.5'	3.5'	not sighted	550
33	small	tree (aspen)	red	lightly painted	edge	southeast	partial sun (only morning or afternoon sun)	9'	6'	not sighted	575
35	small	tree (aspen)	red	yes	edge	south	partial sun (only morning or afternoon sun)	10'	2'	not sighted	700
36	small	tree (aspen)	red	no	interior	southeast	mostly shade (minor sun)	10'	6'	25’	730
37	small	tree (aspen)	red	yes	interior	southeast	partial sun (only morning or afternoon sun)	8.5' plus 2' vegetation	1'	25’	735
38	small	tree (balsam)	red	lightly painted	interior	east	mostly shade (minor sun)	8.5'	2'	4’	735
39*	small	tree (aspen)	red	lightly painted	clearing	south	mostly sunny (minor shade)	10'	3'	10’	845
M41	large	tree (aspen)	brown	no	clearing	southeast	mostly sunny (minor shade)	10'	6'	30'	860
M8	large	tree (aspen)	brown	no	interior	southeast	partial sun (only morning or afternoon sun)	10'	1'	not sighted	MISSING
M17	large	tree (aspen)	brown	no	edge	west	mostly sunny (minor shade)	11'	1'	not sighted	MISSING
M19	large	tree (aspen)	brown	no	edge	west	mostly sunny (minor shade)	12'	1'	not sighted	MISSING
M22	large	tree (aspen)	brown	no	edge	southwest	partial sun (only morning or afternoon sun)	11'	3'	not sighted	MISSING
M24	large	tree (aspen)	brown	no	edge	southwest	partial sun (only morning or afternoon sun)	10'	4'	not sighted	MISSING

Appendix 1b. Bat house metadata for houses installed at the Beaverhill Natural Area in 2021, installation height, distance to trees and obstacles, proximity to other houses and the weir (Low, 2021).

Bat house ID	Height off ground	Distance to tree / obstacle	Nearest bat house	Distance to weir (m)
2**	10'	2'	not sighted	890
3**	8.5'	3'	4'	740
6**	5' plus 3' vegetation	5'	not sighted	695
7**	8'	3'	not sighted	700
9	9.5'	5'	not sighted	675
10	8'	5'	not sighted	654
11*	8'	10'	10'	840
12	10'	20'+	not sighted	835
13	10'	20'+	not sighted	980
14*	10'	28'	not sighted	720
15	9'	4'	not sighted	775
16	8'	4'	not sighted	890
18	9' plus 1' to bush	5'	not sighted	550
20	8' plus 1' bush	2'	not sighted	355
21	10'	3'	not sighted	350
23	9' plus 3' bush	5'	not sighted	340
25	3' to obtruding branches	1.5'	not sighted	330
26	9'	3'	20'	340
27	10'	3'	20'	350
30	9' plus 1' bush	3'	not sighted	475
32	10.5'	3.5'	not sighted	550
33	9'	6'	not sighted	575
35	10'	2'	not sighted	700
36	10'	6'	25'	730
37	8.5' plus 2' vegetation	1'	25'	735
38	8.5'	2'	4'	735
39*	10'	3'	10'	845
M41	10'	20'+	not sighted	860
M8	MISSING	MISSING	MISSING	MISSING
M17	MISSING	MISSING	MISSING	MISSING
M19	MISSING	MISSING	MISSING	MISSING
M22	MISSING	MISSING	MISSING	MISSING
M24	MISSING	MISSING	MISSING	MISSING

Appendix 2. Sample data sheet for occupancy surveys (Low, 2021).

Beaverhill Bird Observatory Bat House Occupancy Check

Date: Day / Month / Year　　　　　　Pages: ## of ##
Observer(s):
Start time:　　Start temp:　　End time:　　End temp:
Start cloud %:　　Start precip.:　　End cloud%:　　End precip.:
Start wind (speed/direction):　　End wind (speed/direction):
Previous night's weather data (i.e. temp, wind, precip):

Bat House # _______	
# present: 0 1 2 3 4 5 _____	Sp: Unknown *Myotis* MYLU EPFU
Comments:	

Bat House # _______	
# present: 0 1 2 3 4 5 _____	Sp: Unknown *Myotis* MYLU EPFU
Comments:	

Bat House # _______	
# present: 0 1 2 3 4 5 _____	Sp: Unknown *Myotis* MYLU EPFU
Comments:	

Bat House # _______	
# present: 0 1 2 3 4 5 _____	Sp: Unknown *Myotis* MYLU EPFU
Comments:	

Bat House # _______	
# present: 0 1 2 3 4 5 _____	Sp: Unknown *Myotis* MYLU EPFU
Comments:	