Status of bat box occupancy at the Beaverhill Natural Area and temporal variations in relation to roost characteristics and weather conditions.

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Abstract

An analysis of *Myotis lucifugus* (little brown bat) roosting preferences in bat boxes and of the factors that may influence occupancy including roost type, habitat and weather was completed in the Beaverhill Natural Area (BNA) from May-September of 2024 as part of the long-term monitoring of artificial roosts. Data were collected following protocols established in previous years, with the addition of weather data for the day and night preceding surveys. Overall, 92% of the 38 houses were occupied at least once. Total weekly counts followed a bimodal pattern, with the largest count (n=344 bats) in mid-June followed by a sudden decline in numbers (to n=176 bats) and rising again weekly until mid-July (n=322 bats) after the young were born. Between years, the number of roosting bats, expressed as highest weekly counts and cumulative counts by year, substantially increased (doubled) from 2020 to 2023. In 2024, the population resembled that of 2023 and there were no significant differences in colony sizes between the two years. In 2024, largest colonies were observed in multi-chambered houses, but patterns of roost occupancy, i.e. the consistency with which roosts are used, varied through the summer. Multi-chambered houses were most consistently used in early to mid-summer, while occupancy rates of single chambered houses increased in mid to late summer. Across habitats, more bats occupied roosts in edges, where most multi-chambered boxes were also located. Under the range of weather conditions encountered, short-term house occupancy did not seem affected by weather, but this merits further investigation.

Introduction

Bats are ubiquitous mammals found in almost all parts of the world, with Canada counting approximately 20 species (Harvey, 2011). Worldwide, bats play important ecological roles including control of insect population, see dispersal and plant pollination. They are seasonal breeders and often only produce one pup per year, thus survival and reproductive success is critical especially in northern areas such as Alberta where the active season in which juveniles must develop prior to hibernation is shortened (McGuire et al., 2016). With the rise of White-Nose Syndrome (WNS) devastating north American bat populations in recent years, this study's species of interest, *Myotis lucifugus* (little brown bat), has been listed as federally endangered in Canada (Nature Conservancy of Canada).

In temperate areas, reproductive female bats play an important role in their roosting preferences. During pregnancy and lactation, successful development and growth of pups requires roost that are sufficiently warm. At the same time, female bats may prefer cool microclimates to maximize torpor and biological energy conservation when their insect prey are in short supply during cold weather. Thus, roost selection becomes a matter of "the Goldilocks Effect," in which bats may leave boxes that are an unsuitable temperature in favour of a more suitable microclimate (Holroyd et al., 2023; Lausen, 2021). Moreover, female bats often return to the same areas over many years, their roost fidelity providing benefits such as roost mate familiarity and the maintenance of social bonds (Lewis, 1995). Benefits of roost fidelity in a suitable roost for rearing young may outweigh constant movement during the maternity season, as energy expenditure must be regulated.

Furthermore, roost occupancy and preferences in little brown bats vary according to sex and reproductive status. Peak group size in maternity colonies of that species have been associated with the start of parturition, when heightened social thermoregulation may be beneficial (Olson and Barclay, 2013). Aquatic habitats were often preferred by lactating little brown bats, providing an abundance of insect prey and drinking water (Nelson & Gillam, 2016). In contrast to females, male bats have been observed to use a wider variety of roost sites, including buildings, rock cliffs, and trees, often switching roosts periodically (Randall, 2014). After the young have fledged and can forage independently, maternity colonies disperse, and bats move to mating sites.

Several bat species have made home in the Beaverhill Natural Area, a protected region near Tofield, Alberta. Established in 1984, the Beaverhill Bird Observatory (BBO), the site of our data collection, holds various habitat types suitable for bats, such as wetlands, grasslands, and forests. However, in June of 2024, several samples around the Beaver Hills Biosphere were reported to have tested positive for *Pseudogymnoascus destructans* (PD), the fungus causing White-Nose Syndrome (WNS) in bats. Thus, several bats in the Beaverhill Natural Area may suffer from the fungus during winter hibernation where the fungus thrives in cold and humid conditions. Bat boxes were first installed and occupancy monitored in the BNA by BBO in 2015. One of the objectives was to monitor occupancy in anticipation of the arrival of PD in Alberta (G.L. Holroyd pers. comm.) The effects of PD on the local bat populations are still undocumented and the continued monitoring of artificial roosts (Low, 2017) will provide important information on the health of the bat fauna in this area. In this report, bat box occupancy in the summer of 2024 will be compared with that of previous years. Furthermore, we aim to expand the understanding of bat roosting preferences at BBO to provide insight that will aid the construction of strategically located bat houses that will benefit the bat population in the face of WNS.

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Previous reports from internships at BBO revealed that multi-chambered houses were more successful in attracting bat colonies than single chambered ones, regardless of habitat in which they were located (Abernathy & Meijerink, 2020; Mejia, 2023). These conclusions were consistent with the hypothesis that multi-chambered boxes provide a better thermal buffer, including mitigating the effects of heatwaves (Tilman et al., 2021; Brouwer and Henrard, 2021). Here we take a closer look at short-term (within year) variations in roost occupancy in relation to weather conditions. The findings of this study may aid in understanding bat roosting preferences of little brown bats, specifically in the context of extreme weather shifts catalyzed by global warming, such as the widespread Albertan heatwave from July 16-26, 2024.

Methods

Study Site Description

Data collection occurred in the Beaverhill Natural Area (BNA) located 8 km east of Tofield, Alberta (53.39873° N, 112.53566° W), with the study site covering 1013.10 acres. As typical with climate in central Alberta, weather in the BNA alternates between hot summers and cold winters (Holroyd and Krikun, 2001). The BNA comprises a variety of habitat types, including wetlands, grasslands, and forests, making the area a suitable home for several diverse bird and bat populations. The bat houses, built and maintained by the Beaverhill Bird Observatory (BBO), were installed in four different habitat types: forest interior, edge, clearing, and open (Figure 1).

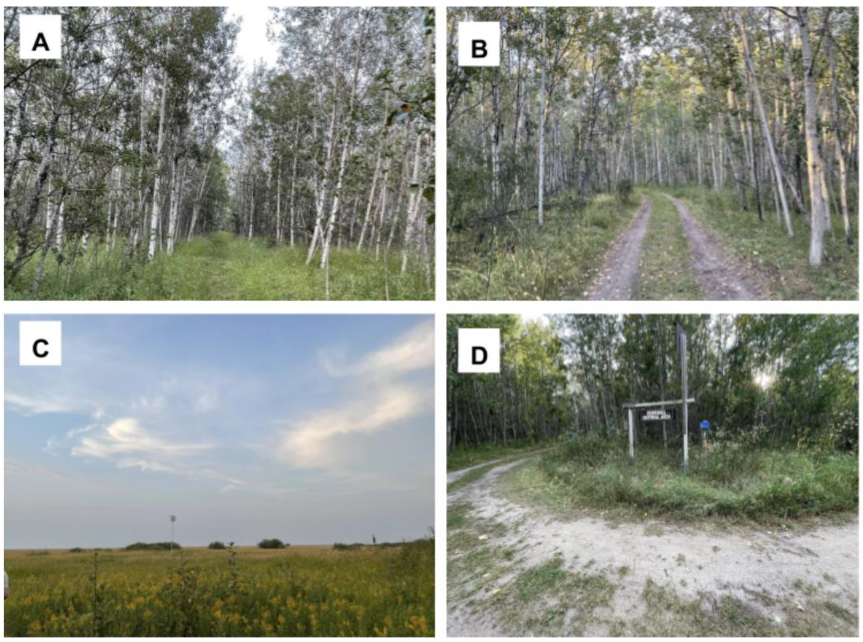

Figure 1. Four habitats in the Beaverhill Natural Area containing bat houses. (A) Interior habitat, characterized by the dense internal part of a forested region. (B) Edge habitat, flanked by trees on both sides and close to a water body (C) Open habitat, or grasslands, containing infrequent trees and bushes. (D) Clearing habitat, an area containing removal of some surrounding vegetation.

The bat houses either possessed a single chamber or multiple ones (2-4) and were placed from 5'-14.5' above ground. Most bat houses were attached to balsam or aspen trees and three were attached to posts. Sun exposure of houses varied, though the majority received partial sun, with a few receiving full or almost no sun. Over the course of the summer, we verified the metadata for all houses and prepared an updated map of their location (Figure 2).

Figure 2. Map of the bat box distribution in the Beaverhill Natural Area (BNA) and the habitat types they occupy. Houses in the forest interior are in purple, those in edge habitat in gray, those in forest clearing in yellow, and those in open habitat in green. Multichambered houses are identified with the letter "M" preceding their number, while single chamber houses do not.

Data collection

We surveyed the 38 bat houses weekly from May 17- September 04, 2024, following the methods established in previous years (Low, 2023). To perform the bat occupancy counts, a flashlight was pointed below the house to get a view of the interior (Figure 3a). For houses with multiple chambers, the chambers in which bats were present were noted. During the maternity season, several bats were layered atop each other during some of the occupancy counts, obstructing the full view (Figure 3b), thus these counts underestimate the number of bats present, and these situations were noted during data collection. We also performed a count of the number of bats exiting two bat houses at dusk and compared it with our roosting bat counts for that day.

As in past years, weather data was collected including cloud cover (%), wind strength (km/hr), start and end temperature (℃), max/min daily temperature (℃), end precipitation (yes/no), and moon illumination (%). For this year's survey we also added the previous day's weather to the data collection (Appendix 1), including min/max temperatures (℃) and precipitation (mm), as it is those conditions that might affect whether bats will be returning and present in the roost on the day of a survey (rather than conditions during the survey itself).

Figure 3. (A) Occupancy counts were performed by briefly shining a flashlight below the house. (B) An interior view of a multichambered maternity roost.

Data analysis

Data are presented as *total weekly* counts (sum of bats counted in all boxes or in a category for a single survey) to show temporal trends in overall occupancy of boxes at BBO and to make comparisons between house type and habitat types. To quantify the extent to which bats used different boxes, we used two variables: *maximum colony size* and *occupancy rate* for each box. Maximum colony size was estimated as the number of bats counted during a single survey throughout the season (i.e. largest of the 14 counts for each house). *Occupancy rate*, *P/A ratio* (Poulton, 2006) represents the consistency with which a box is occupied and was calculated as the ratio of inspections with bats presents/inspections with bats absent. For example, with 14 inspections carried out, if a box was occupied twice, its P/A ratio would be 0.17 (2 present/12 absent). To take sampling effort into account when a box was never occupied a modified ratio was calculated as *1/(number of inspections x 2)*. For a box that was always occupied, the modified ratio was calculated as *2 x (number of inspections)*. Thus, in our sampling, occupancy rates can range from 0.04 (1/28 for houses never occupied) to 28 (2 x 14 for houses always occupied). Because P/A ratios take sampling effort into account, it is therefore possible to compare occupancy where sampling effort varies, as is the case for between-year comparisons. To make inter-annual comparisons in bat house occupancy, P/A ratios were calculated using data sets from 2020, 2021 and 2023. Raw data were not available for 2022.

For 2023 and 2024, maximum colony size between years were compared with a paired t-test, with bat house as the sampling unit. Since the data did not follow a normal distribution, they were log transformed after adding 1 to each variable (maximum colony size), to avoid log 0 for houses with no bats. After the transformation, kurtosis was calculated to be -0.25, an acceptable value for normal distribution (George and Mallery, 2010). The t-test was performed using Microsoft excel.

Because reports from previous years used *cumulative counts* (sum of the number of bats counted during several surveys), we also included this variable to make it possible to compare 2024 bat counts with those reported in previous years. Because cumulative counts are affected by the number of bat boxes and varying sampling effort between years, those factors were also considered in our inter-annual comparisons.

Results

Bat numbers and roost occupancy in 2024

From May 17-Sept 4, 14 bat counts were completed. One house could not be surveyed on two nights after it fell down and another was missed on one occasion, still keeping the completeness of the inventory > 99% (529 box surveys out of 532 possible). During the summer, the BNA received a monthly rainfall average of 52 mm (Weatherspark 2024). Data collection proceeded throughout a heatwave in July, in which the summer reached warmer and drier than average conditions in Alberta (Zenseekers 2024).

Most bats sighted were *Myotis*, though single individuals of other species were occasionally roosting in the houses, including *Eptesicus fuscus* (big brown bat), *Lasionycteris noctivagans* (silver-haired bat), and *Lasiurus cinereus* (hoary bat). Weekly bat counts followed a bimodal pattern (Figure 4), peaking on June 16 (n = 344 bats) and July 12 (n = 322 bats), with a substantial decline in number on June 22. Bat counts began to decline rapidly again in early August. Total bat counts per week were highest in edge habitats (Figure 5), where more houses are located. Houses in all habitats followed a similar bimodal pattern, except for the two houses located in open habitat (field), where counts remained relatively low throughout the entire season.

A bat emergence count took place on 20 July at two boxes near the BBO station (11 and M14). In the house with fewer bats, the estimated number (n = 11), counted while roosting approached that at emergence (n = 13). In contrast to the second house where the number of bats estimated (n = 30) was much lower than that counted at emergence (n = 44).

Overall, 92% of the 38 houses were occupied at least once. The three houses that were never occupied (#10, 20, and 27), were single chambered boxes in the edge habitats with their entrances or interior often obscured by cobwebs, and the nearest neighbor less than 32 meters away. All multichambered houses were occupied for at least four consecutive weeks.

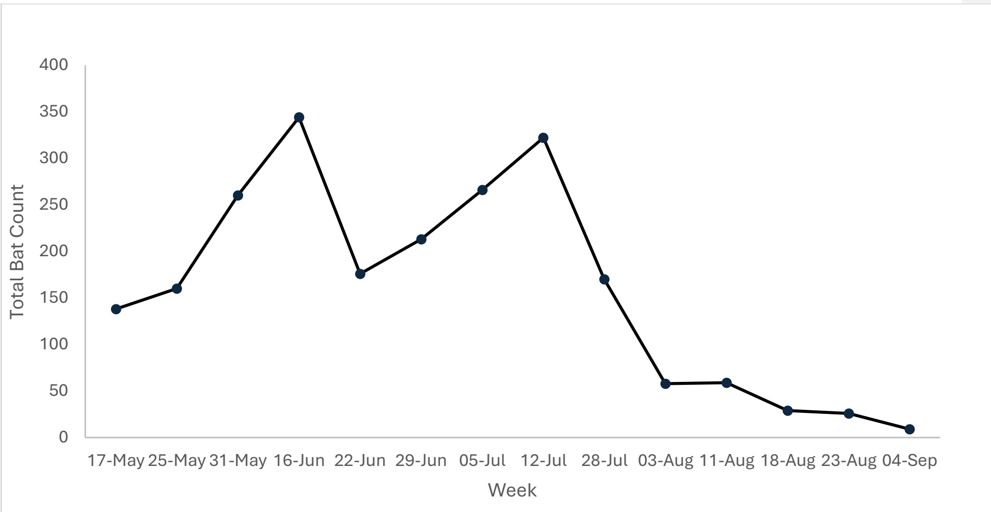

Figure 4. Total weekly counts of bats (all 38 houses) at BBO May 17-Sept 04, 2024.

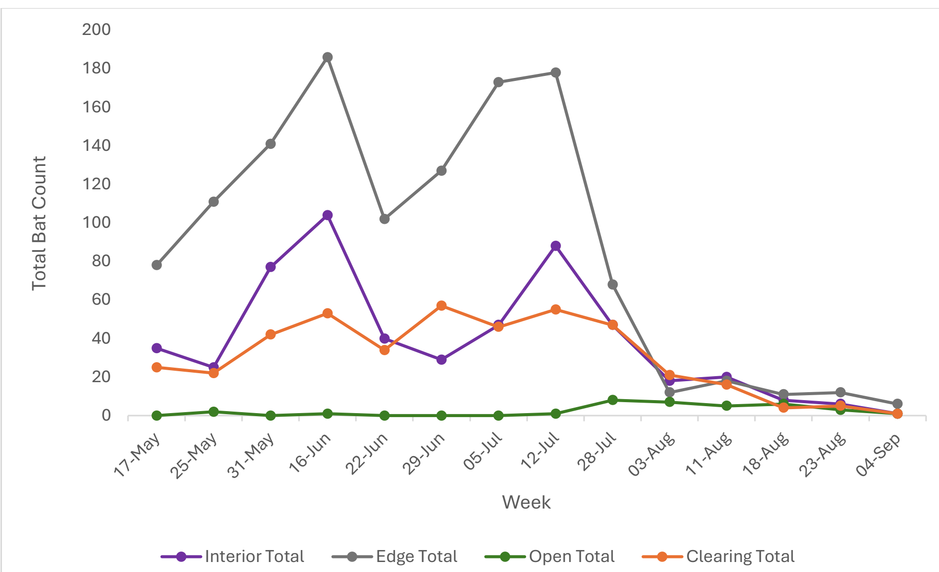

Figure 5. Total weekly counts of bats counted in houses located in each of the four habitat types at BBO (from 13 houses in interior, 19 in edge, 2 in open and 4 in clearing)

Occupancy rates (Figure 6) illustrate the consistency with which different houses were used by roosting bats. Of the houses with the highest occupancy (2, 6, 7, 14, 16, M41, M43, M44, and M46), four were multi-chambered and five single chambered. High occupancy (P/A score ≥ 2.5) occurred in all habitats except in the open. While most houses with high occupancy rate often had high cumulative counts, the two variables were not always related.

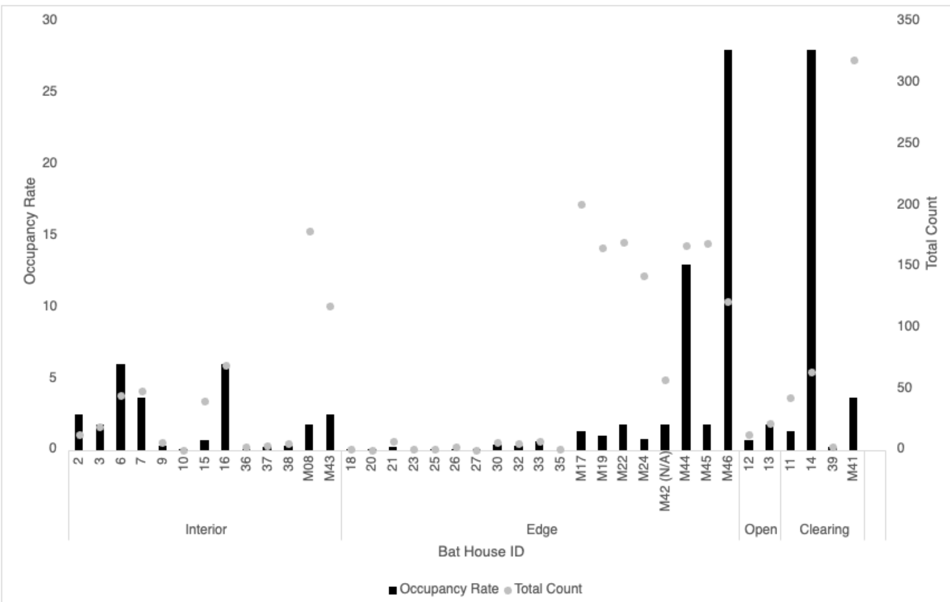

Figure 6. Occupancy rate (P/A ratio) and cumulative count in 38 BBO bat houses by habitat (interior, edge, open, and clearing) over the course of 14 weekly inspections from May 17-Sept 04 2024. 'Total counts' on the y axis represent cumulative numbers for the 14 surveys.

Interannual trends in bat numbers and roost occupancy

From 2020-2024, with fairly consistent sampling effort between years, 2024 held the largest cumulative count while the largest number of bats in a survey was recorded in 2023 (Table 1), after the addition of five multichambered houses in 2023. Cumulative count in 2024 was 3.4 time that of 2020 and 1.6 times that of 2023. However, colony sizes did not differ significantly between 2023 and 2024 ($t = 2.03$, $p = 0.57$, $N = 38$).

Table 1. Bats counted at BBO from 2020-2024 including highest number of bats recorded in a weekly survey and cumulative counts in relation to number of roosts, sampling effort and dates on sampling for each year. Inventory completeness is expressed as the percentage of boxes monitored throughout the entire survey period (e.g. with 38 houses and 14 surveys, 100% completeness represents 352 box surveys).

	Year (2020-24)			
	2020	**2021**	**2023**	**2024**
Highest Count	116	227	364	344
Cumulative Count	645	1547	1396	2233
Houses	34	33	38	38
Surveys Conducted	14	15	13	14
Completeness	98.9	99	97.1	99.4
Dates of Sampling	May 08-Aug 19	May 16-Aug 24	May 19-Sept 08	May 17-Sept 04

Historic occupancy rate and cumulative counts were calculated for individual houses, with data pooled from 2020-2023 (Figure 7). There as well, multichambered houses in the edge habitat often held a high cumulative count of bats, which did not always coincide with the highest rates of occupancy. Thus, houses with high occupancy rate (most consistently occupied) are not necessarily those sheltering the most bats.

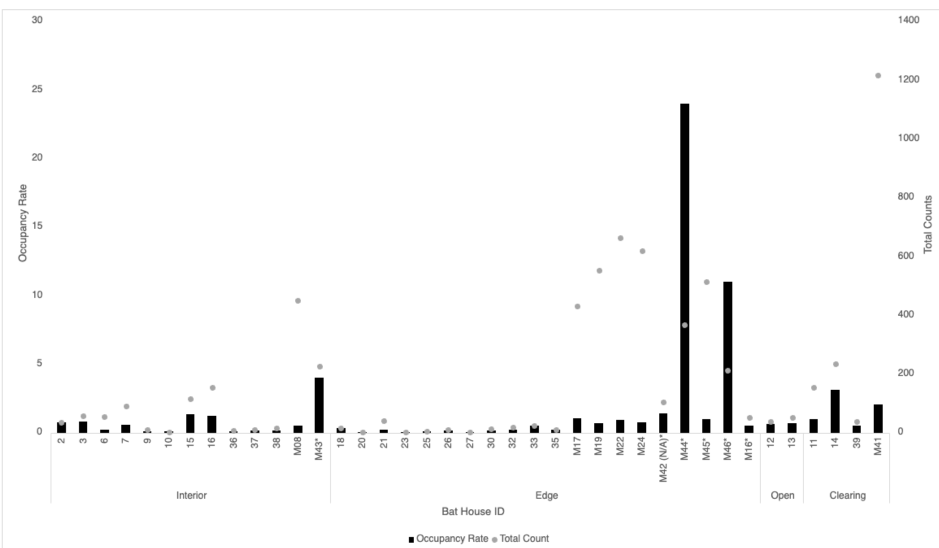

Figure 7. Occupancy rate and cumulative count on pooled data from BBO bat houses from 2020-23. Houses with asterisks are houses set up in 2023. Occupancy rate was calculated using the present/absent ratio taking into account the number of surveys for each house. ‘Total counts’ on the y axis represent cumulative numbers for all years.

Within-year variation in roost occupancy (2024) in relation to house type, habitat and weather

In 2024, multichambered houses, most of them located in edge habitat, registered the highest bat counts, especially so in May, June, and July, (Figure 8) coinciding with the timing of pregnancy and lactation. In August, the median of total bat counts for multichambered houses dropped substantially and by mid-August, total count of bats in edge and interior habitats were equivalent (Figure 5). At that time, weekly total counts in the edge habitats faced a steeper decline than in the clearing and interior habitats. Maximum counts peaked in the open habitat during the transition from July to August, months corresponding to the transition between lactation and the fledging of young. The two single chambered houses in grassland remained almost consistently unoccupied until late July (n = 2) after which we observed 29 bats (cumulative count), from late July-late August. A large number of outliers were apparent every month for single chambered houses, thus any preferences for single-chambered houses in specific habitats are highly variable.

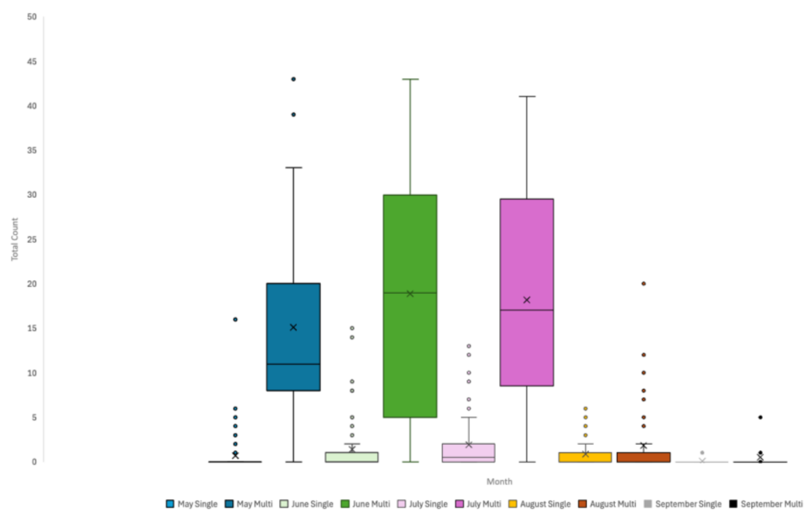

Figure 8. Total bat count by month and house type from May-September of 2024. The months of May-July encompass maternity and lactation periods for bats, while the months of August-September are considered post-fledgling season. Means are marked by “X”.

Patterns of occupancy (Figure 9) provided a different picture. Multi-chambered houses were most consistently used in May and less so in June and July. In contrast, occupancy of single-chambered houses peaked in July. By August, the occupancy of both types of houses was equivalent.

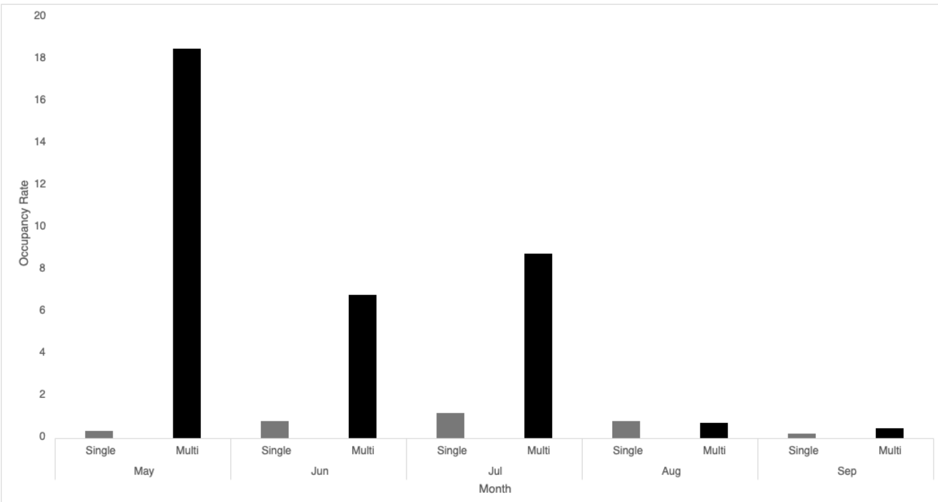

Figure 9. Occupancy rate by month and house type in May-September of 2024. The months of May-July encompass maternity and lactation periods for bats, while the months of August-September correspond to the post-fledgling season of young.

To begin exploring if within-year variation in occupancy, particularly pronounced in the multi-chambered houses, may be related to weather conditions, we examined the timing of maximum bat count for each house and the corresponding weather (Tables 2 and 3). The majority of multichambered house bat counts peaked either in late May, June, or early July. Temperatures at that time ranged from 2-7 ºC (minimum for the night preceding the survey) to 18-28 ºC (maximum temperature for day preceding the survey). In spite of high winds (6 on the Beaufort's Scale) the day before the survey, three houses recorded their highest counts on May 31. In contrast, most single chambered houses (14 of 27) reached their largest colony size from late July to late August. At that time, temperatures ranged from 6-12 ºC (minimum for the night preceding the survey) to 22-29 ºC (maximum temperature for day preceding the survey) and with the wind strength of the previous days remaining relatively consistent ranging from 1-3 on Beaufort's Wind Scale. Thus, majority of single chambered houses reach their highest occupancy during the warmest temperatures.

Precipitation during the night preceding a survey only occurred in two instances: light sprinkles on August 2 and September 3, at the time when colonies were already dispersing (Figure 4). Furthermore, seven houses reached their highest colony size the day following a thunderstorm. The overall decline in bat counts that occurred on June 22 does not appear to have coincided with inclement weather. In all habitats except for the two houses in the field, the survey conducted immediately following the warmest days (July 16-26) coincided with lower bat counts than those of the previous survey (Figure 5) but also coincided with seasonal colony dispersal.

Table 2. Weather conditions on days preceding weekly surveys at BBO.

	Weather Variables					
Date	Previous night Tmin (C)	Previous day Tmax (C)	Previous day wind (BWS)	Previous night precipitation (yes/no)	Previous day cloud coverage (no/partial/full)	Previous night comments
May 17	5	14	4	No	Partial	N/A
May 25	4	15	4	No	Partial	N/A
May 31	6	18	6	No	Partial	N/A
Jun 16	2	19	4	No	Partial	N/A
Jun 22	4	23	2	No	Partial	N/A
Jun 29	4	20	3	No	Partial	N/A
Jul 05	8	23	2	No	Partial	N/A
Jul 12	7	28	1	No	Partial	Thunderstorm
Jul 28	9	22	2	No	Partial	N/A
Aug 03	11	25	2	Yes	Partial	N/A
Aug 11	6	28	2	No	Partial	N/A
Aug 18	10	27	2	No	Partial	N/A
Aug 23	12	20	3	No	Partial	N/A
Sep 04	12	24	2	Yes	Partial	N/A

Table 3. Maximum occupancy of 38 houses by date(s) in the Beaverhill Natural Area.

Habitat	House Type	House ID	Maximum	Date(s) of Maximum Occupancy
Interior	Single	2	3	Aug 23
		3	6	Aug 03
		6	10	Jul 28
		7	13	Jul 12
		9	3	Jul 12
		10	N/A	N/A
		15	15	Jun 16
		16	16	May 31
		36	2	Jul 12
		37	1	Jun 16, Jul 5, Jul 12
		38	2	Aug 11
	Multi	M08	43	Jun 16
		M43	22	Jun 16
Edge	Single	18	1	Aug 18
		20	N/A	N/A
		21	6	May 25
		23	1	Aug 18
		25	1	Jul 28

Habitat	House Type	House ID	Maximum	Date(s) of Maximum Occupancy
		26	1	Jun 16, Jul 28
		27	N/A	N/A
		30	3	Aug 23
		32	3	Jul 28
		33	2	Aug 11
		35	1	Jul 12
	Multi	M17	41	Jun 29, Jul 5
		M19	41	Jul 12
		M22	29	Jun 29
		M24	43	May 31
		M42 (N/A)	17	Jul 28
		M44	22	Jun 16, Jul 05, Jul 12
		M45	30	May 31
		M46	11	May 25, Jun 22, Jul 05
Open	Single	12	4	Aug 3
		13	7	Jul 28
Clearing	Single	11	13	Jul 28
		14	14	Jun 29
		39	1	May 31, Jun 16
	Multi	M41	41	Jul 12

Discussion

In 2024, usage of artificial roosts by bats at BBO was comparable to that observed in 2023. Although the cumulative count was substantially higher in 2024, 1.6 times that of 2023, the highest total weekly count was observed in 2023, and maximum colony sizes did not differ significantly between those years. The higher cumulative count in 2024 was likely driven by the larger sampling effort (one more survey) and inventory completeness, facilitated by more favorable weather conditions. The addition of multi-chambered houses between 2020 and 2023 led to higher bat counts in the area, with bats occupying all the most recently installed boxes (2023) and most others, during at least part of the summer.

The dispersal from maternity colonies observed in June, before parturition, resulted in lower total weekly counts. This suggests that bats moved to sites other than bat boxes. This phenomenon also occurred in 2023 (BBO Bat House Data) but not necessarily every year. For instance, in 2020 numbers continued to increase throughout June (Abernethy and Pearce, 2020). It is unlikely that short-term weather conditions led to long lasting roost abandonment. Furthermore, because it occurred at houses that were not necessarily in proximity, disturbance from predators or from other sources is also unlikely.

Previous reports from BBO consistently documented preference for multichambered houses to be more successful than single-chambered houses (Low, 2017; Caron & Hlewka, 2018; Gualter & Halajian, 2019; Abernathy & Meijerink, 2020; Mejia, 2023). The 2024 data follows a similar trend, with multichambered houses accounting for 81% of the total count from May 17th-Sept 4. The 2024 season also follows a similar trend from previous years, with bats preferring multichambered houses in edge habitats (Waldron & Burke, 2021). However, the difference in count between multichambered houses in edge habitat and those in the forest interior was reported to be negligible in more recent years (Mejia, 2023). This suggests that differences in count between the interior habitat and edge habitat may be dominated by a high use of single chambered houses in the forest interior, as was evident in the 2024 season.

Edge habitats close to a water body serve as an ideal feeding habitat for little brown bats, feeding on emerging aquatic insects (Grindal et al., 1999; Clare et al., 2011). Previous studies reported that little brown bats do not typically feed along forest interiors, thus we must consider that bats in BBO roosting in the forest interior may not be doing so for proximity to food or abundance, as there are more attractive roosting options in the edge habitats (Nelson & Gillam, 2017). In terms of housing preferences during different reproductive conditions, previous studies identified aquatic areas where insect abundance is high, as the preferred habitat for lactating little brown bats (Olson & Barclay, 2013). These findings are consistent with our 2024 season data, with bats preferring edge habitats allowing easy access to Sora Pond especially during the months of May, June, and early July. However, the distribution of the two types of houses among habitat types (Figure 2) does not permit to evaluate this hypothesis against alternatives i.e. a preference for edge habitat, for multichambered houses or simply more roosting alternatives along edges.

Overall, the 2024 season saw an increased use of single chambered houses from August-September coinciding with the rapid decline in bat count within multichambered houses. Previous reports from BBO highlighted the same trend for the abandonment of multichambered maternity roosts around the same time (Waldron & Burke, 2021; Gualter & Halajian, 2019). Open habitat houses only being consistently occupied in late July-late August is not a new observation and is perhaps evidence of the movement of male bats prior to the mating season (Gualter & Halajian, 2019; Fellers & Pierson 2022) or maternity colony dispersal. Most single chambered houses also peaked in number in the hottest weeks of data collection. This may be due to proximity to the nearest water body, as some houses near Sora Pond peaked in number during survey days that had the hottest maximum temperatures on the previous day. Hot temperatures may encourage movement to a readily available source of drinking water. However, other houses, that did not share the same proximity to a water body still displayed their maximum counts during weeks of high temperature.

Conclusion and recommendations

This study highlights the success of the bat box initiative in the Beaverhill Natural Area, despite the threat of White-nose syndrome. Moving forward, the installation of additional multichambered boxes evenly distributed throughout all habitats would allow to further test alternative hypotheses on the relative importance of habitat versus roost characteristics in the success of artificial roosts. Furthermore, monitoring roost temperature as part of future studies would provide direct insight into the effect of temperature on roost selection in the area, especially that some roosts were abandoned in June while other were not. Emergence counts at the largest colonies, once before parturition and once after the young are born would be valuable going forward to complement estimates of roosting bats. They would also assist in estimating annual juvenile recruitment in nursery colonies.

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References

Abernethy, S., & Meijerink, S.P. (2020). 2020 Bat Monitoring Summary at the Beaverhill Bird Observatory. Beaverhill Bird Observatory, Beaver County, Alberta

Bat Conservation Trust. (n.d.). Maternity roosts – bat roosts. https://www.bats.org.uk/about-bats/where-do-bats-live/bat-roosts/maternity-roosts

Brouwer, D., & Henrard, E. (2020). Too hot or not? The influence of colour and material on temperature and relative humidity in flat, single-chambered bat boxes in the Netherlands. *NatuurInclusief*. https://www.natuurinclusief.nl/wp-content/uploads/2021/03/Brouwer_DHenrard_E_2020_Toohotornot.pdf

Clare, E. L., B. R. Barber, B. W. Sweeney, D. N. Hebert, and M. B. Fenton. 2011. "Eating Local: Influences of Habitat on the Diet of Little Brown Bats." *Molecular Ecology* **20**: 1772–80.

Caron V., & Hlewka, J. (2018). Bat House Occupancy Monitoring at the Beaverhill Natural Area. Beaverhill Bird Observatory, Beaver County, Alberta.

Fellers, G.M., Pierson, E.D. (2002). Habitat Use and Foraging Behavior of Townsend's Big-Eared Bat (*Corynorhinus Townsendii*) in Coastal California, *Journal of Mammalogy*, Volume 83, Issue 1, February 2002, Pages 167–177, https://doi.org/10.1644/1545-1542(2002)083<0167:HUAFBO>2.0.CO;2

George, D., & Mallery, M. (2010). SPSS for Windows Step by Step: A Simple Guide and Reference, 17.0 update (10a ed.) Boston: Pearson

Grindal, S. D., J. L. Morissette, and R. M. Brigham. 1999. "Concentration of Bat Activity in Riparian Habitats over an Elevational Gradient." *Canadian Journal of Zoology* **77**: 972–7.

Gualter, J., & Halajian, E. (2019). Occupancy of three bay houses sizes across different habitats at the Beaverhill Bird Observatory.

Harvey, M. (2011). Bats of the United States and Canada. In *Johns Hopkins University Press eBooks*. https://doi.org/10.1353/book.10333

Holroyd, S., Lausen, C.L., Dulc, S., de Freitas, E., Crawford, R., O'Keefe, J., Boothe, C., Segers, J. and Reichard, J. 2023. Best Management Practices for the Use of Bat Houses in US and Canada -- with focus on summer habitat mitigation for Little Brown Myotis, Yuma Myotis, and Big Brown Bat. Wildlife Conservation Society Canada, produced in cooperation with US Fish and Wildlife Service and Canadian Wildlife Health Cooperative for the WNS Conservation and Recovery Working Group. Version (last updated): 20 Sept. 2023. https://doi.org/10.7944/P99K4BF5

Jankowska-Jarek, M., Ciechanowski, M., Bidziński, K., & Postawa, T. (2023). Factors affecting bat occupancy of boxes in managed coniferous forests. *The European Zoological Journal*, *90*(1), 454–469. https://doi.org/10.1080/24750263.2023.2220354

Lausen, C.L. (2021). The Goldilocks Approach – bat boxes in a changing climate and landscape. Invited article. Bat Conservation Trust 124: 20-21. https://cdn.bats.org.uk/uploads/news/Bat-NewsSpring-2021-124-final.pdf?v=1635242627

Lewicki, H. M., Odendaal, L., & Low, E. (2022). Impact of Weather Conditions and Proximity to Water on Bat House Occupancy in the Beaverhill Natural Area. Beaverhill Bird Observatory, Beaver County, Alberta.

Lewis, Susan E. "Roost Fidelity of Bats: A Review." *OUP Academic*, Oxford University Press, 19 May 1995, academic.oup.com/jmammal/article-abstract/76/2/481/958304?redirectedFrom=fulltext.

Low, E. (2023). Internship information packet, Beaverhill Bird Observatory (with contributions By BBO staff & Board members).

Low, E. (2017). Occupancy Monitoring of Bat Houses at Beaverhill Bird Observatory in 2017. Beaverhill Bird Observatory, Beaver County, Alberta.

McGuire, L.P., et al. "No evidence of hyperphagia during prehibernation in a northern population of little brown bats (*myotis lucifugus*)." *Canadian Journal of Zoology*, vol. 94, no. 12, Dec. 2016, pp. 821–827, https://doi.org/10.1139/cjz-2016-0110.

Mejia, M. (2023). Historical bat house occupancy of *Myotis lucifugus* in the Beaverhill Bird Observatory, Alberta: Implications of bat house design in relation to sun exposure. Beaverhill Bird Observatory, Beaver County, Alberta.

Nature conservancy of Canada. NCC: Nature Conservancy of Canada. (n.d.). https://www.natureconservancy.ca/en/?gad_source=1&gclid=Cj0KCQjw7Py4BhCbARIsAMMx-_LTEWw4eo5wkuFY8To2hPAZcBDgBiNQ__zt4RvcWpFMdmPrwGry9AsaAmVhEALw_wcB

Nelson, J. J., & Gillam, E. H. (2016). Selection of foraging habitat by female little brown bats (*myotis lucifugus*). *Journal of Mammalogy*. https://doi.org/10.1093/jmammal/gyw181

Olson, C. R., & Barclay, R. M. R. (2013). Concurrent changes in group size and roost use by reproductive female little brown bats (*myotis lucifugus*). *Canadian Journal of Zoology*, *91*(3), 149–155. https://doi.org/10.1139/cjz-2012-0267

Poulton, S. M. C. (2006). An analysis of the usage of bat boxes in England, Wales and Ireland for the Vincent Wildlife Trust. https://www.vincentwildlife.ie/downloads/poulton-s-2006-an-analysis-of-the-usage-of-bat-boxes

Randall, L. A., Jung, T. S., & Barclay, R. M. (2014). Roost-Site Selection and Movements of Little Brown Myotis (Myotis lucifugus) in Southwestern Yukon. *Northwestern Naturalist*, *95*(3), 312–317. https://doi.org/10.1898/13-02.1

Racey, P. A., & Entwistle, A. C. (2000). Life-history and reproductive strategies of bats. In *Elsevier eBooks* (pp. 363–414). https://doi.org/10.1016/b978-012195670-7/50010-2

Rensel, L. J., Hodges, K. E., & Lausen, C. L. (2023). Myotis roost use is influenced by seasonal thermal needs. *Journal of Mammalogy*, *104*(4), 739–751.

Tahir. (2022, October 31). *When is Bat Mating Season*. Bat Control. https://www.batcontrol.ca/blog/when-is-bat-mating-season/#:~:text=Bat%20mating%20officially%20starts%20from,they%20even%20roost%20underneath%20porches.

Tillman, F. E., Bakken, G. S., & O'Keefe, J. M. (2021). Design modifications affect bat box temperatures and suitability as maternity habitat. *Ecological Solutions and Evidence*, *2*(4). https://doi.org/10.1002/2688-8319.12112

Trust, B. C. (n.d.). *Maternity roosts - Bat roosts - Bat Conservation Trust*. Bat Conservation Trust. https://www.bats.org.uk/about-bats/where-do-bats-live/bat-roosts/maternity-roosts

Weatherspark.com. Tofield Climate, Weather By Month, Average Temperature (Alberta, Canada) - Weather Spark. (n.d.). https://weatherspark.com/y/2565/Average-Weather-in-Tofield-Alberta-Canada-Year-Round

Alberta, BC Weather Update for Summer 2024 brings the heat. ZenSeekers. (n.d.). https://www.zenseekers.com/1story/bringing-heat-alberta-bc-weather-update-summer-2024

APPENDIX 1-

Beaverhill Bird Observatory Bat House Occupancy Check - 2024

Date (Y/M/D): ________ Observer(s): ____________________________

Start time: _______ Start temp: _____ Start cloud %: _____ Start wind(speed/dir):__

End time: ________ End temp: ______ End cloud%: _____ End wind: _____

Precipitation during survey: **No** **Yes**

Current day Tmax: _____

Previous night's weather data (sunset-sunrise): Tmin _____ Wind ______ Rain/hail _____

Previous day's weather data: Tmax _____ Cloud (no, partial, full) _______

Bat species

Myotis (likely *M. lucifugus*- Little brown *Myotis)*

Other: EPFU Big brown bat

LANO Silver-haired bat

Unknown

 # bats seen

If exact estimate cannot be determined due to crowding provide range, average count or > *x*

Multi-chamber house compartments:

#1, closest to back (attachment)

#4, closest to front

Bat house ID	**Species**	**# bats seen**	**Compartment(s) occupied**	**Comments**
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	

Bat house ID	Species	# bats seen	Compartment(s) occupied	Comments
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	
	Myotis Other _____		1 2 3 4	

Date: ________________