

Best Management Practices for the Use of Bat Houses in U.S. and Canada

With focus on summer habitat mitigation for
Little Brown Myotis, Yuma Myotis, and Big Brown Bat

Version: September 2023

Cover photo descriptions and credits, left to right: *Upper* – Bats crowding box exit during heat wave, by landowner Steve Latour; bat box on house with manual awning that can be lowered to shade box during high heat events, photo by biologist Susan Dulc. *Lower* – The largest type of bat house is a 'Condo', photo by Bat Conservation International's Dan Taylor; a 3-chambered rocket box with custom installation of internal heating pads for cold spring weather, photo and construction/design by landowner Richard Waiz; back-to-back BCI-style multi-chambered bat boxes with enclosed adjoining compartment between boxes to allow safe movement between boxes, photo by Heather Gates.

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Executive Summary

Bat houses are artificial structures providing shelter for building-roosting bats. Here we provide guidance on use of bat boxes (small wooden boxes replacing natural tree cavities for crevice roosting bats), bat condos (large structures constructed to house thousands of bats), and mini-condos (smaller versions of condos).

Roost microclimate (temperature and humidity) affects bat reproductive success. Bats need suitable microclimates for pup rearing, and their energy budgets vary with prey availability and ambient temperatures. A special physiological process called torpor helps bats conserve energy during lean times. Reproductive female bats must select appropriate microclimates to successfully raise a pup. In some situations they need to select cool microclimates to make extensive use of torpor, lowering their body temperatures to save energy. But to successfully develop a fetus, nurse a pup and have that pup grow, their roost must warm a bat's body.

In buildings, spaces such as attics offer diverse microclimates for bats. Because bats can find most if not all of the microclimates they need throughout the reproductive season, bats in buildings typically show high site fidelity. In contrast, bats roosting in natural cavities switch roosts often, locating appropriate microclimates while simultaneously lowering predation risk and parasite loads.

Bats seek out optimal roost microclimate, but their selection may be limited. With the effects of climate change, there is increasing concern over potentially detrimental effects of overheating roosts. Similarly, loss of roosts such as through eviction or exclusion may result in few microclimate options and lower reproductive success or even mortality if lethal temperatures are encountered in occupied roosts. When managing roosting habitats for bats, one must consider the "Goldilocks Effect": Bats need the right temperature. This means providing options for roost switching. The ability of a bat to switch roosts safely, especially mid-day if roost temperatures become inhospitable, can be limited by the proximity of suitable alternative roosts.

It is unknown how local bat species diversity may be affected by installation of a bat house in an area where no building colonies were previously known. As such, construction of bat house structures is best done in areas with existing building-roosting colonies. When mitigating for loss of these types of roosts we recommend taking into consideration the roost area. Does there appear to be other suitable roost structures close by? If not, more extensive supplementation will be needed (e.g., multiple bat boxes). When deciding on type (i.e., condo, bat box) and size of replacement structure(s) consider cost, logistics of construction, and colony size (i.e., how much roost surface area may be needed). Provide multiple options and microclimates by varying the placements relative to solar exposure and insulating mounting surfaces such as sides of buildings. Styles and designs may also be varied, such as number of chambers and box dimensions. For most situations we recommend multiple standard 4 chamber maternity bat boxes. Boxes mounted back-to-back on a pole with adjoining access can provide a wider range of microclimates than individual bat boxes. New technologies such as thermally advanced building materials may continue to improve bat house construction.

Creating roosting habitat for bats is a long-term commitment, as these are long-lived mammals with high site fidelity. This means regularly maintaining bat houses and monitoring their use. Monitoring and reporting occupancy rates will help answer fundamental questions such as how effective are artificial

roosting structures. Many knowledge gaps exist: Most urgently needed is a better understanding of how well bat boxes and bat condos perform as mitigation structures.

This document outlines best practices for use of bat houses, and describes management practices for 3 species of North American building-roosting bat species: Little Brown Myotis (*Myotis lucifugus*), Yuma Myotis (*M. yumanensis*) and Big Brown Bat (*Eptesicus fuscus*).

Overview

This guidance document summarizes the best available data on bat houses. **Section 1** introduces why this document is needed and **Section 2** highlights the issues concerning bat specialists regarding the use of bat houses. **Section 3** provides the best management practices for the use of bat houses for the most common building-roosting bats in North America. **Section 4** identifies knowledge gaps in our understanding of how to provision artificial roost habitat for bats. **Section 5** summarizes reporting, maintenance and monitoring practices, lists states/provinces/territories that have current programs and provides suggestions for those that are without.

This document is a current synthesis of the available information on use of bat houses in North America. The review of history and literature provides critical background information on bat energetics, physiology and behaviour that must be considered when designing and erecting artificial roosts and making decisions regarding roosting habitat for building-roosting bats (most applicable to Yuma and Little Brown Myotis, and Big Brown Bat).

This material may benefit future researchers and managers and act as a summary resource document. **Appendix One (Literature Review)** should not be considered simply supplemental but rather it is critical detailed information for understanding the subtleties of managing bats in bat houses. The guidance provided is meant to help any landowner, institution, development proponent or land manager tasked with managing or providing artificial roosting habitat for bat-house using bat species in North America.

This document is intended to be a living document, with periodic updates with revisions as on-going research and monitoring fills knowledge gaps.

Section 1: Introduction and Objectives

1.1. Introduction

What is a bat house?

For the purposes of this document, any artificial structure built to provide shelter for bats will be referred to as a bat house. Small wooden boxes (often with multiple, narrow, vertical, internal chambers) used to replace tree cavities and cracks which would naturally be used by most crevice-roosting bats will be referred to as “bat boxes” (Figure 1). The largest type of structure built to shelter bats that can house thousands of bats will be referred to as a “bat condo” (Figure 2). Smaller versions of the condo that meet certain size specifications will be considered a “mini-condo.” Standard bat boxes mounted back-to-back (e.g., on poles) or immediately adjacent to each other (e.g., on the wall of a building or other structure) will be called a “bat box array” (Figure 1b). Artificial structures that aim to mimic natural “under-bark” type roosts used by bats include material that “wraps” around poles or are attached in sections (such as Brandenbark®) or may include human-created cuts into tree trunks (e.g., using chainsaws) to create a similar type “gap.” These “crevice creations” (under-bark mimic-type artificial roosts and associated tree modifications) for roosting bats will not be included in these BMPs but will be part of the literature review (see Appendix A.1.8. Other types of artificial roosting habitat: bark mimics).

A. *B.*

Figure 1. A bat box is a small type of bat house. A. A bat box is a small wooden box, often subdivided inside as “roosting chambers.” The extension of wood below the box is a landing platform where bats land, and then using their claws, they climb on the roughened wood up into the box. This particular installation has 2 bat boxes mounted on opposite sides of a pole; photo by J. Saremba. B. Bat boxes installed in an "array" on a building wall; photo by C. Olson.

What does a bat house provide and are there concerns?

Bat houses provide shelter from predators, and protection from weather elements such as rain, wind, and direct sunlight. Pregnant and lactating (nursing) adult females using these sites often return to the same location year after year and are joined by their female offspring. Because many bat species exhibit long lifespan (Little Brown Myotis have been recorded living up to 39 years – pers. comm. D. Hobson, Alberta Environment and Parks) and high site fidelity to maternity roosts, stewardship and monitoring must also be an important consideration for bat maternity roosts.

Figure 2. A bat condo, the largest type of bat house. *This particular structure, built in southeastern British Columbia, uses hopper doors to enclose the roosting chambers to reduce airflow and thus increase internal temperatures. Although guano does fall onto the concrete base throughout the season, a thorough cleaning is done annually by opening the doors and sweeping out the guano deposited on the doors. Photo by J. Hobbs.*

Species that commonly use bat houses are colonial, with colony size varying among species. Bat houses, consisting of internal roosting chambers, allow bats to cluster together in a small volume of air. Groups of bats clustering together in a small space can create a warm, moist microclimate conducive to retention of body heat and water, physiologically important for these small mammals with huge surface area to volume ratios (attribute of small body with large wings made of skin). By mediating the temperature and humidity within a roost, female bats create ideal conditions for raising offspring, known as pups. Depending on the construction material, bat houses can also retain heat, creating warm spaces that maximize pup growth (Kurta 1985). Ideally, mother bats want to keep their pups at temperatures typical of the upper range of their thermoneutral zone to maximize growth.

The thermoneutral zone (TNZ) is the natural range of temperatures at which bats expend the least amount of energy (Lyman 1970). The TNZ has an upper and lower critical limit, is species-specific and relative to body size, and may vary seasonally (i.e., different TNZ range in summer versus winter). Large bats have a wider TNZ temperature range (e.g., Brazilian Free-tailed Bat, *Tadarida brasiliensis*, 26 to 33°C or 79 to 91°F; Soriano et al. 2002) but lower tolerance for high ambient temperatures (Stones and Wiebers 1965). Small bats have a much narrower TNZ range (often <5°C span) but may have greater tolerance for higher temperatures (Stones and Wiebers 1965). When bats roost in conditions above or below the TNZ critical limits, several options exist: 1. The bat may enter into torpor when ambient conditions fall below the lower critical of the TNZ (i.e., a bat box that is too cool). This saves the bat energy to simply conform to the cooler surroundings, reducing its cellular metabolism (Reeder and Cowles 1951). 2. If the bat instead tries to maintain a warm body in ambient conditions below their TNZ, body fat is burned so that metabolism can remain high. The bat will die if fat reserves become exhausted. 3. If ambient conditions exceed the upper critical, the bat will change behaviours to try to dump body heat. These behaviours include spreading out so as to not cluster too closely to another individual (this can be very difficult in overcrowded bat boxes!), moving closer to a vent or roost entrance where there is airflow, fanning of wings, licking of fur, urinating on themselves to increase evaporation and thus dissipate heat (in lieu of sweating – bats do not have sweat glands, Burbank and Young 1934), or even fleeing a roost mid-day to find cooler conditions. Bats crowding the opening of a bat box on a hot day is a sign of bats undergoing heat stress (as seen on Cover Page of BMP, bottom left photo). Bats have also been observed flying during hot days to obtain a drink of water (e.g., Hendricks and Hendricks 2010, Jung 2013). Bats will die of overheating if the temperature exceeds an 'upper lethal'. The difference between heat stress and mortality can be as little as a degree or two and often depends on the duration of exposure (Licht and Leitner 1967).

Thermal neutral zones may vary among and within species, but much has yet to be learned. One study found that the summer TNZ for Little Brown Myotis was 32 to 36.26°C (89.6 to 97.16°F, summarized in Speakman and Thomas 2003), and it may be that the summer TNZ for Yuma Myotis is comparable given their similar morphology and tendency to roost in the same structures. Upper lethal temperatures for both species were determined by Licht and Leitner (1967) to be 44.5°C (112.1°F). Little Brown Myotis have been observed in anthropogenic roosts where temperatures exceed the upper limit of the TNZ (Henshaw and Folk 1966; Licht and Leitner 1967; unpublished data from authors); however, Licht and Leitner (1967) observed behavioural signs of heat stress are observed as a bat's surrounding temperature neared 40°C (104°F) and generally, this value is considered the upper safe tolerable limit for bats in bat houses (Crawford et al. 2021APPENDIX FOUR: Bat **Species' Thermal Preferences/Tolerances**).

In summary, bat box suitability and resulting roosting behaviour is directly related to bat thermoneutral zones. Most often, it is likely that roost selection and roost switching behaviour by bats is primarily in response to temperature. Concerns over bat house design and placement arose after several observations of bats dying after extreme heat events. Following best management practices for bat houses may serve to reduce this risk.

What factors are driving the demand for bat houses by people?

Bat boxes are typically used to replace or enhance habitats where bats are knowingly, or presumed to have been, displaced from natural or other anthropogenic roosts (Griffiths et al. 2017, Rueegger et al. 2019). When evictions of bat colonies from human-built structures must occur, replacement of roosting habitat may be provided to facilitate long term persistence of the evicted maternity colony. Exclusions and evictions are often the outcome of conflict between building owners and bats. Conflict typically results from an aversion to piles of guano, urine odour, hearing the noisy communication of a colony, and/or wandering offspring entering human living quarters.

Exclusions should be conducted outside of the maternity/nursery period and success is only possible if all access points are well-sealed. Alternately, bats and humans can coexist safely in the same building if colonies can be maintained in a separate, yet human-accessible space. Within bat-occupied buildings that are very "porous" (e.g., old buildings with many cracks and openings that are impossible to seal up completely), building managers can create a state of safe co-occupancy if care is taken to regularly clean up / maintain the site and follow best practices for managing a colony within a building (See **Appendix Five : Citizen Science-based Bat Roost Monitoring Programs** for a list of programs that both have bat monitoring programs and provide guidance on management of bats in buildings).

With increasing observations of bat population declines (e.g., Little Brown Myotis, *Myotis lucifugus*), there is increasing demand for better management of colonies in buildings, better methods for exclusion and better options for supplementing roost habitat with artificial roosts like bat boxes. In North America, the surge in research and monitoring reflects widespread motivation to conserve, recover or build resiliency into populations being impacted by white-nose syndrome (USFWS 2022, Cheng et al. 2021, Environment Canada 2015). This monitoring is being facilitated by recent advancements and cost reduction in technologies, including temperature and acoustic loggers, high quality affordable game cameras/video (Figure 3), pit tags and break-beam/infra-red/thermal-imaging tools.

A. B.

Figure 3. Monitoring occupancy at bat boxes using cameras. Infrared sensor on this game camera captures close-up imagery as bats emerge, triggered by motion. Susan Dulc (A) installs the camera off to the side of the landing platform just below the chamber openings (B). Blunt-tipped bird spikes are visible on gear to discourage perching birds that may harm bats. Photos contributed by S. Dulc.

Growing public involvement in bat conservation is being driven by outreach initiatives such as community bat programs that recruit citizen scientists to participate in bat monitoring and the public continues to build and install bat houses at a growing rate (see **Appendix Five : Citizen Science-based Bat Roost Monitoring Programs**). There is also a growing proportion of the public that are simply interested in bats and want to support bat conservation. Installing bat houses is a way to help bats, but only if bat house design and installation locations are appropriate for the intended species in a particular area.

Do bats in North America use bat houses?

Canada and the United States are home to forty-seven species of bats and of these sixteen species have been observed using bat houses (**Appendix Two: List of bat species of Canada and the USA**). Big Brown bats and Little Brown Myotis (both found continent-wide,) and Yuma Myotis (western-only; Figure 4), are bat species commonly found using bat houses and buildings, and this document generically refers to these as "the common building-roosting bats."

It is beyond the scope of this document to describe every North American bat species that uses human-built structures, however, the general roost preferences of these three focal species (**Appendix Three: Species Accounts for Little Brown Myotis, Yuma Myotis and Big Brown Bat**) should reflect the needs of other colony-roosting bat species and life cycles will be comparable. There are, however, some notable exceptions to the general patterns (e.g., colonies of Townsend's Big-eared Bat which select relatively cooler and more voluminous nursery roosts; Firman 2003, Betts 2010). For species that show some flexibility in roost use and include the use of buildings in their range of behaviours, it may be that a "type" of artificial roost structure could be constructed for them but may need to be tailored to meet both their physiological and behavioural needs. Research remains to be conducted, and the pattern reported in the literature of boxes being dominated by one or a few species may not actually reflect the range of species that will utilize boxes (e.g., Baranauskas 2007), and instead may reflect the narrow range of box designs and placements usually deployed.

The types of structures used as roosts by bats will vary depending on sex, age, reproductive condition, and other factors (Table 1). Large aggregations of bats during warm months are almost always maternity, or nursery roosts and these sites have very specific requirements. Timing of use may vary with geographic region, regional variation in weather, and other environmental factors. Some roosts are used for reproduction and will be occupied by adult females to raise young, while other roosts may be used by males or non-reproductive females. Roosts may also be used seasonally by bats making long-distance movements between summer and winter habitats. In some areas bats can make significant movements between habitat types for purposes of mating and/or hibernation (Kunz 1982). Bat houses are not typically used as winter habitat and do not provide the appropriate conditions for hibernation. However, in areas of North America with warm year-round temperatures, bat houses may have some level of use year-round.

Table 1. Types of roosts used by bats.

Roost Type	Definition
Ephemeral roost	A bat roost in a feature where the characteristics important to bats (e.g., microclimate) may change quickly and/or unpredictably; for example, an area under sloughing tree bark.
Permanent roost	A roost that is available for bat use over many years and has suitable characteristics (e.g., microclimate, access) that remain stable over time. Examples of permanent roosts include caves, cliffs, mines, bridges, buildings, and large hollow trees of a slow-decaying species that may remain standing several decades or more.
Night-roost	A roost where bats rest at night between foraging bouts. Bats may roost singly or congregate.
Day-roost	A roost where bats rest during the day in spring/summer/autumn. Day-roost types include maternity roosts, bachelor roosts, and mixed male/non-reproductive female/yearling groups. Use of a specific day-roost may be seasonal or variable within a season.
Maternity roost	A roost used outside the winter period by adult females that are capable of reproduction.
Nursery roost	A roost where females congregate to give birth and raise their young (adapted from Knight and Jones 2009). A nursery roost is a type of maternity roost.
Bachelor roost	A roost used by one or more males during the day.
Fall migratory rest stop	A roost used by bats during migration between summer and winter habitats.
Winter hibernation roost	A site where one or more bats hibernate in winter (hibernacula [plural]). A given hibernaculum may be used by bats for only part of the winter and may not be used every winter

Figure 4. Bats commonly found using human-built structures. From left to right: Little Brown Myotis (Photo: J. Headley), Yuma Myotis (Photo: J. Hobbs), Big Brown Bat (Photo: C. Olson).

A critical feature of roost selection is roost microclimate. Temperature and humidity shape the ecophysiology of these small-bodied flying mammals (Kunz 1982, Lausen and Barclay 2003, Ellison et al 2007). Many of the best management practices suggested in this document will directly relate to how to create artificial roosts with the best microclimatic characteristics. Other factors influencing roost choice by bats are accessibility, stability, size, safety, parasite load, light, noise, or other disturbance or contextual factors (Kunz 1982, Lewis 1995). The suite of factors that influence choice will vary depending on the bat's needs during different stages of its lifecycle.

It is important to keep in mind that there are large gaps in even basic knowledge for many species. General information about species identity, and general habitat associations may be the entire extent of the data for some species. Other more well-known bats like Little Brown Myotis and Big Brown bats have had extensive study of their physiology, reproductive ecology, distribution, and summer behaviour, albeit often skewed to studies of eastern North American populations. Interestingly, winter ecology of, and selection of hibernacula by, these species is still poorly understood, particularly in the western part of the continent where hibernating individuals have been found in caves, rock crevices, mines, and buildings. Research continues to examine the appropriateness of bat house design, materials used, colours for bat house exteriors, size of the box and spacing of crevices by species, inadvertent hazards, and appropriate installation (site, aspect, height).

Are there standards for bat houses?

Currently, there are no official standards for bat house use, and few blueprints for designs. Bat boxes have been in use for several decades (Tuttle and Hensley 1993, Tuttle et al. 2013, Tuttle and Cordani 2022), but only recently has there been a widespread push to understand occupancy, health, and reproductive success in relation to designs and placement of these structures, particularly in reference to their microclimatic conditions (Flaquer et al. 2014, Rueegger 2016, López-Baucells et al. 2017, Bideguren et al. 2019, Brouwer and Henrard 2020, Crawford and O'Keefe 2021a, Crawford et al. 2022). Recent studies assessing suitability and safety of bat boxes have attempted to control for potential sources of variation like solar incidence, presence/absence of bats, surrounding habitats, bat box styles and colours (e.g., Hoeh et al. 2018, Tillman et al. 2021). These studies will help inform best practices.

1.2. Objectives for this document:

1. Identify the issues of concern with regards to bat houses.
2. Provide best management practices for the use of bat boxes for bats based on energetics, physiology, roost availability, and social interactions (using current research and expert opinion).
3. Identify knowledge gaps in our understanding of how bats use bat houses and how these structures can be effective mitigation tools for habitat loss.
4. Summarize the history of bat house development, design and deployment and provide a literature review of the current research focused on bat roosting ecology in artificial structures.
5. Provide resources in the form of appendices covering background information underpinning this BMP (physiology, ecology, behaviour, species), new technologies, case studies, citizen science and monitoring initiatives in US and Canada, and details of bat house installations.

Section 2: Identifying the Issues

Concern for the welfare of bats who have become dependent on our human-built structures is not unique to North America. World-wide there is growing concern for the effects of climate change on bats roosting in bat boxes that can overheat (Flaquer et al. 2014, Bideguren et al. 2019). Bats with small body sizes and large surface-area to volume ratios, as well as exhibiting high roost fidelity, may be particularly vulnerable to climate change (Adams and Hayes 2008, Welbergen et al. 2008, Adams 2010). Some of the other ongoing threats for bats across the globe include habitat loss (e.g., deforestation, timber harvesting), effects of pesticide use on prey availability, and direct mortality (reviewed by Frick et al. 2020, this includes the massive loss of bats from white-nose syndrome across North America).

Bat houses (boxes, mini-condos, condos) are increasingly becoming a tool to mitigate habitat loss for crevice-roosting bats. Extensive loss of natural habitat, such as old trees with appropriate crevices, hollows, or sheets of peeling bark, may be a result of urbanization, resource extraction, and industrial development (Frick et al. 2020). In our human-manipulated environments, natural roosts become either unavailable or fail to offer the same benefits as artificial structures (Lausen and Barclay 2006; Kurta 2010; summarized in Voigt et al. 2016). Loss of bat roosting habitat can be somewhat mitigated for some species through use of bat houses.

In North America, the common building-roosting bats roost colonially in summer, with clusters of females congregating often at the same roosts year after year to raise young. Reproductive success of individuals in these maternity colonies depends on the quality of roosting and foraging habitats. Reproductive females depend on warm, stable temperatures that expedite gestation, promote milk production, and maximize growth rates of young bats (Kunz 1982). Temperatures offered by roosts will vary temporarily based on weather, geographic location, micro-site properties (e.g., solar incidence), and structural properties including the substrate's thermal properties, volume of internal space, vents or holes creating airflow (e.g., Fontaine et al. 2021); microclimate largely underpins roost selection by bats (Boyles 2007, but see Willis and Brigham 2007, Bartonička and Řehák, 2007).

Specifically, there are several issues that are a concern for bats that may be ameliorated through adherence to a set of best practices. These issues are discussed in greater detail below, and best practices addressing each issue are provided in Section 3.

2.1. Threats to Bats and Impacts from Human Activities

Bats face unprecedented and cumulative threats (Frick et al. 2020), far more than we can review here. However, below we list some key threats in the context of building-roosting bats, and specifically those using bat houses.

2.1.1. Extermination and/or exclusions from buildings; transient bats

Little Brown Myotis, Yuma Myotis and Big Brown Bat are impacted by eradication activities conducted by homeowners or hired pest/wildlife control professionals during evictions from homes (Barclay et al. 1980). Additionally, during migration between summer and winter hibernation sites, transient bats often roost exposed on the outsides of human structures (Kunz et al. 2007, Frick et al. 2010a) and risk mortality and harassment when discovered.

2.1.2. Habitat loss and degradation; impacts from industry

Bats are impacted by habitat loss and degradation (e.g., destruction or degradation of hibernacula, maternity roosts, and foraging areas), disturbance or harm (e.g., collisions with or barotrauma from wind turbines, intentional harm to individuals, recreational or scientific disturbance, and industrial disturbance), pollution, and climate change (Evelyn et al. 2004, Arnett et al. 2008, Adams 2010, Tuttle 2013, Environment Canada 2015).

2.1.3. Disturbance/Mortality at hibernation and maternity roost sites

Bats are vulnerable to mortality and disturbance while roosting. This is of critical concern when bats are hibernating, using deep torpor that inhibits movement, but this also applies to nursery and maternity roosts during the season of use. Torpid bats (whether in winter hibernation, or deep torpor during inclement spring/summer/fall weather) cannot rouse quickly to respond to threats, and arousing can use up valuable fat reserves, putting them at risk of starvation prior to availability of sufficient supplies of available insect prey (Thomas et al. 1990; Thomas 1995). It is estimated that only 40–50% of young bats survive their first winter (Humphrey 1975), emphasising the importance of early births and optimal microclimates which may expedite pup growth and fledging (e.g., Lausen and Barclay 2006). Arousal during winter can negatively influence population growth rates because females emerging from hibernation with severely depleted fat reserves may not be able to support successful implantation and gestation of pups (Holroyd 1993, Barclay 2012). Because of their slow reactions and inability to take flight, torpid bats are vulnerable to many sources of mortality, such as predation and roost destruction (building demolition, tree harvest, mudslides over rock crevices, etc.)

2.1.4. Other anthropogenic threats, noise, lighting at night, air quality issues, entrapment

Anthropogenic threats are real and pervasive for bats globally (Voigt et al. 2016). Light, noise, dust, and smoke can disturb roosting bats and humans can inadvertently create environments that can entrap bats. Disturbance of bats at summer roost sites repeatedly, and/or at critical times, can cause roost abandonment and can result in population decline if reproductive rates are reduced (Brigham and Fenton 1986).

Anthropogenic noise, whether due to traffic, construction, or human entry into a roost have all been shown to affect bats and can cause roost abandonment (e.g., Humphrey and Kunz 1976; Siemers and Shaub 2011; review in California Department of Transportation, Caltrans 2016). There are observations of bats using sites under bridges or in other areas where noise levels could potentially be disruptive but bats exhibit tolerance. There may be site-specific responses for certain colonies with regards to tolerance; there may be variation depending on species, reproductive stage or simply a particular group has learned to adapt. Noise and associated vibrations that can be sources of disturbance can include:

- Blasting and the use of construction tools which may create noise louder than most natural noise, even thunder or a thunderclap (Caltrans 2016). Vibration and ground movement from any source should be considered a potential source of disturbance, however, impacts on bats may be site specific (Summers et al. 2022).
- High intensity (above 80dB), high frequency (between 20-200kHz) broad-band noise inaudible to humans can be especially disturbing for bats, which operate using ultrasound, and may cause roost abandonment (Johnston 2018).
- Loud noise (audible and/or inaudible to humans) from various sources can interfere with bat echolocation and their ability to hunt for prey, but the effect may vary depending on the type of noise and the species of bat (Schaub et al. 2008; Bunkley et al. 2015). Some bats may avoid foraging along highways as traffic noise may mask their acoustic signals and interfere with hunting (Siemers and Schaub 2011); however, additional research is required on this issue (Caltrans 2016).

Artificial lighting at night (ALAN) can affect bats directly and indirectly in several ways. Lighting directed at bat access points to roosts or on roosts can:

- disturb bats and delay emergence time, causing bat to miss peak feeding periods (Bat Conservation Trust 2014).
- cause roost abandonment by bats (Bat Conservation Trust 2014).

Lighting at night may also affect bat foraging.

- **Light can create patches of insect prey around intense lights like streetlamps (Hickey et al. 1996, Rydell 2006).** This may benefit some bat species (such as high-flying Big Brown Bat, Silver-haired Bat, Red Bat and Hoary Bat; Hickey et al. 1996) or open area flyers (such as Yuma or Little Brown Myotis). But this may also make them vulnerable to night type predators (Rydell 2006, Bat Conservation Trust 2014).

- **Some colours of light can affect insect prey.** Light fixtures emitting white, blue-white, or ultraviolet spectrum wavelengths may be highly attractive to moths with the end result a change in the prey abundance and composition in an area (Stone 2013, Bat Conservation Trust 2014). Attracting prey to a single light source may reduce the habitat quality of adjacent dark areas that may be preferred by some bat species that are shy of lights.
- **Light may also fragment habitats for bats**. Some bat species perceive light, especially lines of light from features like streetlamps, as barriers to movement (Stone et al. 2009, Bat Conservation Trust 2014).
- **Artificial lighting at night may also interfere with migration patterns.** This has been demonstrated for some bat species in the UK (Bat Conservation Trust 2014), but this is not well understood in North America.

Road building and/or dust kicked up from gravel roads adjacent to bat roosting habitat can impact bats; smoke or other airborne particulates may have similar disturbance effects on bats (Davis 1970, Parsons et al. 1986, Thomas et al. 1990, Dickinson et al. 2010). Disturbance of bats at summer roost sites repeatedly and/or at critical times can cause roost abandonment and can result in population decline (Brigham and Fenton 1986).

- **Bat house is installed at a site that is too noisy/too dusty/ too hazardous.** Bat houses installed over roads or other busy sites may represent a hazard to juvenile bats, falling pups or bats leaving the roost may be vulnerable to collision; dust issues from traffic on road surfaces may affect roosting bats.
- **Bat house is installed at a site that is too smoky**. Bat houses installed near burn barrels or air vents, and sites with smoke or poor air quality, strong blasts of air or effluent from industrial air conditioners can deter bats from using the bat box or could negatively affect bat health.
- **Higher risk situations can arise during periods of cool weather** when bats may be using torpor which increases their vulnerability to fire or smoke or other particulates as it can take them up to 40 minutes to rouse from this state upon which flight is possible (Thomas et al. 1990). Preliminary research indicates that, if bats have enough time, they can flush from tree roosts to avoid disturbance such as fire and smoke and can sometimes carry young pups before they become too big to carry (Davis 1970; Parsons et al. 1986).

Entrapment and/or Drowning

Some artificial ponds, in-ground and above-ground swimming pools, cattle drinking troughs, and other containers that hold water, should have some device that enables bats to escape if they happen to fall into the water (Taylor and Tuttle 2007). If bats accidentally fall into water sources contained in areas with steep, smooth sides, they may not be able to escape.

2.2. Population Recovery from Losses due to White-nose Syndrome

Little Brown Myotis, Yuma Myotis and Big Brown Bat are all vulnerable to infection by (*Pseudogymnoascus destructans*) *Pd*, the fungus that causes white-nose syndrome (WNS; Frick et al. 2010b, WNS 2021). Little Brown Myotis have been impacted severely with up to 90-95% mortality at some hibernation sites in the eastern part of their range, leading to their listing as endangered by the Canadian government (Environment Canada 2015).

It should be noted that while each of these bat species faces cumulative threats, the Little Brown and Yuma Myotis are most impacted by WNS. Little Brown Myotis has already been devastated by WNS in its eastern distribution (e.g., Frick et al. 2010b), and in Washington, the site of the only known western WNS cases to date, Yuma and Little Brown Myotis are experiencing roughly equal WNS mortality rates (A. Tobin, WNS Coordinator, Washington Department of Fish and Wildlife, pers. comm.). Also notable: to date, all of the bat species that have had diagnostic symptoms of white-nose syndrome in Canada and the USA are all potential bat house users (see www.whitenosesyndrome.org and **Appendix Two: List of bat species of Canada and the USA**).

- Big brown bat (*Eptesicus fuscus*)
- Cave bat (*Myotis velifer*)
- Eastern small-footed bat (*Myotis leibii*)
- Fringed bat (*Myotis thysanodes)*
- Gray bat (*Myotis grisescens*) ***endangered USA***
- Indiana bat (*Myotis sodalis*) ***endangered USA***
- Little brown bat (*Myotis lucifugus*) ***endangered Canada***
- Long-legged bat (*Myotis volans*)
- Northern long-eared bat (*Myotis septentrionalis*) ***threatened USA, endangered Canada***
- Western long-eared bat *(Myotis evotis)*
- Tricolored bat (*Perimyotis subflavus*) ***endangered Canada***
- Yuma bat (*Myotis yumanensis*)

The fungus that causes white-nose syndrome, (*Pseudogymnoascus destructans* or Pd), is spread via spores. These spores can be present in bat guano and persist in soils or sediments of bat roosts such as caves or mines (Reynolds et al. 2015). They will degrade in sunlight, and with heat, however, spores are still viable at 24°C, 30°C and 37°C (75°F, 86°F, and 99°F) for 150, 60 and 15 days respectfully (Campbell et al. 2020). Maternity roosts do not typically remain at a consistently high temperature, (temperatures fluctuate with ambient temperatures and nights are often much cooler). This means that spores can remain viable in summer on bats much longer than expected (Huebschman et al. 2019). The fungus is not harmful to humans, it is only harmful to hibernating bats.

Bat house owners sometimes place bat guano in their bat houses in an attempt to attract bats. This unproven practice may put bats at risk if bat guano contains Pd spores. There is potential for accelerating white-nose syndrome spread, infecting bats that have until then avoided the disease.

Spores of *Pd* are found even late in summer under bridges (C. Olson, pers. comm.), and because maternity colonies of some species have been discovered to roost under bridges during some or all summer months, this artificial roost structure type needs to be monitored cautiously as it may be a source of disease spread, especially during fall migration when bats are mating and moving to hibernation roosts.

2.3. Thermal Suitability of Artificial Roost Structures for Bats

A solid understanding of bat energetics and thermoregulation is needed to understand roost properties that are important for bats and an in-depth review has been provided in Appendix One: A literature review of bat roosting ecology and physiology and use of bat houses.

If specific roost microclimate conditions are limiting in an area or if roosts are eliminated (e.g., through roost destruction, colony eviction), reproductive success and survival of maternity colonies may be negatively impacted. As climate change continues to result in hotter weather and more frequent/extreme heatwaves in some areas (e.g., Bratu et al. 2022), particularly in western North America (NatureServe 2022a,b), precautions should be taken, and bat boxes should be built and installed to withstand these potential events. Additionally, extreme heat may not be just a southern phenomenon -- even in northern climates, it is possible for bat boxes to reach and exceed upper tolerable limits for bats (e.g., Leung et al. 2022).

Microclimate has recently been at the forefront of bat box research. Of the few studies currently available, many have documented dangerously hot temperatures in bat boxes (e.g., Brittingham and Williams 2000; Flaquer et al. 2014; Griffiths et al. 2017; Bideguren et al. 2019; Hoeh et al. 2018; Rueegger 2019; Tillman et al. 2021). There are concerns that some bat houses may function as ecological sinks (see Appendix A.1.7.6. Bat Houses as Ecological Sinks) and may represent a significant threat to some bat species. Attention has been on features of bat houses that affect thermal stability, specifically, design, colour, placement, and number of bat houses provided, and these features are the focus here.
Bat houses may offer environments that are too cold or too hot for bats and this can be influenced by four main factors:

- **Bat house design.**
  Retailers across Canada and the USA offer a variety of simple bat houses for purchase and there is a huge variation in terms of the number of chambers, the treatment of interior roosting chambers (i.e., the use of metal or fibreglass screen materials, versus physically roughening the roost boards), as well as the overall size of bat houses. Large single chamber boxes (such as 89 cm x 46 cm or 35 in. x 18 in. or greater) may have issues with overheating (i.e., regularly reaching temperatures over 40°C or 104°F) which is problematic if bats have no cooler roost options (C. Olson, ACBP, unpublished data, Crawford et al. 2022). In Alberta it has been discovered that large multi-chamber boxes can overheat but there will often be at least one area of refuge in the box that is less than 40°C (C. Olson, ACBP, unpublished data); this cooler area is typically at or near the opening/vents, and roosting in these more exposed areas may pose predation risk to bats that would otherwise typically hide up inside the box.
    - Small bat houses (e.g., boxes that are approximately the size of typical bird houses), even if they have two or more chambers, may not have enough height to produce a gradient of temperatures inside, nor enough mass to retain heat to be suitable for adult females with dependent young that remain in the box at night. Small bat boxes may serve a purpose as non-maternity roosts.

- Bat houses without any type of venting to create cool areas or escape zones can overheat and trap bats. This can be an issue if bat houses are extremely full of bats and environmental conditions are exceptionally warm.
- Large bat boxes (e.g., approximately the size of the standard 4-chamber BCI design nursery box) are likely to be the best choice for maximizing temperature options, however, these boxes must be taller than they are wide – taller is better, to produce a temperature gradient of air. The more chambers, the more variation there will be in temperatures and thus the greater selection of microclimates for reproductive females. Passageways between chambers typically enable the bats to access the various microclimates.

- **Bat house colour.**
  Several studies report bats preferring dark coloured boxes over light ones (e.g., Lourenço and Palmeirim 2004, Doty et al. 2016). In the past, maps based on climate and solar radiation were used as a coarse general guide to help decide on box colour recommendations (e.g., Tuttle et al. 2005, 2013), but an appropriate colour for a bat house should reflect the daily and seasonal temperatures determined on a local scale as well as consideration of solar exposure.
  Studies have found that bat houses painted black can overheat in warmer climates (Bideguren et al. 2019). Overheating events at bat houses, leading to stress or death of pups and adult bats, have been observed at sites across North America, both in southern and northern regions (e.g., Brittingham and Williams 2000, Andrusiak and Sarell 2019, Lausen et al. 2022, Lausen et al. 2023). In Yukon, Canada, researchers determined that the simple exchange of the bat box roof to be black versus white can greatly expand the microclimates available to bats (Leung et al. 2022).

- **Bat house placement.**
  Location of installed bat houses influences the internal microclimates. Boxes facing directions that maximize solar exposure (typically south and west when exposure is unobstructed) will be exceptionally warm, especially in the late afternoon if the boxes capture the heat of the setting sun. East-facing boxes will capture the warmth of the morning sun, heating the box during the coolest part of the day. North-facing boxes may provide the coolest roost conditions and are unlikely to be used by maternity colonies in areas where ambient temperatures remain cool but may provide important thermal refuge during hot weather. However, in areas with very hot ambient temperatures, north-facing boxes may be highly attractive to nursing female bats who are trying to escape the heat.
  Bat boxes attached to buildings may capture more solar energy than bat boxes on poles. Walls, or large flat areas function as solar collectors, and the mass of buildings will hold heat energy over night (and release it back to the bat house) creating a warmer microclimate. Bat boxes on poles may be cooler because of the lower mass to the structure (which is less likely to retain heat) and may be more subject to convective cooling from wind. Bat houses attached to trees can experience cooling if the tree shades the bat house for a significant portion of the day. Trees can work well to support a bat box if the trunk is very “pole-like” as installation is easier; varying degrees of shade from branches will affect the microclimate of boxes, and this can be used to great advantage when trying to erect boxes with myriad of

microclimates (Goldilocks Approach).

- **Number of bat boxes**.
  Installing a single bat box may not provide the roost microclimates that bats need as reproductive and environmental conditions change over the pup-rearing season. A single bat box would ideally have a large enough range of temperatures available to facilitate roosting for a 12–24-hour period (daily). A tall bat box provides a gradient of temperatures, and if it is multichambered, there likely will be a greater range of microclimates to provide suitable daily conditions for a colony. If cool enough options are not available within the roost, overheating may become a problem and bats may need to flee the roost mid-day. Hence the importance of having more than one bat box installed. If close-by options do not exist, the colony may have no escape from an overheating box, and mortalities can occur. Having more than one bat box to choose from is not only critical on a daily basis, but on a seasonal basis, given that female bats need to shift around to temperatures that are conducive to reproduction. A single large bat condo is less likely to overheat and more likely to meet the needs of a colony for an entire season because the range of microclimates within one structure is extensive and bats can shift around to stay within their TNZ.

2.4. Suitable Capacity of Bat Houses to Accommodate Bat Colonies

Although microclimate options are a critical consideration when designing artificial habitat for bats, minimum capacity is also very important. Bat houses vary in size and design and the capacity to house bats varies as well, although bats do tend to pack large numbers into small spaces (Figure 5). The typical colony size varies with bat species. Some species can form colony sizes of up to 5,000 or more bats (e.g., Yuma Myotis). Little Brown Myotis can range up to 1,000 or more, while the largest colonies of Big Brown Bats are usually less than 1,000. The size and number of bat houses available to bats will influence the capacity to provide shelter for the colony being managed.

Figure 5. Large colony of Yuma Myotis in a bat box, British Columbia. Photo: J. Saremba.

Cost of construction and installation will vary with design. Bat condos are the costliest type of bat house to build, and while they may be useful for large colonies, they are not necessary for smaller colonies. Smaller versions of bat condos (i.e., mini condos) have less capacity than the full-size condo and may be a more affordable option. A bat box may be cost effective, but a single box will *not* be adequate to meet the thermal needs of a reproductive colony and may not have the capacity to fit an entire colony at one time. Multiple bat boxes installed approximately 100 metres of each other can form a roosting 'area' which may meet the needs of an entire colony for the reproductive season. This is often referred to as a "bat box array." There is no magic number of boxes that are needed for a colony, given that the decision needs to be based not just on numbers of bats in relation to capacity of boxes, but on the availability of additional suitable roosts in the area (other human-constructed roosts, or natural roosts) that will provide the requisite variability of roost microclimates (as discussed in above sections). It is important to provide adequate roosting space, especially for colonies that are being excluded from buildings or colonies that have lost their building roost through some type of building loss.

Large condos are increasing in popularity as they more closely mimic the attic building roosts that they typically replace, but cost and area of land needed to be secured can be impediments. Much research has yet to be conducted on the use of these structures and how well bats fare in them relative to other roosts.

Multiple roosting sites in one area will support roost switching, a behaviour that has been observed for many temperate bat species using natural roosts (including Little Brown Myotis, Yuma Myotis and Big Brown bats) and colony dynamics are often described as a fission-fusion system (Willis and Brigham 2004). During the maternity season colony members may move between roosts periodically, splitting and merging into various sub-groups (Kerth and Konig 1999, Willis and Brigham 2004, Garroway and Broders 2007, Abernethy et al. 2019). Switching between a primary roost and alternate roost(s) may occur frequently, ranging from every 1.5 days in Little Brown Myotis (Olson and Barclay 2013) to every 4.8 days by Yuma Myotis (Evelyn et al. 2004). A study of Indiana Myotis found that their main roost trees were in later decay stages and provided very warm roost temperatures; the alternate roosts were in decay class 2 trees which were cooler, but water-tight (Callahan et al. 1997). Bats were observed using the alternate roosts when it was raining or when temperatures got extremely high (i.e., greater than 40˚C) which may explain why bats need a variety of roost trees (Callahan et al. 1997).

Fewer studies of roost-switching behaviour have been conducted on bats roosting in either buildings or bat houses. Bats have been shown to use networks of human-built roosts (bat houses, buildings) in roost areas just as they do when using natural roosts (Rensel 2021), but this remains to be more thoroughly studied. Lausen and Barclay (2006) found Big Brown bats switched locations within a building roost, presumably to exploit different microclimates. The extent and frequency of roost switching by bats occupying bat boxes is currently under investigation. A pilot study of bats using bat boxes in British Columbia found Yuma Myotis switched roosts every 2.5 days (S. Dulc, unpublished data).

Reasons for roost switching may be a response to one (or more) of the following:

1. Human disturbance (Brigham and Fenton 1986).
2. A predation event or as a predator avoidance strategy (Lausen and Barclay 2002).
3. Roost microclimate and the implications for energy strategies (e.g., extreme temperatures (Lourenço and Palmeirin 2004, Ellison et al. 2007).
4. Precipitation (Vonhof and Barclay 1996, Patriquin et al. 2016).

5. High parasite loads (Brittingham and Williams 2000, Reckardt and Kerth 2007, Bartonička and Růžičková 2013).
6. Social affiliations (Kerth et al. 2011, Johnson et al. 2012).

2.5. Suitability of design features and materials (considerations other than thermal suitability).

For a discussion of the solutions to these problems, see **3.5. Suitability of Construction Materials and Design Features.**

- **Use of chemically treated materials to build a bat house could negatively affect bat health.** Bats roosting in bat houses are in close contact with the surfaces of roosting panels. Pups are born pink and hairless and are left behind when mothers leave to forage. Pups will have bare skin contact with roosting surfaces. Adults are furred but groom constantly, wings are cleaned by licking, fur is combed and licked with their hind feet. Construction materials treated with preservatives and/or adhesives (e.g., plywood), or stain or paint that contain chemicals or volatile compounds could be easily transferred to bat fur and skin (Mitchell-Jones et al. 1989). Grooming could lead to consumption of traces of chemicals or volatile compounds. Surface treatments that heat up with solar exposure may release gases that are breathed in by roosting bats.
- **Crevices (chamber) spaces are too wide or too narrow.** Bats may not use a bat house with improper crevice spacing.
- **Bat house is built with an unprotected roof surface or untreated exterior.** This can contribute to a more rapid deterioration of the bat house as materials are affected by weathering. Potentially the interior of the box may become wet during rain events.
- **Use of smooth interior roosting panels or use of window screen for climbing/roosting surfaces may be unsuitable for roosting bats.** Bats grip interior roosting surfaces using the tiny claws on their hind feet and climb with the aid of the claw on their thumbs. Smooth wood surfaces may not provide adequate footholds for roosting bats (especially pups). Some bat house builders will use metal staples to attach polycarbonate window screen to the interior roosting surfaces which does make a good climbing surface but can detach from the roosting substrate over time, creating spaces where bats, especially pups, and bat guano can get trapped. This can lead to pup death and unnecessary amounts of maintenance to keep the box clean. Guano accumulations can lead to increased numbers of parasites. Detached screens can also prevent proper entry/exit of bats in and out of the box.
- **Failure to provide a landing pad or the landing pad is smooth without ridged or rough surfaces may deter bats from using a bat house**. Bats may not be able to access the bat house without a rough landing pad (see Figure 6).

Figure 6. Roughened landing pad visible at the base of BCI style bat box. Photo by C. Currie.

- **Bat house is nailed together instead of using weatherproof screws.**
  Any warping of the wood will cause nails to pop and attachment points to separate, creating gaps that may provide unwanted ventilation or exposure to rain.
- **Failure to use caulking to seal seams to ensure box is weather-tight.**
  Water and wind exposure during periods of bad weather can lead to less suitable conditions for bats. Bats may not use a bat house that leaks or is drafty.
- **Bat house is not built to recommended design standards.**
  The internet is full of highly variable bat house designs and not all are appropriate or effective. Similarly, stores/vendors do not typically know what makes a high-quality bat box. Unfortunately, you cannot assume that just because the blueprint is posted online, or the box is available for sale, that it is a good one. Often the boxes available for purchase can be far too small to be useful to bats (i.e., anything the size of a typical bird house is too small to function as a nursery roost for bats). These short height and often narrow boxes are cheap and easy to install but likely will be too cold for female bats raising pups. Similarly, large single chamber boxes are the most cost-effective boxes and relatively light, for easy installation, but these boxes typically heat up quickly and cool down rapidly. This type of box installed in a south or west-facing direction may get too hot in some sites putting pups at risk, and pups left behind at night in these boxes would be too cold.
- **Parasites and other non-bat occupants.** Large structures like condos can be problematic because ectoparasites may build up due to continuous availability of hosts (Voigt et al. 2016). While effects of ectoparasite loads are poorly understand, high loads can result in roost switching by bats. Partly a design issue, bat houses that retain high loads of bat guano or horizontal surfaces that collect materials may also support the retention of parasites and create

environments unsuitable for bats. Bat houses with closed bottoms may accumulate guano and result in high parasite loads. It should be noted that while bats can have large numbers of ectoparasites, these mites, flies, and bugs are specific to bats and do not represent a concern for humans (Figure 7). Wasps and spiders are just two examples of other life that may become established in a bat box.

Figure 7. Bat with bat bugs (Cimex spp.) attached to forearm. Although they look similar, these are not *bed bugs and are specific to bats. Photo by H. Gerlach.*

2.6. Suitability of Access for Bats

For a discussion of the solutions to these problems, see **3.6. Suitability of Access for Bats Using Roost Structures.**

Accessibility of a roost to a bat will affect occupancy.

Flight ability varies with species, with some bats capable of more maneuverable flight than others. Bat wings consist of elongated fingers with a special skin membrane between each finger and extending along the body to the ankle. Wing shape varies depending on bat species. Wing shape together with the size of the bat, determines speed, agility, and maneuverability (Norberg and Rayner 1987). Small, maneuverable bats can navigate complex environments (e.g., sites with trees, shrubs, or other objects) and are more likely to be able to exploit smaller and less accessible roosts than bats that have less maneuverable flight. However, all bats have limits and require clear flight paths for access.

Bats typically move around roosts by crawling using their clawed toes and their thumbs, the small, clawed digit on each wing. Roost surfaces must be rough enough for the bat to move around with their claws. These clawed digits are also important in landing. When bats approach a roost some will roll in the air immediately prior to landing such that they grab the landing substrate with their toe claws and already in the upside-down position. Others will land head up, and then maneuver to an upside-down roosting position (Norberg and Rayner 1987). Bats with small thumbs will have difficulty crawling into or within a roost if there are barriers to movement such as uneven boards or smooth surfaces.

Some bat species are able to take flight from the ground – despite it being energetically demanding --while many are not well adapted for this type of take-off. Most bats typically take flight with ease by dropping out of elevated positions, with the initial fall providing momentum for flight (Norberg and Rayner 1987). This means that by nature, bats tend to climb upwards, and thus artificial roosts built for bats should be designed for bats to climb upwards from an entrance, rather than down.

- Access may be blocked for bats to enter bat houses where vegetation is immediately below or in front of the bat house. Sites where vegetation has been allowed uncontrolled growth may block access to bats attempting to enter or exit the bat house.

2.7. Accessibility for Predators to Bat Roosting Structures

For a discussion of the solutions to these problems, see 3.5. Suitability of Construction Materials and Design Features**3.7. Accessibility for Predators to Bat Roosting Structures.**

- **Bat house is installed too low or in a site with easy predator access**. Low bat houses create conditions where domestic cats hunting bats may easily jump into the air to capture exiting bats that drop and fly as they leave. Domestic cats have been identified as a significant threat to bat populations worldwide (Ancillotto et al. 2013, Kauhala et al. 2015, Khayat et al. 2020, Oedin et al. 2021, Beattie et al. 2022) and have further been flagged as a risk for spreading zoonotic disease because of their propensity to hunt bats (Salinas-Ramos et al. 2021). **Other terrestrial predators may attack colonies in bat houses.** Boxes mounted on posts or other features that can be climbed by rats, squirrels or other ground predators will leave a colony vulnerable to predation.

- **Large structures like condos can be problematic by creating exploitable concentrations of prey for predators that may exploit the routine patterns of large numbers of emerging bats** (Voigt et al. 2016). **Owls may prey upon bats as they exit bat houses,** especially if there are nearby, suitable perches where owls can sit and wait for exiting bats at dusk (Jung et al. 2011, Bergstrom and Smith 2017, Figure 8).

Figure 8. Barred owl perches on bat box (Photo by: M. Evelyn, from BC Building Homes for Bats Guidebook). Owls are predators of bats and owls have been observed taking bats emerging from bat boxes (S. Dulc, pers. obs.).

2.8. Site Suitability and Potential Problems with Installations.

For a discussion of the solutions to these problems, see 3.6. Suitability of Access for Bats Using Roost Structures **3.8. Site Suitability for Bat Houses.**

2.8.1. Physical features that affect site suitability

- **Sites with toxic drinking water sources, and/or contaminated food supply** (e.g., insects emerging from contaminated sediments in ponds/streams) may pose a threat to nearby bat colonies.
- **Unsupervised sites with high levels of human traffic** may leave bat colonies in bat houses vulnerable to vandalism or harassment.
- **Consider local climate. In some areas, bat boxes may be too cold, too shady, or too windy to ever be used by bats.** Bat boxes placed in a location that is always shaded, cold or a site that receives a lot of wind (and thus, experiences convective cooling or unstable and unpredictable temperature fluctuations) may not be used by breeding females raising pups. This will be site-dependent though, and as roost / ambient temperatures rise above the TNZ or approach lethal limit, shady or windy boxes may be important if natural cooler rock crevice roost options are limited.

  Bat boxes built in areas where bats are less likely to overheat are likely to find that boxes in constant shade may never see any use by bats. Bat houses mounted on poles may be particularly susceptible to convective cooling. However, cooler sites might be used by solitary bats (males, non-reproductive females), especially if the location receives at least some late afternoon sun.

- **Bat box is installed in a location that is too bright.** Street or house lights shining on a box can create an inhospitable environment if the bats perceive this as increasing their predation risk when they enter or exit each night; reflective surfaces positioned underneath bat houses may create bright interior light conditions that may deter bat use.
- **Bat house is installed at a site that is too cluttered/too hazardous**. Bat houses installed over thorny vegetation or sites where vegetation will eventually grow up around the bat house may be a hazard for fledging bats and/or impede flight access. Invasive plants like Burdock (Arctium spp.) can kill bats as they brush the vegetation during flight (Figure 9, Lausen et al. 2022).

Figure 9. Bat in burdock. This invasive weed can present an entanglement threat to bats. Photo by N. deBruyn.

- **Bat house is installed in disconnected habitat.** Bats are highly mobile, but some species require habitat connectivity to navigate landscapes. Or other features (such as brightly lit areas at night, areas with high levels of air pollution or noise) may deter them from crossing geographic areas. These isolated sites may not be used by some bat species.

2.8.2. Choosing sites that are suitable for the intended purpose of a bat house

Bat houses may be installed for different purposes. These may include mitigation, general interest, education, integrated pest management or conservation purposes.

- Mitigation is discussed further in Section 2.9.

The general public may wish to install bat houses simply out of interest. However inappropriately situated boxes or poor design could attract bats with unintended consequences (see Appendix A.1.7.6. Bat Houses as Potential Ecological Sinks).

- Bat houses set up for education purposes are often in areas of high traffic for humans and may be at a higher risk for vandalism. Installations should be effective for their purpose but be mindful of risks to bats.

- Bat houses used as part of an integrated pest management scheme should ensure that installations are not set in areas where bats may be at risk.
- Bat houses may be used as part of conservation initiatives. There are ways of making these initiatives effective for both bats and people.

2.9. Appropriate Use of Bat Houses for Mitigation

Bat houses, in the right location, can provide important, alternate roosting habitat in response to lost roosting habitat. This is especially true in urban or developed areas that are unlikely to regenerate natural roosting habitat. In urban parks or residential areas, trees may never be allowed to mature to the point where they can offer suitable bat roosting habitat -- the trees that would provide bats with roosting spaces are generally the oldest age class, and these may be deemed hazardous and be removed.

Based on research and monitoring to date, bat houses do not provide roost features for all bats. Some bat species prefer roosting under natural-type roosts such as under sheets of peeling bark. Artificial bark materials wrapped around poles or trees may provide an alternative solution but the effectiveness of these "bark mimic" artificial roosts remains to be proven. A discussion of bark mimic roosts can be found in the Appendix A.1.8. Other types of artificial roosting habitat: bark mimics.

- Bat houses are not appropriate in areas where there is insufficient or lack of appropriate foraging/drinking habitat, or near contaminated or toxic foraging or drinking habitats. Bats drink on the wing and different sizes and shapes of bats with different flight capabilities have different minimum diameters of drinking water ponds that they can approach and successfully drink. Different species of bats also feed on different sizes and types of insect prey. Both Little Brown and Yuma Myotis are known to be 'water skimming' bats, meaning that they typically feed on insects immediately above or on the surface of water (Lausen et al. 2022). As such, bat house success for these species depends on proximity to open water.
- Bat houses may not be appropriate in areas where there is an identified hazard for bats, such as a busy roadway, or other flight hazards such as wind turbines.
- Provision of a large network of bat houses may cause a shift in composition of the local bat community, with a bias towards species that successfully colonize artificial roosting structures. Urbanization and landscape development have shifted community structure of bats and it has been observed that it is often just a few bat species that dominate in many urban settings (Russo and Ancillotto 2015). Bat house installations are most appropriate in urban areas.

Section 3: Best Management Practices

Overall, best practices when it comes to the use of bat houses as replacement roosting habitat for bats is this: heterogeneity (Lausen et al. 2023; Czenze et al. 2022) -- more boxes, diversity in design and installations, with a mix of solar exposures – the more choices the better chance that one will provide enough roosts to meet the needs of these small mammals with highly specific thermal and physiological needs that vary daily and seasonally. We like to refer to this as the "Goldilocks Approach" (Lausen 2021; Lausen et al. 2023).

3.1. Best Management Practices Re: Threats and Impacts from Human Activities

Best Practices for pest/wildlife control operators or situations of human conflict

- Bat houses can be a primary mitigation tool when bat colonies are excluded from buildings or other human-made structures. Whether colonies are excluded because they are unwanted or because the structure is being removed or renovated, alternative roost(s) can replace lost habitat as long as they are used effectively (Section 3.9 for further information on mitigation).
- Bat exclusions should not occur during the season when females are raising pups. Delineating specific timing windows during which exclusions should occur with minimal impact on roosting bats is an effective way to protect bat colonies. Most importantly, exclusions should not occur when there is likely to be dependent (non-flying) young present, as young may become trapped or abandoned, or during times when bats may be hibernating in the human-built structure. It is often difficult to know if a structure is used for hibernation, as bats are inactive and often hiding in crevices or under insulation. Hibernating bats are unable to move and can be trapped or injured.
- Bat colonies can remain in buildings with no human health concerns, but this may require some proactive measures to ensure bats and humans are separated appropriately. Best practices for managing bats in buildings are encouraged. One example is *Acceptable Management Practices for Bat Control Activities in Structures: A Guide for Nuisance Wildlife Control Operators*, available at whitenosesyndrome.org
- Bats found and reported roosting in unusual locations (such as on doors, on the sides of buildings, or in public spaces), may be at risk.
    - These bats should not be first considered a “risk to people” but “at risk” to harm (from people or predators). However, appropriate protocols are required for found bats.
    - Bats roosting in unusual locations in late summer may be juveniles learning to fly and hunt. They often become stranded, hungry, and thirsty and do not represent a significant risk to humans or pets.
    - Late season and early season bats may be bats moving between winter and summer roosting habitats that have not found a safe roosting place at dawn. These bats may stay in one place for a few days before moving on and do not require intervention (however, placing a simple bat house or shelter as a half-way house for them, may benefit these bats).
- When a bat is found exposed or downed.
    - If the bat is out of reach of pets and children, and is hanging on a surface, leave the bat alone and it should fly on its own at night within a few days. If the bat does not leave, is found on the ground, or is low and accessible to pets/children, then:
        - Where possible, contact a local, qualified bat rehabilitator immediately.
        - No handling bats with bare hands.
        - No bare skin contact.
        - Using thick gloves, scoop bats into a small box or container with a tight-fitting lid and air holes.
        - Do not feed or water the bat as this could inadvertently harm the bat.
        - Contact and transport to a wildlife rehabilitation centre that takes bats or contact your local wildlife department.

        - If bare skin contact has occurred, recommend immediate follow up with a physician (for humans) or a vet (for pets and animals).
    - Standard provincial/territorial or state practices should include providing easily accessible information on what to do if a bat is found. This includes the above list.

Best Practices for habitat loss and degradation

- Retain natural roosting habitat wherever possible (e.g., old trees/snags, rock features with crevices). If a tree needs to be cut down, considering leaving the trunk, or part thereof, which may become a wildlife tree as the bark peels or woodpeckers create cavities over time.
- Actively retain trees for the purpose of creating older age class trees in the future to provide habitat for wildlife tree users like bats (also known as green tree recruitment).
- Protect wetlands, ponds, and other types of riparian habitats that could serve as foraging and drinking areas for bats.

Best Practices for hibernation habitats

- There are increasing numbers of reports of bats hibernating in buildings, even in extremely cold regions (e.g., Alberta, Saskatchewan, New Brunswick).
- Observations to date suggest that bats typically do not hibernate in bat houses (however it is unclear if bats may use bat houses year-round in geographic areas that are generally warm year-round, such as the Pacific Coast or southern USA).
- Most hibernating bats leave bat houses in late summer and may fly long distances (hundreds of kilometres in some areas) to hibernation sites, where they remain until the following spring. Hibernation habitat has unique characteristics and tends to be limited in its availability. Characterized by low stable temperatures (0-9˚C) and high relative humidity, these sites are critical habitat for wintering bats in North America.
    - Hibernation sites should be fiercely protected from winter disturbances.
    - Site integrity should be maintained.

Best Practices for limiting anthropogenic noise

- During the season of use, noise levels around a roost should be minimized as bat hearing is sensitive in a broad range of frequencies, including ultrasonic and audible, and this differs by species (bats and noise considerations, see Caltrans 2016, BC MFLNRO 2014). Bat houses should ideally be installed in quiet locations.
- Human activities within 200 metres of bat foraging or roosting habitats that produce broadband noise within the range of 10-100 kilohertz (kHz) and greater than 80 decibels (dB), that cannot be moved, should reduce sound output either by using physical sound baffling methods or changes in technology that would reduce the sound intensity to a range that will not disturb the bat species in the area.
- Anthropogenic noise issues can be complicated because some bat colonies may become accustomed to very loud and constantly loud sounds. Not every loud site may represent an issue, but it may be more of an issue when the sound is novel to the site. It is worth being aware of potential disturbances from noise but monitoring bat behaviour may indicate that existing loud noise is not an issue for certain populations.

Best Practices for Lighting

- Do not directly shine light on or into bat roosts, especially at roost exit or entrance points.
- Avoid the installation of light fixtures in ecologically sensitive areas (e.g., near ponds, lakes, rivers, wetlands, areas of high conservation value or in habitats known to support particularly light-sensitive species of conservation concern). If installation in these types of areas is unavoidable, use best practices to minimize the impact of light on the site.
    - Do not use more lighting than necessary and minimize the amount of light shining upwards into the sky where bats would be flying. Avoid the temptation to "over-light" because of the higher luminous efficiency of LEDs.
    - Avoid using light fixtures emitting wavelengths in the white, blue-white, or ultraviolet spectrum. Red light is less disturbing to bats as most bats aren't very sensitive to light in the red spectrum (Fure 2006).
    - Minimize the spread of light from each light source; keep light at or near horizontal, direct light only at the task areas, use shields or accessories on lights to direct light to the required areas, using fully-shielded fixtures that direct light downwards. Avoid using reflective surfaces under lighting fixtures.
    - Carefully evaluate the mounting height for lighting. Lower lights can result in more light spilling outside of the task area or may require more lighting sites to meet lighting needs; mounting heights for lights should balance light needs and mitigation measures.
    - Shield sensitive areas from lighting either by using vegetation or temporary close-boarded fencing until vegetation matures.
- Consider other options than lighting to achieve goals: reflective paint, white lining, good signage, reflectors, or low-light level solar-powered LED lights to manage roadways, possibly limiting lighting to high-risk areas such as intersections or crossings.
- Use adaptive lighting strategies that can reflect the human occupational safety needs as well as the needs of local wildlife. Cycle lighting schedules to provide dark periods; for example, sites such as roadways and parking lots may be used less after midnight; vary the lighting levels to reflect the changing levels of use at the site, either by reducing light levels or turning them off completely for certain periods of time.
- Consider hiring a lighting specialist for the job (who will know the best place, use, and type of lighting and lighting control system for each situation).

Best Practices for dust, smoke or other particulates affecting air quality

- Install bat houses in areas that do not typically experience low air quality (e.g., in areas with significant smoke, dust or high concentrations of other particulates) while occupied by bats.
    - e.g., Dusty gravel roads can kick up extreme amounts of dust, burn barrels or industrial effluent can affect air quality.

- Ensure that sites are chosen to avoid this kind of exposure for bats. If a planned activity will generate particulates and may directly affect the roost site, plan to conduct that activity during the part of the year when bats are not occupying the roost.

Best practices to avoid bat entrapment

- Rain barrels and pools should be covered to prevent bat access or equipped with escape terrain (such as a ramp or simply a piece of wood that can be used by bats for climbing out to the edge of the water containment and escaping).
- Entrapment can also occur if bats accidentally drop into open buckets or other smooth-walled containers. These types of containers should be turned upside down when they are near bat roosts, as young of year can occasionally drop into these types of containers, and distress calls can lure other bats in, resulting in multiple bats becoming trapped and dying.

3.2. Best Practices to Mitigate White-Nose Syndrome

While prophylaxes may be on the horizon for disease management (e.g., vaccine Rocke et al. 2019; probiotic; C. Lausen, N. Cheeptham and J.P. Xu, unpublished data), the most direct management practice to reduce the threat of WNS to bats is to minimize the chance that humans spread it to uninfected bats/areas. One should minimize the spread of *Pd* spores by limiting your contact with guano (and bats).

- **Do not apply bat guano to any part of bat houses in an attempt to encourage bat occupation.** This is not a proven method of attracting bats. Bat guano can harbour the fungal spores of *Pseudogymnoascus destructans* (Pd) that causes white-nose syndrome. Transportation of guano for any purpose out of a given area should be discouraged.
- **Be aware of the potential for disease spread.**
    - Disinfect footwear with a 10% bleach solution if walking through areas underneath bat houses where guano has accumulated. This will prevent the spread of Pd fungal spores away from the roost. While the disease may be widespread, it can be patchy so even in areas where the disease is endemic, limiting spread has benefits to bats that have not yet contacted the fungus.
    Ensure that wildlife or pest control operators that might interact with bats in roosts are aware of the most up-to-date decontamination protocols for limiting the spread of white-nose syndrome (see www.whitenosesyndrome.org).

3.3. Thermal Suitability of Artificial Roost Structures for Bats

Bat house owners need to consider whether their bat box(es) is(are) providing appropriate refuge from temperatures extremes (both hot and cold) and make changes if microclimates are shown to be deficient (i.e., either overheating or not providing a warm enough site; Carroll et al. 2017). Owners can add more options for microclimates by installing additional bat boxes in more or less shaded / windy locations, and/or changing paint colour. If existing boxes are not being used by bats after one or two years, owners could consider changing aspect to a sunnier location, or moving a box to a less windswept site – slight changes in siting may significantly alter the bat house internal temperature profile.

3.3.1. Best Practices for bat house design to increase thermal suitability

- **Build large bat houses with multiple chambers.** Consider the needs of the bat species, the local climate and environmental site characteristics to determine the best design to support your bats. Large, multi-chamber bat houses are more successful than other available bat house types, and are commonly recommended (Dodds and Bilston 2013, De la Cruz et al. 2018). The large size and multiple chambers offer a variety of internal temperatures to the bats and can host large maternity colonies (Brittingham and Williams 2000). Any of the following designs may provide suitable multichambered structures for bats, the best choice will depend on the situation.
    - **Four-chambered maternity box.** The most recommended bat house design in North America today is the BCI four-chambered maternity box (Figure 10), which comprises four ¾ inch (2 cm)-wide chambers and venting along the front and sides, typically in the lower third of the bat house (Tuttle et al. 2005). The standard four-chamber bat house (BCI design) is fairly large (H 90 cm x W 46 cm x D 18.5 cm or H 35.5 in. x W 18 in. x D 7.25 in.). Bat houses smaller/shorter than this may not retain enough heat to be useful to bats in some areas (C. Olson, Alberta Community Bat Program, unpublished data). Use multiple chambers and increase the height of the box to create a wider range of internal microclimates within the vertically mounted bat box.
    - **Multichambered rocket box.** The Rocket Box style of bat house is built around a central mounting pole (Figure 11). It often consists of two chambers continuous around the central post, thus bats can move around the chamber in all aspects (all four sides of a square post), allowing bats exposure to more microclimates than a traditional bat house with a single aspect.
        - One of the challenges with a Rocket-box style bat box is the box chambers are built around the pole. The box should thus be built on a short pole that is then attached to another pole that is dug into the ground. The joint where the 2 poles join can be of great advantage when it comes time to lowering the rocket box for maintenance – it can pivot down on the joint so that it is closer to the ground (similar to Figure 12). There is more challenge when the pole is metal. To make such maintenance easier, consider putting in a metal sleeve device to enable lowering of the Rocket-box without having to lift it off the pole. More information about the 'Easy-Up Swivel Pole Bracket' installation can be found at BatsBirdsYards.com (https://www.batsbirdsyard.com/bat-house-pole-bracket.html) with details shown for this mounting with a swivel arm via this link.
    - **Bat condos.** Large bat condos (Figure 13) and mini condos (Figure 14) typically house thousands of bats (Pennisi et al. 2004). These structures include multiple sets of roosting baffles (Figure 13) and may include an interior flight space (Butchkoski and Hassinger 2002). Additional roosting space may be accommodated under the roof and/or siding. These structures strive to replicate the conditions found in buildings by providing a large range of roosting spaces; condos which also offer flight space inside more closely mimic an attic. Bat condos offer a wider variety of microclimate opportunities than their smaller counterparts (bat boxes) and can host extremely large maternity colonies (e.g., https://batwatch.ca/bathouse-list).

- Design modifications or new innovative bat boxes should be monitored to ensure appropriate conditions are maintained for roosting bats. Successful modifications should be shared with the bat conservation community. (see **APPENDIX SEVEN: Innovative New Bat Box Design – A Case Study from Alberta by Northern Alberta Institute of Technology**., for example of new technology).

Figure 10. Standard four-chambered nursery box (BCI design – Photo by C. Olson).

Figure 11. Multi-chambered rocket box mounted on a pole (Photo by C. Lausen).

Figure 12. A jointed sectional pole to strategically hoist a bat box or rocket box. This swivel design allows one to pivot the box. It not only assists with installation but makes long-term box maintenance easier. It allows you to raise and lower the box, pivoting on the swivel point (at arrow). This picture shows a standard 4 chamber maternity box but the same approach is often used with rocket boxes. Rocket boxes are more difficult to erect, given that the chambers are built around a section of pole (see Figure 11). The section of pole that has the rocket box built around it can be of any length, with the position of the swivel varying accordingly. Photo by C. Olson.

A. B.

Figure 13. Large bat condo in Oregon. A. Looking up from underside. Sets of roosting baffles visible. B. The same bat condo with doors installed on the underside to help retain heat within the structure. Photo by D. Taylor.

Figure 14. A mini condo is installed in late fall at Lillooet, British Columbia. Photo contributed by V. *Birch-Jones. This structure is larger and offers more roost microclimate options than a standard multichambered bat box. This particular design was modified to contain a pillar of sand in the middle to function as a heat sink – stable and warm at night for pups, but unlikely to overheat despite the fact that this region is typically the hottest location in Canada (outdoor ambient temperatures have reached 47°C or 117°F; Environment Canada 2021). This site will continue to be monitored for effectiveness.*

3.3.2. Best Practices for bat house colour to ensure thermal suitability

Bat boxes need to be warm (or even hot – up to ~40-42ºC) for a reproductive colony of bats to select a roost site in a bat box (See Appendix A.1.6. Roosting Behaviour and Roost Habitat). However, in areas where overheating may occur (i.e., extended periods of time with internal roost temperatures greater than 40˚C), bats may need multiple boxes with a variety of available choices of roost temperatures and this may be especially important with a changing climate.

In the past, latitude has been used as a guide for colour of bat box (Tuttle et al. 2005, 2013):

- In southern latitudes, with consistent hot weather, bat houses should be painted or stained with lighter tones of brown, with the very lightest shades (including white) used in exceptionally hot areas (hues of green may be suitable, especially if attempting to camouflage the bat house into a forested background).
- In northern latitudes with consistently cool temperatures, bat houses can be painted or stained with darker shades of brown or black, but it is prudent to pair boxes with a cooler option as it is possible a dark bat box could overheat in summer, though it is likely to be advantageous to bats in the cool weather of spring as it will soak up the sun to provide warm roost conditions for gestation (Leung et al. 2022).

However, because of the longitudinal differences in climate, and a changing climate, relying solely on latitude may not be appropriate, careful evaluation of the site microclimate may be required. Some areas can be high latitude yet very hot and dark boxes would not be recommended due to an extreme risk of overheating (e.g., Lillooet, British Columbia, Canada is at a northern latitude of 50.7º and yet summer temperatures here have exceeded that of Death Valley, California (Environment

Canada 2021, Weather Archives). Bat boxes in Yukon, Canada (>60°) have been documented overheating (Leung et al. 2022).

The best strategy, regardless of location, is to provide a number of bat houses within a roost area that offer a variety of internal microclimates. In terms of external colour, this means providing bat houses that range in colour from dark to lighter tones to either absorb or reflect solar radiation.

- **Warning!** External colour of the bat house can significantly influence internal microclimates. Lighter coloured boxes, or natural wood stain colours are often cooler than boxes that are stained dark brown or black. The combination of a dark coloured exterior and a hot aspect (e.g., south-facing) during periods of very hot weather can create conditions that can kill bats and pups.
- **Strategies for preventing overheating:** Awnings can be built to shade bat boxes (e.g., Figures 15, 16, 17 and 18), and these awnings might be temporary and manually controlled by owners to respond to high heat during hot days/heat waves, or permanent installations. In the latter situation, a variety of boxes is encouraged, some with shade awnings and some without.

A. *B.*

Figure 15. Two types of awnings. A. A rollup blind shade that is manually released via string (seen by bat box, extending to ground) with shade being applied by landowner only during periods of high heat (photo by Susan Dulc, design by Steve Latour, BC). B. A permanent awning designed to cast shade on bat boxes when the sun is highest in the sky; inset shows top of awning (photo and design by J. Saremba).

A. B.

Figure 16. Methods for temporarily providing shade to bat houses. A. Light coloured drape over a four-chamber nursery box which worked well to lower the inside temperature of this monitored bat box by several degrees during a heat wave when bats were seen fleeing to the nearby trees and crowding the exit (sunshade installation, observation and photo by S. Dulc); B. temporary sunshade on a pole that could be moved to shade the bat box as needed (photo by M. McLaughlin).

Figure 17. White sheet used as a temporary sunshade. It was draped over an array of four-chamber nursery boxes in British Columbia during a heat wave, in response to more than 60 bats falling out of the bat boxes as they overheated. Based on the temperature loggers that were in several of the bat boxes, the application of the sheet quickly lowered the inside temperatures of the boxes below lethal temperature (L. Rensel, J. Saremba, pers. comm.; Lausen et al. 2023). (Photo by J. Saremba).

Figure 18. Landowner-installed sunshade -- insulated foam board attached to roof flashing as a temporary sunshade to protect bats during an extreme heat event. Photo by J. Thomson.

3.3.3. Best practices for bat house placement and installation to ensure overall suitability

In many cases, some bat houses are more likely to be used than other roosts. One might find one or a couple of bat boxes are more often occupied and can be referred to as 'main' roosts. Other roosts that are used less frequently or by less bats, can be referred to as alternate/satellite roosts. All roosts make up the 'roost area' for a colony and each typically plays an important role during the active season. For example, a shaded roost may be too cool throughout much of the reproductive season but is an important refuge during a few hot days each summer. These satellite roosts may show low occupancy but nonetheless play a critical role. Placement and installation can make significant differences to microclimates and thus occupancy rates (main versus satellite roosts).

Mounting location can affect box suitability plus suggested methods for installation

Bat houses are typically mounted in three types of locations: on trees, on the sides of buildings, and on poles or posts.

- **Bat boxes mounted on trees.**
    - These sites may work well for some species; however, if it is shaded by branches, it is unlikely to be a 'main' roost. In other words, conditions are likely to be too cold for the bulk of the maternity season, but a shaded box may play a critical role as an alternate/satellite roost in high heat summer days when bats may need to seek cooler roosts.

- There should be open space around and below the bat house (i.e., few branches and low or no understory vegetation that may impede flight access to the bat house). By keeping branches away from the box, there is reduced risk of predatory birds perching near the emergence opening. Regularly inspect the bat house to ensure that overhanging limbs do not grow close to or overtop of the roost (limbs may block access to the bat house and/or create easy perching conditions). If there is desire to make this a 'main' bat box, ensure branches do not shade the box, facilitating solar warming.
- Typically bat boxes mounted on trees are not 'main' roosts and this may be in part due to the tendency for boxes to be shaded by branches, but also an inherently higher predation risk that may come from terrestrial predators that can climb trees, or predatory birds that can perch in proximity. Metal flashing around the base of a tree is one method of reducing predation risk, but this applies to a dead tree.

- **Bat houses mounted on buildings.**
    - Bat houses mounted on buildings often successfully attract bats (White 2004). These bat houses benefit from the heat that transfers back to the box from the building over night plus the walls where boxes are mounted can act as large solar collectors (transferring that energy to the box as heat).
    - Choose a suitable aspect (the direction the bat house will face; see below for recommended orientations for bat houses).
    - Securely attach the bat box to the building. Suggestions for attachment:
        - Use several 1" x 2" wooden rails placed either horizontally or vertically on the rear of the bat house, slightly longer than the dimensions of the house. Bolt or screw these directly into the exterior wall of the building.
        - Use a French Cleat by adding 2-inch by 4-inch (5-cm by 10-cm) wooden boards to the back of the box and on the exterior building wall.
    - If using some single-chamber and/or small bat boxes in the selection of bat boxes that you are deploying to create a roost range for a colony, it is preferable to install these types of boxes directly onto a building as the building structure will transfer heat back to the box and buffer internal microclimates from rapid changes in air temperatures.

- **Pole-mounted bat houses.**
    - Pole mounted bat houses offer the greatest amount of flexibility for determining the height and orientation of the bat houses and can be built to include considerations for future maintenance. Bat houses affixed to poles may experience greater convective cooling, especially at sites with persistent winds. This should be a consideration when using poles or posts for mounting bat boxes.
    - Suggestion for installation:
        - Use either a 6' x 6' pressure-treated post or a metal pole that is at least 6 - 8 meters (16 - 25 feet long to ensure the bat house is set at the right height after the post has been sunk into the ground at the appropriate depth); determine the appropriate depth required for your post height (this may vary depending on the type of anchoring material used) and ensure that the type of pole used is suitable to support the weight of your bat house set up.

- Large bat boxes or back-to-back boxes can be mounted using two posts (one post at each end of the box, Figure 19). Two bat houses (such as the standard BCI four-chamber bat house) mounted back-to-back with a semi-enclosed space between the boxes that can be used for roosting or simply moving safely from one box to the other without having to fly, will offer a greater variation of microclimates for roosting bats. The boxes may be joined using a single roof (roof materials can include galvanized steel or any number of options) with partial walls (ensure it is not fully enclosed as guano will still need to drop out of the bottom). Alternatively, having a rough passageway like a tube running from one box to the other allows crawling from one box to the other.

A. B.

Figure 19. Two four-chamber nursery boxes (BCI design) mounted back-to-back on a post with a single roof and with side coverings for the mid-section. A. side view. B. view from bottom -- note the box is still open from below. Photos by M. Kelly.

Boxes mounted on trees (Boyd and Stebbings 1989), buildings (White 2004, Long et al. 2006), and poles (Flaquer et al. 2006) have all reported successful occupancy by bats. However, questions remain as to whether different bat species or bats in different reproductive stages might use these structures differently, and how this might equate to differential reproductive success. All three mounting options may successfully attract bat colonies if the bat houses provide appropriate interior microclimates, have good access for bats, are located in a site with tolerable levels of disturbance (which may vary depending on the colony), and are located in places that can be discovered by bats.

Variation in reported occupancy rates by bats using bat boxes mounted in these three ways differ across geographic location, the dominant type of roost typically available to local bat populations, roost availability, or even differences in local microsites. For example, some northern populations of Little Brown Myotis may choose bat boxes mounted on buildings over poles because of the temperature stability offered by bat houses mounted on buildings and greater heat absorption capacity of buildings which result in keeping bat houses warmer over cool night periods than pole-mounted boxes (Long et al. 2006, Fontaine et al. 2021, ACBP preliminary data [C. Olson, unpublished data]). Conversely, Little Brown Myotis populations in extremely warm southern locations may choose pole-mounted boxes because daytime temperatures are cooler and more tolerable than those mounted on buildings (Flaquer et al. 2014).

Providing multiple bat boxes with differing amounts of shade is important (i.e., Goldilocks Approach, Lausen 2021), with concern arising largely from overheating observations. Boxes that are continuously cool may not be used for reproduction yet may be important for nonreproductive bats or bats after weaning (post-lactating) in preparation for hibernation. And with increasing heat waves in some areas, cool roosts may provide safe refuge mid-summer. Bat boxes mounted on trees, with the overlying canopy restricting solar heating, may provide a cool roost (White 2004). In the hottest areas, or even in northern areas during the hottest parts of the season, bat houses can be partially shaded by an overhanging tin roof/awning or varying roof colour that protects them from the day's hottest sun (Tillman et al. 2021, Leung et al. 2022). If you observe bats constantly occupying the lowest portions of a bat box, it is probably too hot or overcrowded (Chenger 2021b), and additional bat boxes should be deployed in the adjacent area that can provide more space and/or cooler roosting microclimates.

In any location, if there are consistently periods of very hot weather (even short period of a few days), regardless of latitude, ensure that there is either a second bat house deployed within 100 metres (ideally adjacent where possible) that offers cooler temperatures, or the site is managed with a temporary shade screen to keep temperatures optimal for bats (Figures 16-18). If pole-mounting a bat house, consider mounting two in tandem back-to-back with a gap in between the two that can also be used for roosting (Figure 19). A single unified roof over both helps create a single roost structure with a variety of internal roost temperatures (Figures 19). Placing bat boxes back-to-back and connecting them via a central tunnel facilitates movement between boxes and can provide important refuge for bats if temperature in one box exceed upper limits.

Recommended Installation Height for bat houses:

- Bat houses should be installed such that the exit is approximately three to five metres (10 to 16’) off the ground (measured from the ground to the bottom of the landing pad) (Tuttle et al. 2005).
- Ideally, the bat house is high enough that exiting bats that “drop and fly” can avoid leaping ground predators, such as housecats.
- Height recommendations takes into consideration the airspace typically used by bats as they exit the bat house, though this does vary by species.
    - Bats may also require enough height to allow them to reach appropriate flight velocity when they drop out of the bottom of the bat house (Powers et al. 1991). A clear flight path for bats for entry and exit is important.

Recommended Orientation (Aspect) for bat houses:

Bat box orientation can also have an effect on internal temperature and should be selected depending on local climate. In an open location, the sunniest aspect to face a bat house is south. However, this does not mean you face a bat house in this direction. Considerations include obstacles that may create shade (e.g., a building or tree), or landscape features which may alter the amount and/or timing of solar exposure such as mountains, or cliffs. Depending on the sex and age or reproductive phase, bats may prefer roosts that receive early morning sun, or late day sun. Generally, a minimum of three boxes is a useful strategy for one box of each orientation (East, West and South). In geographic locations that typically experience very high heat, north-facing boxes may be preferred by nursing females. However, it is still a good strategy to deploy multiple boxes in multiple directions.

Maternity or nursery colonies:

- East-facing bat houses benefit from warming with the heat of the rising sun during the morning period that typically is the coolest part of the day, and therefore may provide the most benefit for bats raising pups (Long et al. 2006, Fontaine et al. 2021; see Appendix A.1.2. Differences in Roost Use by Age, Sex, and Reproductive Condition).
- Bats may prefer a site that combines early morning solar exposure and 6-7 hours of sunlight over the day (Brittingham and Williams 2000).
- Boxes facing south typically have a warmer microclimate than those facing north, and generally have a greater likelihood of occupancy (Brittingham and Williams 2000, Kerth et al. 2001, Dillingham et al. 2003, Flaquer et al. 2006) but may be more likely to overheat, especially in warmer regions (Bideguren et al. 2019). However, bat boxes mounted on western exposures have been found to overheat during the mid-day hours in the hottest climates (Brittingham and Williams 2000, Flaquer et al. 2006, Crawford et al. 2022).
- Bat boxes mounted with the warmest exposures may be used more during the early part of the season when environmental temperatures are cooler and more variable, however, this will depend on abundance of prey and use of torpor. Bats may shift to bat houses mounted with cooler exposures during midsummer when temperatures are peaking or during periods of prolonged high temperatures.

- **Bat houses not intended for maternity or nursery colonies:**
  - Individually roosting bats (such as males and non-reproductive females) prefer cool sites where they can use torpor during the day (Riskin and Pybus 1998).
  - Bat houses that may not be appropriate for maternity or nursery colonies (small bat boxes or single chambered boxes) can be installed in shaded locations, and cool aspects. Ideally, these boxes would experience an hour or two of late afternoon sun to help bats passively rewarm in preparation for activity at dusk.

3.3.4. Best practices for providing the appropriate number of bat houses

To determine the number of bat boxes required for a site there are two aspects to consider:

1. The number of boxes required to meet the thermal needs of roosting bats (and other needs such as predation avoidance)
2. The number of boxes needed to provide enough capacity or roosting space to house the colony in need of roosting habitat (see Section 3.4 below).

Bats need roosts with different temperatures depending on their reproductive condition, sex, and age, and these needs change with changing environmental conditions and temperatures. Installing several bat boxes in close proximity with varying features (size, colour, design, location) can provide the variability required to meet their needs. Generally, more is better, and variety is important.

A network of bat boxes over an area can simulate a natural roosting range, such as a forest of trees with cavities for roosting, and bats may switch between them regularly (e.g., Bartonička and Řehák 2007, Hoeh et al. 2018).

First, consider fluctuating local environmental conditions and be prepared for adaptive management:

- **Climates are changing**. Consider that for any given area, even short periods of extreme heat or intense solar radiation may cause heat stress in bats in an overheating bat house. Geographic areas with highly variable, local environmental temperatures may need to provide additional bat houses. Be prepared to troubleshoot if you see bats in distress (e.g., use of temporary/make-shift awnings like white sheets, corrugated plastic, or shade screens to offer relief from intermittent periods of extreme temperatures [Figures 16-18]).
- **Adaptive management for bat houses with issues.** When assessing a site that has experienced an overheating event, typically one should aim to *supplement*, *not remove*, roosts that are being used. In other words, expand the roost options within a colony's 'roost area' but do not remove or make significant modification of boxes that are used by bats (unless maintenance is required, or predation risk has been deemed high). Immediate fixes should start with temporary modifications that remedy the overheating risk. For example, during unusually hot weather, installation of sunshades may be needed as a stop-gap measure until additional adjacent or connected roosts can be installed, offering cooler temperature options. Awnings and white sheets/coverings to reflect sun away from the bat box have been shown to provide some immediate relief from the heat, lowering internal bat box temperatures even a few degrees below lethal upper temperature tolerances of bats. These modifications do not involve direct, long-term, or significant modification of the roost boxes, but are also not permanent and require ongoing vigilance by people to add or remove sun-reflectors sometimes on an hourly basis. While some landowners have diligently raised and lowered bat box awnings during periods of extreme heat, this is not a long-term solution. The addition of adjacent or connecting bat boxes that offer cooler conditions might be as simple as having one light-coloured bat box next to the dark-coloured box. The new light-coloured box will provide refuge to bats that may otherwise overheat in the dark-coloured box but keeping the dark coloured box in place is critical to ensure that this warm box is available to bats outside of the peak summer heat (e.g., reproductive females may need these warm bat boxes early in the season when ambient temperatures are cooler).

Second, determine the target bat species:

- **Know the species of bat being housed**. While in theory, any bat that uses tree cavities might use a bat box at some point if available, but the preference of type of openings, type of access, dimensions of interior spaces, etc. may vary significantly between species, and in practice many species of bats do not *typically* use bat boxes (see **Appendix Two: List of bat species of Canada and the USA**) providing there are natural roosts available.
- **Gauge the size of the colony**. Yuma Myotis in particular can form very large colonies (>1000 bats), Little Brown Myotis may also do this, and in some areas these species will form mixed colonies with each other. If bat boxes are crowded and packed to the top with bats, it may cause overheating issues due to increases in internal relative humidity and inability to cool on hot days. A large colony of Big Brown Bats is usually only in the hundreds and sometimes just

dozens. Colony size can be gauged by carefully watching bats emerge multiple times across the active season.

Third, determine size, design, and placement of bat houses:

- **Even for the smallest of colonies, install multiple bat houses** (at least two or three but assess the size of the colony if more are needed), within 100 meters (≤ 300 feet) of each other. Choose a variety of designs and sites for installation, increasing microclimate variation.
- If possible, create an "array" of bat boxes that are adjacent to each other (back-to-back, or side-by-side) to minimize the distance mother bats might have to move with heavy pups.
- **Preferably, use multi-chamber bat houses.**
- No single bat house is likely suitable to meet all the differing thermoregulatory requirements of bats during the spring and summer, particularly reproductive females. Offering a variety of bat houses with different microclimates will be far more effective than one single bat house and lessens the chance of creating an ecological sink – this consideration is most important in the case where bats are excluded from a significant (primary) building roost.

In some cases, variation in style (including single chamber, smaller bat boxes, condos, mini-condos etc.; see section 3.3.1. discussing bat house designs), along with variation in exterior colours and aspect may meet the needs of a larger number of bats and bat species in a particular location. Best options for replacing primary/main maternity roosts include:

  - Multiple multi-chamber and large (i.e., at least four-chamber nursery box such as the BCI standard four-chamber nursery box design 44.5 cm (17.5 in.) wide x 78.75 cm (31 in.) long x 11.5 cm (4.5 in.) deep – plus the landing pad) boxes where possible to provide temperature gradients.
  - Mini-condos or full-size bat condos with multiple chambers -- requires only a single roost structure be built.

3.4. Suitable Capacity of Bat Houses to Accommodate Bat Colonies

- For colony sizes of approximately 1,000 bats or more – one could build a large number of bat boxes, but less area is needed to build one large structure, called a "bat condo." And because a bat condo best mimics an attic roost, this is an especially suitable structure if a large colony is experiencing loss of a building roost. A single, large condo can provide an array of roost microclimates in one site and, depending on the size and design, can house thousands of bats (Figure 13). A slightly smaller version of this can also be considered (mini-condo; Figures 14 and 20), but this is less likely to replace all microclimates that an attic roost could provide and does not provide any room for bats to fly within the structure, unlike some bat condos which are designed with internal flight space.
- For colony sizes of under 1,000 bats - provide multiple large multi-chamber bat boxes or an appropriately sized bat "mini-condo" (Figures 14 and 20). A BCI standard four-chambered bat box can hold an estimated maximum of 350 bats (but many colonies are much smaller). General advice is to keep bat boxes within at least 100 metres (< 300 feet) of each other to create a network of roosts, however, side-by-side mounting on a wall (with boxes stained in contrasting colours, light/dark to provide a cool/warm box) or back-to-back mounting of boxes on a pole (with boxes facing opposite directions creating a cool/warm microclimate) may be especially

effective as this reduces the effort required by females and risk associated with moving a large pup -- minimizing the travel distance required between roosts.

- For colony sizes of one hundred or less, provide at least three (or more) bat boxes (standard four-chambered size). Again, choose a mix of installations and bat box designs that provide both warm and cool microclimate options that consider the changing local seasonal climate.
- Be especially vigilant when providing alternative roosting habitat for colonies in the process of exclusion from a building or colonies that have lost a well-used roost site. In these cases, not offering enough options or inappropriate ones could create a habitat sink if bats have no natural or suitable artificial roosts available to them. Ensure that alternate roosts created to replace lost habitat have large enough capacity to house displaced bats and provide ample choices with different roost microclimates.
- Understand that every situation is unique and that an effective solution to mitigating the loss of a bat roost may also require a cost analysis. Bat condos can be effective and provide good roosting options, but they can be very costly. A set of bat boxes installed strategically adjacent to the area where a roost has been lost (or a colony excluded) may also provide good roosting habitat at a lower cost. Evaluations should consider local environmental conditions, availability of natural roosting habitat if it exists and the species of bat in question.
- Avoid offering only a single bat box with no nearby or adjacent alternative roost options.
- Monitor bat houses carefully before removing or relocating them. Keep in mind that a bat box that is only used occasionally can still be an important roost. Even if used for just a few days in a season, it might be playing an important role for the maternity colony of bats that use it. Bats can take several years to start to use a new bat house, and relocation may result in a change in use.
- Bat boxes that may not be appropriate for maternity colonies (e.g., under-sized bat boxes or single chamber designs), but may be effective for non-reproductive females, males, and juvenile

Figure 20. A variety of mini-condo styles. Photos: left and centre by C. Olson; right by J. O'Keefe.

bats after they begin flying in late summer. Single-chambered bat boxes, or small bat boxes can be installed in cool locations that receive a bit of late afternoon sun, allowing occupants to use torpor during the day and passively rewarm with the sun in the late afternoon in preparation for the evening hunting period. These types of boxes may have ideal conditions for bats that have low energy demands (i.e., not reproductive females). These boxes may also provide “half-way” houses for bats moving between summer and winter roosting habitats in early spring and at the end of summer.

3.5. Suitability of Construction Materials and Design Features

This section reviews the best practices for the construction and design of bat houses. The following aspects are discussed:

- Construction materials.
- Gap sizes for chambers.
- Roofing materials and exterior treatments.
- Interior panels.
- Landing pad.
- Parasites.

3.5.1. Construction Materials

- For the bat house exterior, use exterior grade plywood and exterior materials and they should be at least 1/2 inch (1.9 cm) thick for durability.
- Interior wood:
    - Interior roosting panels may be thinner plywood (i.e., 3/8 inch or 1 cm thick) to reduce the weight of the house, but if possible, use old (weathered) plywood, or wood that is not plywood and is not planed (ie. rough sawn wood), as this reduces the chance that adhesives used in brand new plywood could repel bats.
    - Other types of wood such as cedar, which are naturally resistant to rot, are also recommended, however this increases the cost of materials over simple plywood construction.
    - Scavenged or recycled wood materials can be used as long as the material has not been chemically treated. Remember, bats will be roosting directly against the wood surface interiors, and bats can be sensitive to some chemicals; pressure-treated wood should be avoided because of the potential for toxicity.
- Wood screws (especially exterior grade, weatherproof woodscrews, i.e., construction grade, galvanized, stainless, or Teflon-coated screws to resist corrosion) should be used to ensure that the bat house attachment points remain secure. Be sure that all sharp tips are bent over or filed off so as to not provide a potential source of injury for bats flying/crawling in the bat house.
- All seams should be sealed (and maintained) with waterproof caulking to provide a dry and secure interior roosting space.
- In Europe, there is evidence that wood-concrete (woodcrete) boxes, which are constructed with a hybrid material, made by mixing sawdust and concrete, allow for a more stable internal temperature regime, as well as improve box durability, lasting up to 30 years (e.g., Poulton

2006, Aughney 2008). In North America there has also been experimentation with bat box-like structures made of woodcrete (e.g., Figure 21), and different mixes of concrete with variable thermal properties (Justin Stevenson, RD Wildlife Management, pers. comm.). The effectiveness of these structures remains to be seen.

- Verify that bat house design features used, meet current acceptable standards.

Figure 21. Bat houses made from concrete mixed with fibre in British Columbia (Andrusiak and Sarell 2019). Photos by M. Sarell.

3.5.2. Gap Sizes for Chambers

- Use the recommended gap size between chamber walls for the intended bat species using the bat house. For Little Brown Myotis and Yuma Myotis is approximately 1.9 centimetres (¾ inch wide) and slightly larger for Big Brown Bat (2.5-3.8 cm/1-1.5 in.; Tuttle et al. 2005). Varying chamber widths within and among bat boxes can increase the number of species using the boxes.
- For multichambered bat houses, cut or drill access slots through the interior roosting panels to allow bats to move from one interior chamber to the next without the need to climb to the bottom of the box. Either drill circular holes about 3.8 cm (1.5 in.) wide or plan into the design a 1.9-2.5 cm (3/4 -1 in.) wide slot along one side of each chamber for bats to freely move among chambers; ensure cut edges are sanded smooth to avoid injury to crawling bats. Similarly, gaps can be left along the top of the roosting panels to allow bats movement between chambers but ideally this gap would not be along the entire length of the chamber, as bats do tend to roost along the top of the chambers, comfortably pushing their back end into the roof of the chamber. If the bat box is going to be mounted on a building in such as way that there will be a gap between the back of the bat house and the building wall, consider creating an untreated roosting panel on the back of the bat house (creating another possible roosting space for bats between the building wall and the bat box).

3.5.3. Roofing Materials and exterior treatments

- Staining the exterior with waterproof sealants will also extend the life of the box; darker or lighter stains change the thermal properties of a bat box, so even if leaving the natural wood colour, the outside of the box should be treated with a clear sealant of some kind. This also helps prevent wood from warping and may keep seams from opening, exposing bats to weather. Cedar is naturally resistant to decay, however, to ensure an extended lifespan of the box, even this type of wood may be treated to resist weathering.
- Paint the exterior of the bat house with three coats of flat, exterior-grade, water-based paint, or stain to increase its lifespan. Consider hues that may blend in with the local environment during the bats' active season to reduce visibility to predators, balance colour choices with local microclimate and solar exposure.
- The lifespan of the bat house will be increased with the installation of some type of roofing material to extend the life of the box, or perhaps offer shade. Use of composite wood for roofing, (e.g., wood-concrete materials) may also extend the life of the bat house.
- Roofing material may improve the ability of the box to shed water and may increase the lifespan of the bat house by reducing the degree of weathering.
- Consider roofing materials (e.g., tar paper, shingles, tin or copper sheets, composite wood) appropriate to your climate. Colour of roofing material may affect interior temperatures. In exceptionally hot areas, dark shingles (asphalt and duroid) may become excessively hot; alternate materials may be more suitable, or one might consider alternating light and dark roofs (e.g., Leung et al. 2022).
- Consider a roof overhang, or custom awning that may be permanent or removable for shading the boxes in the extreme heat of summer (awning examples, Figures 15-18).

3.5.4. Interior Panels

- The interior surfaces of the bat box should have a roughened texture to allow bats to move easily and allow them to securely grip the surface of the roosting panel (both sides of the panel should be roughened). Purchasing wood that is not planed or using inexpensive (rough) plywood may provide that roughened texture.
- If needing to roughen the landing platform and/or the wood creating the chambers, create a series of horizontal grooves to provide a rough surface for roosting or crawling, space grooves at 0.5-1 centimetres and no more than 0.15 centimetres deep (1/4 -1/2-inch intervals no more than 1/16 inch deep); the surface of the interior back board panel of the bat box should be scored for the full length as well. This is a time-consuming task, but ultimately helps reduce long-term maintenance effort. Grooves can be created using hand saws or other more automated methods (e.g., shallow set skill saw).
- Interior panels should be left untreated. Stained or painted interior roosting panels are not as textured for bats to grip with their feet and claws as unfinished wood. Stain and paint may also release odours (volatile organic compounds or VOCs) that may deter bats from roosting and could have detrimental health effects for roosting bats. However, urine can rot wood over time, and therefore, a thicker board is likely to provide greater longevity to the bat house structure.
- Ensure all nails are pounded in completely and that no sharp screw or nail ends protrude inside the structure which could catch on bat skin as it crawls or flies within the structure.

- Mesh is not recommended for use as a roosting surface, as degradation over time can leave ragged edges that damage bat wings. Mesh or screen may also pull away from the interior roosting panels as staples and nails loosen over time, or mesh will stretch creating a trapping hazard for pups and adults. Mesh and screening may also trap guano and urine inside the bat house; this creates more maintenance issues and can also promote the presence of bat bugs or bat parasites.
- Avoid cleaning the inside of bat houses with water, particularly with pressure washers. This may cause the plywood baffles to delaminate, break down and possibly release objectionable odors.
- Gently clean out bat houses using a small brush with an extension when the bat house is unoccupied to remove paper wasp material or extensive spider webs.

3.5.5. Landing Pad

- Ensure bats have a "landing pad" to enable them to enter bat houses from below the box. This consists of a piece of wood that projects out the bottom of the box where bats can safely land and crawl up into the box.
- Landing pads should be roughened (like the interior roosting panels) to allow bats to gain purchase and should be at least 10 cm (4 in.) in vertical length.
- Landing pads should be stained to protect from weathering (unless untreated cedar is used for the bat house exterior as it is naturally resistant to rot). Stain is preferable to paint (which can fill grooves and not offer the same availability of secure footholds as untreated, roughened wood surfaces).

3.5.6. Parasites

- Avoid bat house designs that allow bat guano to collect inside the bat house (e.g., horizontal surfaces or use of screen material inside the bat house can catch and collect guano and provide a safe harbour for bat ticks and other parasites).
- Aim to create vertical panels that allow bat guano to roll or drop out of the bat house to the ground below rather than collecting inside the bat house.
- Conduct annual maintenance checks of bat houses and ensure bat houses are clean prior to spring occupation by bats.

3.6. Suitability of Access for Bats Using Roost Structures

Roosts that are well above the ground facilitate flight by allowing bats to drop from elevated positions, with the initial fall providing momentum for flight. This is energetically beneficial for bats.

- **Avoid clutter directly below and adjacent to bat houses.** The level of clutter surrounding a bat house can also affect successful occupation by bats. Clutter is defined as any object (but especially, tree branches or bushes, but could also include anthropogenic features such as wires, etc.) that impede the flight path of bats and create physical obstacles for flight. Bat houses should be placed in a low clutter environment to allow bats to navigate more efficiently in and out of roosts; especially consider the areas directly beneath and in front of the bat house as bats usually "drop and fly" out of the bottom of the bat house. Be careful to prune back vegetation and mow long grasses that might grow up around or directly beneath bat houses.
- **Install bat houses at the recommended height.** There should be a minimum distance of at least three meters (~10 feet) between the ground and the bottom of the bat house.

- **Consider installing bat houses with a 10˚ tilt backwards.** Little research has been done to determine whether a slight backward tilt would be advantageous for bats with young. This may reduce the number of pups falling from bat houses. However, a tilt would be a trade-off, ensuring that guano does not accumulate in the bat box, necessitating extra cleaning/maintenance.

3.7. Accessibility for Predators to Bat Roosting Structures

- Elevating the roost keeps exiting bats high enough above the ground to keep them out of the reach of ground predators such as domestic cats. Recommended height is 3 to 5 meters (~10 to 16 feet) from the ground to the bottom of the bat house.
- Keep pet cats inside, especially between sunset and sunrise. Consider building your pet a catio to limit their impacts on wildlife. If barn cats or feral cats are present, ensure the bat roost (wherever it is located) has some kind of predator guard for cats. Bat echolocation calls are audible to cats and the smell of bats will alert cats to their presence.
- Do not install bat houses near branches where owls or other potential avian predators can perch and wait for bats exiting the roost at dusk.
- Avoid installing bat houses near sources of light such as streetlights, as this can make emergence riskier for bats because they are more visible to avian predators.
- “Bird spikes” may need to be installed on or near a bat house if there are obvious areas for avian predators to perch (Figure 8), and one may modify them to make them blunt to avoid any chance of injury to bat wings, e.g., Figure 3).
- Prevent ground predators (such as squirrels) from accessing bat houses by wrapping metal sheeting or other types of predator guards at the base of poles that support bat houses (e.g., Figure 22).
- Avoid installing bat boxes on trees that may provide easy climbing surfaces for ground predators.
- Install condos along hedgerows or vegetated windbreaks/shelterbelt, or something that would allow bats to hide in moon-shadow or amongst branches as they emerge to forage, allowing a colony to disperse and less likely to be preyed upon by predators that may cue into a long-term roost. These vegetative safeguards can be planted near already-constructed condos.
- Consider a steep roof design or installation of plastic (or plastic-pointed) bird spikes on any part of the bat house where birds of prey could potentially perch close to the bat roost exit. Install the bat house such that the exit is not immediately accessible to avian predators that might perch on a nearby branch/post.

3.8. Site Suitability for Bat Houses

3.8.1. Physical features that affect site suitability

At sites where bat houses are proposed to be installed:

- **Evaluate the ecological risk to bats**. Ensure the bat house is installed at a site that is not hazardous/cluttered.

- Avoid sites with toxic drinking water sources, and/or contaminated food supply (e.g., insects emerging from contaminated sediments in ponds/streams) may pose a threat to nearby bat colonies. Remember that most bat species travel several kilometres from the roost to forage. Evaluate drinking and foraging habitat resources within a 10-kilometre radius of the roost site.
- Bat houses installed over thorny vegetation or sites where vegetation will eventually grow up around the bat house may be a hazard for fledging bats and/or impede flight access. Invasive plants like Burdock can kill bats as they brush the vegetation during flight (Figure 9, Lausen et al. 2022). Avoid planting thorny shrubs under bat houses; conduct vegetation control to eliminate plants that represent a hazard to bats. Monitor the vegetation community under bat houses annually.

- **Evaluate the risk to bats from humans/vandalism/harassment.** Is the proposed site in an area with elevated levels of human traffic? Is the site unsupervised at night or during the day? Will the bat house be highly visible and accessible to humans? This may leave a bat colony vulnerable. Avoid building houses in high human-traffic areas.

- **Consider installing fencing** around areas with large bat roosts to reduce intrusion by people walking by, particularly in public parks, as well as reducing the need for cutting grass under the bat boxes, which can be relatively noisy and disturb the bats.

- **Evaluate if the site is too cold, too shady, or too windy**. Consider the local climate when conducting this evaluation.
    - **For breeding females and growing pups.** If a bat house is intended to replace a primary/main roost for a maternity colony, avoid placing it in a location that is always shaded, cold or windy (and thus would experience convective cooling or unstable and unpredictable temperature fluctuations). A single bat box mounted on a pole may be particularly susceptible to convective cooling.

      While it is good to have a selection of bat box installations for a colony (some with good solar exposure and some with shade), a maternity colony of reproductive females needs a very warm roost and thus the main or primary roost should receive as much solar radiation as possible. However, alternate / satellite roosts should be installed around/adjacent – a collection of different designs, colours and/or levels of solar exposure all in one immediate array is referred to as an array. Bat box arrays are important to meet the needs of a maternity colony of bats.

      Know your weather and keep tabs on how climate change is influencing bat box temperatures. Decisions about placement, materials and level of intervention to shade boxes during heat waves will need to be on a case-by-case basis.
    - **For sites that will be used by bats not raising pups (males, non-reproductive females, or transient bats).** Bat houses may be installed in cool locations, especially if the site receives at least some late afternoon sun.

- **Evaluate the levels of artificial light at night (ALAN).** Choose dark sites over bright ones. Avoid sites where street or house lights shine on the bat house.

- **Evaluate the light levels during the day.** Avoid installing reflective surfaces underneath bat houses that may elevate the amount of light shining into the box interior.
- **Consider habitat connectivity when choosing a site.** Bats will use landscape features such as tree lines, hedgerows, shelterbelts, or forest edges as travel routes between roosting areas, and foraging or drinking areas (Entwistle et al. 2001). Many bat species avoid open spaces where they may be vulnerable to night-time aerial predators, and these landscape features allow them secure cover flying in the shadows. Setting up bat houses along these features may improve the likelihood of occupancy (Chenger 2021d). Bat houses may be more effective if set within 10-30 meters (30-90 feet) of treelines, hedgerows or shelterbelts which may provide cover for flying bats from nighttime or early evening predators like owls or goshawks.
  Avoid building bat houses in open areas. If open landscape, install near vegetative connectivity (e.g., hedgerows, windbreaks/shelterbelts of trees in farmland) that connects to the nearby foraging/drinking areas.

3.8.2. Suitability for intended purpose (mitigation for loss of roost, general interest, education, integrated pest management, conservation initiatives).

- **Mitigation.** See section 3.9 below.
- **General interest.** Bat houses installed on private property by interested individuals should follow the best practices that apply to their site. Provide guidance to bat house owners for both long-term maintenance and stewardship (See **Section 5: Maintenance, Monitoring and Reporting Practices**). Bat house owners should be made aware of the best practices to build bat houses in urban or rural areas where colonies of building-roosting bats already exist but may lack a suitable number of appropriate roosts.
- **Education.** If bat houses are being used as a conservation talking point, ensure that they are in urban or easily accessed rural areas, and are visible with interpretive signage to further reach audiences. Well-situated bat houses with interpretive materials can provide an opportunity to learn about bats and their habitat requirements, an accessible location to watch bats and increase public participation and support for bat stewardship. Such an installation is an excellent starting point for a bat walk (events that often include equipping participants with hand-held bat detectors that provide the ability to hear bats echolocating). Participants can listen to bats echolocate as bats exit their roost, after which the group can walk to nearby sites with foraging bats. Before installing bat boxes for the purpose of public education, consider all of the information provided in this guidance document and in particular:
    - Use of multiple box sizes and designs, and varied installations in a small area, to maximize the likelihood of uptake by many bats.
    - Where possible, bat houses should be installed in suitable areas to maximize both educational value and benefits to bats, rather than focusing solely on education.
    - An interpretive sign should be installed. Consult a bat professional. Make sure information is accurate and eye-catching.
        - Signs last a long time. Take care to ensure contact information on the sign is also long duration.
    - Support the development and provision of promotional materials such as bat house interpretative trail maps/handouts and maintaining the trail and bat boxes.

    - Ensure that a plan is in place that outlines responsibility for long term care, maintenance, and monitoring of the boxes. Enlist volunteers to be stewards of the boxes, monitoring them for use by bats and inspection for maintenance issues (see **Section 5: Maintenance, Monitoring and Reporting Practices**).

- **Integrated pest management.** Bat houses installed at sites with the goal of integrating bats into a management program to consume insects (such as in agricultural settings).
    - Provide a variety of bat houses in various locations.
    - Follow suggestions for maintenance and monitoring (See Section 5).
    - Ensure that bats are not at risk from other aspects of the integrated pest management strategy (e.g., do not set up artificial roosting structures for predators such as owls or other raptors next to bat houses).
    - Provide and integrate natural habitat spaces (such as areas of native vegetation or older age class trees, wetland/pond) for bat roosting, drinking, and foraging in the managed landscape. Bats may consume pest insects but also require other insect prey throughout the active season.

- **Conservation Initiatives: Bat-friendly Communities and Municipalities**

  "Bat-friendly communities" are those that promote bat conservation in numerous ways, including installing bat houses in community spaces where appropriate. Bats may occupy community-owned buildings and public structures such as bridges or other anthropogenic features. Because these sites may be important roosting habitat for local bats, municipalities need to provide good conservation planning for bats. There are instances of municipalities installing bat house-type features on the underside of bridges for bat roosting (Caltrans 2016); other communities have managed buildings to safely house bat colonies (see https://bcbats.ca/get-involved/bat-friendly-communities/ for a successful, community-based program). These types of features may require additional best practices to ensure safety for bats is considered, especially as part of ongoing maintenance and repair activities that may be required.

  Communities can use bat houses in "bat-friendly" ways by:

    - Creating long-term plans for maintenance and care for any bat house structures installed in public spaces. These structures not only help with the conservation of local bat populations but can also provide talking points for engagement and education, and in some cases, form a major tourist attraction (e.g., bat condo - Pennisi et al. 2004; bats in attic – BEEPS n.d.).
    - Incorporating educational signage for conservation and safety.
    - Install appropriate barriers (e.g., natural fencing or other barriers) to reduce the amount of people who may wish to get too close the bat house(s).
    - Legislating bat-friendly policies for industries that routinely encounter bats in buildings or affect bat habitats (e.g., restrictions on timing of work activity to avoid impacts to active maternity colonies for pest/wildlife control professionals and roofers).

3.9. Appropriate Use of Bat Houses for Mitigation

There are a series of questions to answer prior to deciding to use bat houses for mitigation. These include:

- Will this bat species about to be evicted/excluded use bat houses?
- Is the location appropriate for bat house(s) – bat boxes, condo, or mini-condo?
- Are bat houses necessary or is there an abundance of good quality natural roosting opportunities?
- What is the size of the colony and what type of roost is being displaced?
- How many and what size of bat boxes, or what size of condo is appropriate?
- Will there be a bat house steward to ensure long-term maintenance of the bat houses?

Before installing a bat house, ensure it will provide a net benefit for bats by considering whether the planned location meets one or more of the following criteria (Alberta Community Bat Program 2018):

- Bat houses are installed to help manage bats in buildings, such as to mitigate the effects of a required exclusion (e.g., the original roosting structure is expected to be lost, demolished, or has been razed due to unexpected circumstance, such as a fire). Note that it is preferable to retain bats in buildings, separated from human space. Buildings provide a much larger range of microclimatic regimes, provide safe spaces for juvenile bats to practice flying, and are typically less susceptible to predation issues.

- Bat houses are intended to be used to compensate for roosting habitat that has been degraded and is unlikely to be restored, such as often occurs in urban areas with residential development and removal of trees, farmland, acreages, and industrial lands. Tree management in these areas typically involves the removal of trees just as they reach the stage of decay and defect that provides roosting crevices for bats.

- Bat houses are installed in conjunction with restoration of natural roosting habitat and will help bridge the time until tree roosting habitat becomes available.

- Bat houses are offered as an alternate roost structure to compensate for the loss of a bat roost in an anthropogenic feature like a bridge (due to planned repairs and/or demolition); for example, in California, bridge reconstruction projects have included the addition of artificial bat roost habitat built-in to the underside of the bridge decking at sites that were previously occupied by bats (Johnston et al. 2004).

If bat boxes are intended for educational purposes to raise interest in bat conservation, appropriate messaging must accompany the activity of building such boxes. One should clearly delineate with workshop participants that a single bat box should not be used to replace a lost building roost. Bat boxes created in bat box workshops (see Appendix Five A.5.3. Bat Box Building Workshops) could become a major feature in an urban nature park with an interpretative program or along a route used for a bat walk and talk for the public, for example, adding to roosting habitat already present in an urban setting. Participants building boxes should be encouraged to install boxes in clusters/arrays.

3.9.1. Decision Tree to Determine Appropriate Mitigation for Roosts

We have developed a decision tree (in the format of a dichotomous key) to help decide what type of bat house is appropriate for different mitigation situations. Although this guide is unlikely to meet all needs and will not cover all scenarios -- it can be used as a loose framework to assist your decision-making, recognizing that each scenario needs to be considered on its own merit, and may require seeking advice from a local bat expert. This guide pertains only to summer roosts and focuses on those most likely to be used by reproductive females.

All efforts should be made to keep an existing bat roost. However, if a roost is to be lost, the following key may be helpful in determining best actions.

1. a. The roost being lost is a building roost. **2**
   b. The roost being lost is not a building roost (i.e., it is a natural roost or a bat box). **4**

2. a. The building is used consistently by bats (Conclusion: bats are dependent on this structure). *Multiple Bat Boxes (or a bat box array) providing myriad of microclimates, or a Bat Condo, is recommended.*
   b. The building is used inconsistently by bats. **3**

3. a. The building is used mainly in the middle part of summer when young are being reared. *Multiple Bat Boxes (or a bat box array) providing myriad of microclimates, or a Bat Condo, is recommended.*
   b. The building is used mainly in early and/or late summer. **6**

4. a. The roost is a bat box. *Replacement of bat box is recommended.*
   b. The roost is a natural tree or rock crevice roost. **5**

5. a. This tree or rock crevice roost is used by a colony of a species with flexible roosting habitats (i.e., a species that is known to use bat boxes). *Replace a tree roost with at least one bat box, a bark mimic structure, or creation of a snag-type roost; planting trees can also be a compensatory action for recruiting future bat tree roosts. Rock crevice roosts may not be replaceable so these roost-types should be a high priority for protection (although concrete creations may be tried); large tree roosts are also invaluable, and efforts should be made to conserve and protect bat tree roosts wherever possible.*
   b. This tree or rock crevice roost is used by a species of bat that is not known to use bat boxes, or the species of bat is unknown. *Consider replacing with tree-type roost[1] (e.g., BrandenBark, create snag/wildlife tree with chainsaw cuts to create crevices/cavities for bat roosts). Rock crevice roosts may not be replaceable, these roost-types should be a high priority for protection (although concrete creations may be tried).*

6. a. Based on expert opinion or research, there is a large selection of natural roosts nearby that can be used by this species. *Bat houses not advised.*
   b. Based on expert opinion or research, there are no or few natural roosts nearby that can be used by this species to successfully raise young. *Bat houses are recommended, particularly those offering warm microclimates.*

Notes and further guidance pertaining to above key:

Consult Best Management Practices above, in particular 3.4. Suitable Capacity of Bat Houses to Accommodate Bat Colonies and 3.3. Thermal Suitability of Artificial Roost Structures for Bats. Also consult A.1.7.2. Current Bat House Design.

[1]Bark mimics can be used to create roosts for bats that roost in tree crevices – e.g., resin-roosts (Mering and Chambers 2012), BrandenBark (Adams et al. 2015). See A.1.8. Other types of artificial roosting habitat: bark mimics. Bats that use crevices and cavities in trees may use trees that are modified using chainsaw cuts to carve out hollows and crevices (e.g., wildlife tree/snag creation, Griffiths et al. 2018a, 2020a, Rueegger 2017). See A.1.8. Other types of artificial roosting habitat: bark mimics.

3.9.1. Inappropriate Use of Bat Houses

Protecting and retaining natural roost habitats, such as retention of old/mature trees and early decay snags, should always be the first choice for providing habitat to bats. When not enough trees of appropriate type and size remain in an area when a colony of bats is excluded/evicted, then bat houses should be considered. The goal is to meet the needs of a colony of bats over an entire reproductive season, and if there is not enough natural roosting habitat in an area, then mitigation is encouraged.

Outside of urban areas, bat houses should *not* be used as the *primary* means of maintaining roosting habitat for bats. This is most important in areas where the roosts being lost are natural (e.g., as a result of timber harvest, road development in a non-urban setting, etc.). Industries that have large scale, landscape level effects on forest cover, rock talus or other features used by bats should engage bat specialists to create habitat management plans that retain natural features of sufficient quality and quantity to support local bat populations without the necessity of deployment of artificial roost structures. In some cases, a natural roost feature can be used by bats for decades if not centuries, while in other cases, natural roosts may be more ephemeral, requiring that there be roost recruitment and a plan to ensure there are not only roosts currently, but well into the future. This is most important given the longevity of individual bats and the tendency for some roosts to be used generation after generation. There is no guarantee that any industry would be capable of supporting local bat populations through the provision of artificial structures over such a long timespan.

It is not yet understood whether, in areas that are not urban, bat houses may inadvertently change bat community dynamics such as species diversity, and this is one more reason that they should be avoided outside of human-dominated landscapes. In these cases, one should think 'outside the box' (Lausen et al. 2023). More research is needed to determine the impact of artificial structures on bat community structure to know to what, if any, extent bat houses should be used in areas where buildings do not already occur. If mitigation with human-developed roosts in non-urban landscapes is required, other types of structures should be considered (e.g., tree modifications, Griffiths et al. 2018a, 2020a; see A.1.8. Other types of artificial roosting habitat: bark mimics). In rural and urban areas these tree modifications should also be considered in combination with the provision of bat house(s).

3.10. Best Practices for Troubleshooting

Overcrowding and overheating. If bats are continually seen "bulging" out of the bottom of the bat house (e.g., Figure 26) or constantly found near the bottom of the box throughout the season, or if bats are found on the exterior of the bat box, it may be too hot (Flaquer et al. 2014). Overheating bats have also been seen flying during the daytime, either to cool off, look for water, or to look for an alternate roost site (e.g., Jung et al. 2013; S. Dulc, pers. obs.). Immediate solutions may include a temporary shade (see section 3.3. Thermal Suitability of Artificial Roost Structures for Bats). The longer-term solution should be to install one or more additional bat houses with cooler roosting options in the immediate area (see Best Management Practices above, including providing lighter coloured boxes and/or boxes installed in shade or with shading features like an awning or heat shield, e.g., Figure 15; see Appendix A.1.7.5. Heat Stress).

Poop problems. Guano will accumulate directly beneath bat boxes and even medium-sized colonies of 30-40 bats can produce a noticeable amount of guano. Avoid mounting bat houses directly over windows, doors, and walkways to avoid problems. Bat guano makes an excellent plant fertilizer, and a strategically placed planter may work to tidily capture guano deposits, though it may be better for the occasional pup that drops out of the box, to have a guano catcher instead. Bat guano and/or urine may stain certain paints on structures (Chenger 2021d), thus be strategic when choosing an installation site. Either install a guano-catcher or ensure that the features beneath the box can be periodically hosed down to minimize any staining. Similarly, avoid placing bat boxes near vehicle parking areas as the droppings may impact vehicle paints and finishes (Chenger 2021d). If the only location for a bat box is above a window, door, walkway, or patio, it is also possible to install a shield or deflection material to reduce the amount of urine that drops down on travelled surfaces.

Bird and parasite problems. An open bottom with multiple interior chambers may prevent guano accumulation, ectoparasites from building up, and bar non-target species. Chamber widths can be further adjusted to promote box occupancy by specific bat species. Three quarter inch (1.9 cm) chamber widths are desirable for most box roosting species such as Little Brown Myotis and Yuma Myotis, however, larger species, such as Big Brown Bat, may prefer roosting spaces up to 1 ½ inches (3.8 cm) wide (Tuttle et al. 2005). If other designs/opening sizes of bat boxes have been used, there may be issues with non-target species using the boxes (e.g., Aughney 2008). Installing bird boxes nearby may offset the issue of birds occupying and evicting bats from some types of bat houses (Meddings et al. 2011).

Woodpeckers may cause damage to bat houses, often by excavating holes though exterior surfaces in attempts to create a nesting cavity. Bird excavations can be repaired by simply installing a solid board or piece of thick metal overtop of the damaged area; if interior surfaces have been splintered, they should be sanded down to ensure bats are not injured by sharp surfaces. Installing bird houses relatively close to the bat house may also redirect bird nesting efforts.

Day-flying bats. Having a bat colony nearby means that you may see bats flying around your yard. Bats seen flying during daytime hours do not constitute a health hazard and does not necessarily mean the bat is unwell. Occasionally, bats might be seen flying during the day as a result of disturbance (e.g., burning leaves, loud lawn mowers or chainsaws, children, or the presence of predators such as cats), or on very hot days, individuals may need to take flight to seek drinking water (Jung et al. 2013), cool their bodies (Muise 2022), or switch roosts (S. Dulc, pers. obs.). Day-flying bats are also a more common occurrence in late summer or early fall when they can be seen swarming in preparation for mating, and may leave their roosts before dusk while temperatures are warmer and insect prey is still active (e.g., Rea and Huxter 2020).

Accessibility for maintenance. Avoid installing bat houses in locations that are difficult to access. Remember, maintenance (although perhaps minor) may be required annually.

3.11. Best Practices for Human Health and Safety

- *Rabies.* Two primary rules should be followed when you have a bat colony in a nearby structure or in your attic:
  1) ensure pets are rabies-vaccinated; and,
  2) ensure everyone knows not to touch bats (if a grounded bat needs assistance, ensure thick gloves are worn to move it and avoid bare skin contact: no touch = no risk).

    - **Grounded or day-flying bats.** People should be cautious when seeing a bat with what appears to be erratic flight, or if the bat is found on the ground. Avoid direct physical contact with what may appear to be a distressed or injured bat. Grounded bats or bats found in unusual or exposed roosts in late summer may be juveniles learning to fly and are not an issue, but standard rabies precautions apply (no touch = no risk). Young bats exhausted from first flights may cool off and become torpid and unable to fly. A safe strategy is to put the bat in a soft pillowcase (using heavy gloves, to avoid being bitten) and hanging the pillowcase in a tree in a position that gets late afternoon sun (this protects the bat until evening when it hopefully resumes flight after rewarming with some help of the solar heating). Be especially vigilant at this time to keep cats inside at night.

Bats cannot be held without permits. Bats do not make good pets because it is difficult to provide a balanced diet to support them (many die early deaths in captivity). Injured bats should be transferred to qualified wildlife rehabilitators or contact your local wildlife agency. Any bare skin contact with bats should be immediately followed up with local health authorities (rabies post-exposure vaccinations may be required, although rabies is rare in bats with typical rates estimated at less than 0.5% of the population contracting the disease annually, it is a fatal disease and potential exposure should be taken seriously and immediately; Lausen et al. 2022). Seek further advice from community bat program websites (See **Appendix Five : Citizen Science-based Bat Roost Monitoring Programs** for some links where you may find information about what to do if you have found a bat in your area).

- *Histoplasmosis***.** Histoplasmosis is a lung disease caused by the spores of *Histoplasma capsulatum*, a fungus that can grow in bird feces or bat guano/carcasses. It can be especially prevalent in very humid sites or climates (Benedict and Mody 2016, Diaz 2018). Histoplasmosis is much more common in eastern North America, especially in more southern areas but is quite rare in the great plains and further west. Guano supporting growth of the fungus becomes a hazard when the material dries out and becomes airborne in dust; spores from the fungus maybe become airborne if physically disturbed and may be inhaled and cause infection. Most people recover on their own after exposure and may not even be aware they were exposed. However, some individuals may experience more serious health consequences and may need to seek antifungal treatment. This disease is easily avoided by taking precautions, especially when working in dusty or dirty locations like attics or garages. Appropriate respiratory protection, gloves, and coveralls should be worn if disturbing the feces of any wild animal, especially in confined areas such as attics. Wetting an area prior to cleaning (e.g., by using a spray bottle containing a 10% bleach solution) will help reduce the amount of dust generated. Respiratory protection should include at least an N-100 (high-efficiency) respirator for protection from histoplasmosis.

3.12. Best Practices for Increasing Chance of Occupancy of Bat Houses

Little Brown Myotis, Yuma Myotis and Big Brown Bat use trees, and in some places rock crevices, as natural roosting sites in summer. Tree-cavity roosting bat species typically retain several primary tree roosts that they use repeatedly but may use more than 30 roosts over the course of the summer (either as small sub-groups of the main colony or the whole colony may move, (e.g., Olson and Barclay 2013). Radiotracking of bats has confirmed that sometimes in between foraging bouts they will spend short periods of time in roosts to which they have not yet been tracked, suggesting this may be a form of exploration of new roosts in their roosting range (C. Lausen, pers. obs.). It is during these explorations that bats may find a newly erected bat house, and while they may not necessarily use this new roost right away, it might be that this is their way of always knowing about alternate roosts available in their roost range should they need them. Research from Alberta on bat houses found that it can take up to five years for a bat house to become occupied by bats (Hiles 2019), however, bats that have been excluded or those that have lost their roost due to demolition or fire may immediately take up alternate roosts in the season following roost loss (Cory Olson, unpublished data). We are only beginning to understand how bats use bat houses and how they find them.

Although there have been suggestions over the years to place bat guano into newly created roosts as a way of potentially expediting occupancy, there is no evidence to date to show this is an effective method of attracting bats. In fact, an experiment conducted by Brown et al. (2020) investigating three species of bats, suggested roosts are not more likely to be detected when seeded with guano/urine. However, as long as the guano used is of the same colony that has been excluded, there is unlikely to be harm in trying this should one be willing to transfer guano from the old/lost roost to the new potential roost.

Urban bat populations may use human-built structures more often than natural ones because of lack of available roosts in old trees, and/or the opportunity to cluster in larger groups in a wide range of suitable microclimates; behaviourally, this may lead to populations favouring anthropogenic-type roosts such as buildings or bat houses. Following a bat exclusion from a building roost, or the loss of a building roost due to demolition or fire, bat houses may be more quickly occupied simply due to adjacency and potentially the lack of availability of local natural roost sites (Arias et al. 2020). Bats that use buildings seem to favour building roosts after exclusions (Brigham and Fenton 1986). Bats have a greater chance of becoming familiar with new bat houses if they are installed along known flight paths of bats emerging from roosts associated with exclusions; this may increase the possibility of future occupancy.

Ideally, bat houses should be installed in an area at the beginning of the summer prior to any bat exclusion work. This gives bats time to explore and find the new bat houses and allows bat houses made of new materials to weather and reduce odours that bats may find objectionable. If bat houses need to be relocated, try to plan for relocations during the winter when bats are not present. Try to avoid moving the bat house after the first summer of occupation as this may result in the colony abandoning the roost site; it may be that movements of a few hundred meters may be tolerated after occupation has been established, but more research is needed on this.

As is the case for human real estate trends, location is everything. A bat house located near good drinking water sources and/or foraging habitat is more likely to be favoured (regardless of mounting type) as roosts are often located close to these types of resources (Evelyn et al. 2004). Not all boxes will be occupied by maternity colonies, and it may take several years for occupancy to occur (Long et al. 2006).

Other actions you can take to try to attract bats, or have them discover the roosts you create:

- **If possible, choose sites near water.** Sites near water (500 meters or 1,500 feet) may be exceptionally attractive to bats (Chenger 2021d). After roosting in a hot summer day roost, the first thing most bats do is seek out drinking water and aquatic habitats may also provide a source of insect prey. Drinking water is particularly important for nursing females. Many bat species can fly quite long distances; roost sites for some species may occur several kilometres or more from water sources likely because more suitable roosts do not occur closer to their water source.
- **Enhance local habitat diversity.** Plant native vegetation that supports local insect populations. Retain a mixture of forest, shrubs, wetlands, and small clearings. Mosaics of habitat types may ensure a constant supply of insects over the summer as different insect species may be associated with different habitat types and hatch out at various times over the spring, summer and fall seasons. Keep trees (and plant trees!) as much as possible, such that they may eventually create natural crevice habitats, and can be useful for providing shaded roosts.
- **Protect and retain wetlands**. Marshes and ponds with healthy aquatic ecosystems that produce emergent aquatic insects will benefit bats.
- **Position roosts to take advantage of connectivity.** Treelines, lines of shrubs, shelterbelts/hedgerows, fence-lines, nature trails and connected forested spaces all may provide features that bats typically use when commuting between roosting and foraging sites. The presence of these features may help bats locate your artificial roost habitat, and particular features (e.g., treelines) may provide safety for bats as they commute to/from their roosts to foraging areas. Such strategic locations are often referred to as flyways (e.g., along movement corridors).

Section 4: Knowledge Gaps

Research on bat houses has been increasing in recent years, with many knowledge gaps remaining to fill. Most urgently needed is a better understanding of how well bat boxes and bat condos perform as mitigation structures. In particular: How often do bats successfully occupy replacement structures (e.g., bat boxes, bat condo) after a roost is lost (e.g., following exclusion or eviction, or destruction of a roost)? How long does occupancy typically take? Are there steps that can be taken to increase the likelihood of uptake? How well do the bats do in these new structures relative to their previous roost, and does this change over time? Additionally, how effective are supplemental roosting structures if they are installed *in addition* to existing roosts rather than replacing them? Well-designed and published studies that address these questions are needed.

In general, many questions surrounding bats in buildings and mitigation structures remain unanswered, including the non-exhaustive lists in the following sections.

4.1. Bat House Efficacy/Use and Knowledge Gaps

- What aspect(s) of bat health/fitness should be measured to evaluate bat houses?
- What should it be compared to – bats in buildings, natural roosts, and/or among bat houses?
- How does use of bat boxes differ from use of natural roosts? Do bats fare differently (e.g., in terms of reproductive success, or health)
    - Do some bat house designs result in higher rates of reproductive success?

- Why do some species use bat boxes and other human-built structures in some areas of their range and not others? (e.g., Northern Myotis, Pallid Bat)
- Why does it take so long for many bat houses (boxes and condos) to be used by bats?
    - Would occupancy by bats be expedited if it were to be constructed out of old wood, or wood from their old roost? (And/or does it depend on other roosting options in the area?)
    - Is there a design feature/placement that would make bat houses easier for bats to find and lead to regular use?
- How will climate change (i.e., less stable spring/summer/fall temperatures, more extreme temperatures, extreme weather events, drought etc.) affect bats living in bat houses?
    - Can we recognize vulnerable roosts/roosting areas that may need interventions such as increased number of bat boxes from which to choose? What are the signs?
- Do bats that use human-built structures accumulate a higher load of ectoparasites?
    - If so, does this impact bat health?
    - If so, what steps can be taken to reduce this issue?
    - Is there something that can be done?
- How can we best determine when it is necessary to replace a roost?
    - How do we identify a "biologically important roost" (Neubaum et al. 2017) for species in a given context?

4.2. Bat House Placement/Mounting Knowledge Gaps

- Boxes mounted on trees (Boyd and Stebbings 1989), buildings (White 2004, Long et al. 2006), and poles (Flaquer et al. 2006) have all reported successful occupancy by bats, although whether different species or reproductive stages might use these structures differently, and how this might equate to differential reproductive success, has yet to be studied.
- Are bridges good places to mount bat boxes? Where? Under what circumstances? Boxes on outside to receive solar, or under out of the sun?
- What is a maximum (or optimal range of) distance(s) between boxes for the various species and under varying contexts?
    - Can we apply what we know about distances between natural roosts, and does that indicate what additional research needs to be done?
    - How does flight distance to a nearest refuge make a difference to lethal vs non-lethal overheating events?
    - Is this dependent on stage of reproduction? Landscape features in area (e.g., trees or shelter belt to offer some level of cover for day flights)?
    - What is a maximum distance between roosts that is likely to allow overheating bats to seek refuge?
    - What type of configuration is most likely to result in bats shifting between bat boxes to avoid heat stress? (e.g., tube between boxes, fully connected boxes, adjacent boxes on a wall?)

- Are there certain practices that may increase the likelihood of occupancy of replacement roost structures? E.g., building and installing bat boxes prior to eviction? Using wood from the old roost structure (even just the landing platform)?

- Is there more concern for disturbance at a bat box in its first summer of occupancy? Can the box be moved, and if so, how gradually would this need to occur (e.g., movements of a few hundred meters over the winter, in the active season, or more gradually over the active season?)

4.3. Bat House Construction/Design Knowledge Gaps

- What alternate materials should or could be used for building bat boxes in some areas or contexts?
- Is there a concern with plywood, cedar, or other materials off-gassing?
    - Do these chemicals represent any health hazard to bats, and if so, how?
        - If bats are given no choice but to roost on new plywood or particle board (relatively fresh adhesive chemicals), are any ill effects observed (e.g., hair loss)?
    - And if so, how long does it take for the material to be suitable (desirable/healthy)?
- Are there styles/designs of bat boxes that should be promoted in certain areas? Materials (e.g., woodcrete)?
- Although a few designs ("blue-prints") of bat condos and mini-condos circulate, there are few to choose from and none that are particularly well-vetted. Building plans for most condos that have been successful are either not available as the design is custom, or not circulating as the plan/custom-install is commercially sold.
    - Further construction of varies types of condos and mini condos is urgently needed, with publications that describe the designs and level of success in relation to different contexts and species. This could be a long-term and expensive study, which could require several collaborators.
    - Once vetted, having condo/mini-condo blueprints widely available would benefit everyone who is able to build bigger structures than bat boxes, such as local governments, industries, organizations, municipalities, communities, etc.
- What are the conditions under which bats overheat, succumbing to heat stress? i.e., why do they not move roosts before the temperature becomes lethal?
    - Why do some boxes result in lethal events and not others, despite similar exposure to heat events?
    - Is there a certain stage of reproduction/age that makes bats more or less susceptible to mass mortality events in overheating events?
    - How does relative humidity contribute to overheating (heat stress index) and how does this relate to bat box occupancy/overcrowding?
- Do all bat houses increase potential of predation? How does this compare among primary roosts (i.e., core building or bat boxes used on a regular basis)?
    - What modifications or add-ons can be used to decrease predation risk? (e.g., do bird spikes effectively reduce predation risk at bat boxes?)
- Much recent research has focussed on temperature differences among bat box designs, but few actually compare boxes occupied by bats. How do occupied boxes differ from unoccupied boxes -- if bats modify their own environmental temperature and humidity, how can one best contrast suitability of box designs using unoccupied boxes?

- What method of monitoring internal microclimates is best? Some dataloggers produce ultrasound, but it is not clear if just putting a sensor end inside is better than putting an entire logger in the box. Should the sensor be put in through a drilled hole or from the bottom using something like a dowel? (e.g., there are anecdotal reports of pups becoming entangled in sensor cables wrapped around a dowel).

4.4. Bat Ecology/Physiology Knowledge Gaps

There are significant gaps in our knowledge of roosting ecology for many of North America's bat species, particularly for species that have had few natural roosts documented. These knowledge gaps can impact the effectiveness of even well-intentioned conservation and mitigation efforts, such as the installation of bat boxes (Rueegger *et al.*, 2019).

- More research, aided by recent technologies and methods, into the roosting ecology of temperate species in anthropogenic structures (buildings or bat boxes) is warranted to address gaps.
- What cues or characteristics are used by bats to identify and select roosts?
    - Despite a growing body of research on roost characteristics and selection, our understanding of the species-specific cues and mechanisms that drive selection of a particular roost is limited for both natural structures (Kunz and Lumsden 2003) and anthropogenic roosts such as bat boxes (Mering and Chambers 2014; Rueegger 2019). While patterns and roosting preferences can be distinguished in natural landscapes (e.g., Evelyn et al. 2004; Kalcounis-Rüppell et al. 2005) and in anthropogenic structures (e.g., Hoeh et al. 2018), predicting or encouraging use of a particular structure as a roost often has limited success (e.g., Rueegger et al. 2019), evidence that further research is needed.
- There are mixed reports regarding whether the installation and occupancy of bat boxes by large colonies of one or two species change bat assemblages or species communities (including other species like avian predators)? Does this differ in urban versus natural contexts?
- Are there species-specific sensitivities to climate change that need to be considered when provisioning artificial roosts? (e.g., Townsend's Big-eared Bat selects cooler roosts than most other bats.)
- What are the species-specific maximum temperature thresholds?
    - Does this vary with latitude, altitude, ecoregion, or other factors?
    - Are there differences in behavioural strategies among species or geographic locations that affect heat tolerance?
    - Are there factors that may increase or decrease tolerance of bats to heat? e.g., health factors such as underlying viral or ectoparasite loads? e.g., environmental factors such as humidity of environment?
- Examination of relationship between roost microclimates and reproductive success of bats that use artificial and natural structures (e.g., building attic vs building roof vs bat boxes vs bat condo, etc.).
    - How do bats that use a mixed suite of roosts (e.g., bat boxes, buildings, or under roofing material such as tin) fare compared to bats that make use of mainly one roost type (e.g., building attic, or an array of bat boxes)?

- Are there certain features of some artificial roosts that can be identified as detrimental?
    - e.g., do bats roosting under tin roofing material run the risk of burns (e.g., Lausen 2022a, p. 18 "nubby ear mystery")? (could/should bats be deterred from roosting under metal as it may be an ecological trap?)
    - Do certain artificial roosts facilitate spread of WNS? (e.g., under bridges) If so, what, if anything, should be done?
    - We know that bats can tolerate conditions that humans cannot (e.g., hibernating in sulphuric air in thermal-heated cave, G. Horne and D. Critchley, pers. comm., BatCaver.org), but to what extent are bats roosting in some types of human-built structures experiencing higher risks than in other structures?
        - Bats day-roosting under bridges – are they impacted by transportation maintenance activities like cleaning of bridges, re-surfacing, weed spraying?
        - Do bats roosting under busy bridges experience higher levels of stress?
        - Do bats use creosote bridges?
        - Bats roosting in attics of old buildings that may still contain asbestos?

- Is social structure of bat colonies changed with roost structure? (e.g., when a large colony is evicted from an attic that has been a primary roost, to use a network of bat boxes that cannot hold the entire colony at one time)

4.5. Organizational Gaps

Some bat species are synanthropic, (i.e., they are found using human infrastructure across North America), and as urbanization and land conversion continues, this undoubtedly will increase, and in fact, more species may become dependent on human-built structures over time as more species possibly adapt out of necessity (e.g., Northern Myotis using bat boxes at Indianapolis International Airport, Whitaker et al. 2006). There will increasingly be a need to educate and assist the public to ensure bat conservation. *More local 'community bat programs', whether state/provincial/territory led or private, will be needed.* These may be grassroots, or initiated by agencies, and may depend on governments or organizations. Encouragement and networking of citizen scientists are likely to leverage efforts of locating roosts, monitoring roosts and effective roost stewardship.

There is currently a surge of uptake for deploying bat boxes by the general public, but in most cases these boxes are not being tracked by anyone. Keeping a database of bat house locations, and engaging networks of volunteers to monitor and report numbers of bats from these structures into a central data repository, can be extremely informative for tracking population trends of some species. In the US there is the North American Bat Monitoring program (nabatmonitoring.org) which is soliciting these types of data and tracking trends; in Canada the Neighborhood Bat Watch (batwatch.ca) is a national repository for these types of data, but this program suffers from lack of financial support, buy-in from all provinces, and capacity to actively manage the program and data as it is does not sit within a national government framework.

As long as data remain uncollected, or collected in scattered databases, little learning can occur and regional, provincial/territorial/state, national and continental-scale understanding of bat conservation is hampered. Sometimes the issue with data on bat roosts being shared is that it is considered sensitive information and/or landowners have not provided consent to share information. The North American

Bat Monitoring program has made this process easier by facilitating sharing of location information only at the level of the grid cell (or quadrant) level (i.e., roost location is submitted only as the grid cell number and where possible, the quadrant). Each grid cell is 10 km x 10 km bisected into 4 quadrants (Loeb et al. 2015) and having the exact location of a roost within a grid cell or quadrant is not needed for NABat analyses (i.e., location can be buffered within cell), and thus circumvents any issues of roost location / landowner sensitivity. It is recommended that organizations collecting location and/or monitoring information about roosts, ask the submitter to fill in a consent form or agree to a list of terms, when they submit information.

Sales of bat houses are becoming more common and widespread. This includes custom-installs of bat condos and mini-condos. And while there are a few bat condo and mini-condo plans, they have yet to be thoroughly vetted. Once there are a few successful designs published, these plans should be made widely available through community bat type programs, or bat-friendly portals on government websites, etc.

Similarly, although there are many newly emerging companies that sell bat boxes, there are relatively few standard 'blueprints' available. There are plans for the standard 4-chamber maternity box (BCI design) that can be found in resources such as BCI's Bat House Builder's Handbook (e.g., https://batweek.org/wp-content/uploads/2018/01/BHBuildersHdbk13_Online.pdf). Beyond this, the public is left to 'buy at their own risk' not knowing what box designs have been vetted and proven safe and effective for what species and where. In some cases, major shopping chains are offering bat boxes, and yet these boxes are not necessarily effective or safe for bats. There is a growing need for some sort of formal vetting process that would facilitate at minimum some basic level of standards for bat boxes and designs made available to the public. Similar to how rules are now in place for not feeding wildlife, it may be time for at least well communicated guidance so that the public does not inadvertently harm bats.

4.6 Monitoring Methodology Gaps

Protocols are evolving for how to monitor maternity colonies at bat houses and yet many gaps remain, including:

- How can one estimate species-specific colony sizes at mixed species roosts?
    - There is research now being conducted by British Columbia Government in partnership with Wildlife Conservation Society Canada to establish a protocol that will allow Yuma and Little Brown Myotis to be monitored separately – it is recommended that due to the current conservation status difference between these species, that they be monitored separately. The goal is to establish a relatively inexpensive method of estimating each species using a combination of techniques such as acoustics and emergence counts. Genetics techniques are being used to validate a proposed protocol.
- What is the best protocol for monitoring the size of a colony? (e.g., a combo of tools including laser break-beam, infrared video, PIT tags, emergence counts, radiotelemetry, etc.).

Section 5: Maintenance, Monitoring and Reporting Practices

Providing effective artificial roosting habitat is a long-term commitment. Bat houses (condo and boxes) will need some level of maintenance and should be examined annually at minimum. It is important to identify bat house stewards and provide them with the knowledge and information needed to maintain and monitor these artificial bat roosts. As natural roost options disappear, and bats become dependent on human-built structures, the disappearance of a primary roost structure may have catastrophic outcomes for hundreds or thousands of these long-lived mammals. Similarly, as the structure degrades, these highly philopatric individuals may continue to use sub-optimal roosts, which may compromise reproductive success. A limited number of roost options may be to blame. While it is not always possible to know what other roosts may exist in an area for a colony, it is within ones' control to upkeep structures being used by bats, especially if the structure is used by a large number of bats for a significant portion of the reproductive season.

5.1. Maintenance

Bat Roost Inspection Schedule. To ensure the functionality and performance of all types of bat houses, regular and frequent inspections are the foundation of a maintenance program.

- A suggested inspection schedule includes:
  - Conducting a major inspection of the structure/roost early in the spring prior to the earliest known arrival of bats, such as late February or early March. Of particular importance is the overall condition and stability of the structure.
  - Conduct monthly checks of structures during the peak season of use (e.g., from April until August), which can be combined with bat guano collection tray cleaning and checks for bat occupancy or as part of a bat count program. Occupancy can be checked by exit counts in the evenings. Avoid frequent lighting of colonies with a flashlight to count roosting bats.
  - Conduct an inspection and preparation/cleaning of the structure after the bats have left for the season. In some areas, cleaning out large accumulations of guano prior to winter, may make it more difficult for ectoparasites to find places to take shelter from extreme cold in winter, and this could reduce the load of parasites in a roost.

Maintenance activities that are needed (work should occur outside of the period when the bat house is used by bats):

- **Scrape out wasp/hornet nests**. Paper wasps form grey papery nests on the interior ceilings of bat houses; they are not aggressive and can coexist with bats. These nests can get quite large and cause a problem if they take up large amounts of space inside the bat house. Wasp nests should be removed in winter; use a long rod or stick to clean out the wasp nest but check carefully for bats prior to maintenance. Yellow jackets and Bald-faced Hornets build conical nests that can get quite large. These are aggressive insects that may cause bats to abandon a bat house. It is important to destroy these nests before they get established; try knocking them out during cold evenings (but be aware that solitary bats can be hidden in dark or shadowed corners inside the seemingly empty bat house and take care to avoid being stung [Chenger 2021c]).
- **Scrape out any large guano accumulations.** Current bat house designs usually have open bottoms and guano tends to drop out of the box and onto the ground directly below the box. Bat guano will naturally biodegrade, and can be left on the ground below the box; however,

it is excellent fertilizer, and one may choose to scoop it and spread it on flowering plants and shrubs to support plant growth (in small doses – a little goes a long ways!). Be sure not to transport bat guano out of the immediate area to prevent the potential spread of white-nose syndrome (see 2.2. Population Recovery from Losses due to White-nose Syndrome).

- **Re-caulk joints and repair roofs if needed.** Loosened boards can be fixed by tightening wood screws or adding more screws; fresh caulking can be used to fill seams. Inspection of bat house seams can be conducted by simply looking into the bat house interior and look for daylight entering around the roof or along the wall seams (although light may also enter the box through any vents that are part of the bat house design).
- **Refinish the exterior of the bat house.** Wooden-exterior bat houses should be resealed and repainted every 3 years or so to extend the life of the box. Conduct the refinishing in the autumn after bats have left so that any odours have dissipated by the time bats return to occupy the bat house in the following spring. Interior of the box should be left unfinished. Ensure that paint, stain, or sealants are low odour-emitting materials (very odorous materials may repel bats from roosting).
- **Interior roosting panels.** Inspect the interior panels for warping; over time, plywood can warp with exposure to weather or damp conditions. Bats may continue to use the bat house, but severe warping may limit bat use in some cases and the bat house may require removal and replacement of boards to effectively repair it. Installing wood spacers strategically in the baffle chambers may help prevent warping.
- **Screen that has deteriorated or detached from interior roosting panels.** If the bat box you have purchased includes screen it can shred over time and detach (which can trap both guano and baby bats; this is why mesh screening in bat boxes is not recommended). It may be possible to remove the screening and then roughen the internal roost panels (to help roosting bats gain footholds); however, it might be simpler to replace the box with a more appropriate design that does not include screen material but has rough internal surfaces instead.
- **Woodpeckers/flickers.** These birds have sometimes been observed drumming on bat houses. The damage can be repaired by patching or by filling holes when bats are not present (Chenger 2021c) – birds have been known to re-peck holes through wooden patches, so patching with some metal sheeting may be necessary.

5.2. Monitoring

Many occupancy studies record presence or absence of bats infrequently, checking boxes on a monthly basis, or sometimes once per season (e.g., Boyd and Stebbings 1989, Lesiński et al. 2009, Chytil 2014). Few studies record occupancy on a daily or weekly basis (e.g., Ritzi et al. 2005). Timing of occupancy checks can cause skews in data. If boxes are not checked throughout the season, accurate usage patterns may not be reflected. Occupancy is commonly confirmed by visual inspection (i.e., shining a light up into the box), counting individuals upon emergence at sunset, or by presence of guano under the box. Other methods, such as the use of acoustic roostloggers (e.g., Titley Scientific, Missouri)PIT (passive integrated transponder) tagging (e.g., Biomark, Idaho), and physical capture (using mistnets or harp traps; BC MLWRS 2022) may be appropriate at sites that are being used for research or ongoing monitoring for conservation purposes.

5.2.1. Guano collection

Guano-catchers for monitoring and research.

A collection tray below bat boxes can be used as a simple means to monitor bat box occupancy (Figure 22). Presence of bat guano is a good indication that your bat house is occupied. Bat guano can be analyzed to determine bat species, to monitor for the presence of *Pseudogymnoascus destructans* (the causative agent of white-nose syndrome) and for research-type questions such as examination of diet (DNA metabarcoding of insect bits making up bat guano). Pollutants such as various types of pesticides may also be extracted from bat guano under bat houses, and viral loads may be collected and studied using fresh guano (Joffrin et al. 2022) which may provide multiple insights into bat ecology and health.

Guano trays may catch distressed, injured, or dead bats rather than having them drop to the ground. This makes retrieval easier and reduces safety concerns for pets that may encounter a bat carcass on the ground. This elevated flat surface may also increase the chance that a female might rescue her fallen pup, rather than having the pup land among vegetation below. Guano-collecting trays can also be used to reduce the amount of guano falling on the ground or on building surfaces such at patio decks in a situation where a bat house is mounted on a building. For bat roosts in public areas, such as parks, guano trays reduce the possibility of people, particularly children, from coming in contact with guano on the ground around bat roosts. In most cases guano trays are elevated above the typical reach of a human, and thus require a step or short ladder to access. Homeowners may find a guano tray useful for easily collecting guano to both contain it and enable easy disposal/use in their garden as fertilizer material.

Best practices for monitoring using guano traps:

- Install a guano catcher directly beneath the bat house several metres (~6 feet) below the box opening. This ensures that the tray is not in the way of bats entering/exiting the roost, but not on the ground easily accessible to humans or other animals. However, in some cases, the guano collector may need to be installed on the ground (e.g., below a bat box that is mounted on a building). Guano trays are typically placed well above the ground to prevent animals from potentially licking or eating the guano (e.g., ungulates, cows), or preying on any pups that might fall from the bat box onto the catchment.
- Design the guano traps such that they are flat and do not prevent a bat from taking flight out of them. If a pup were to fall onto the guano catching tray, the mother should be able to land and rescue it. She will need to take flight from the edge of the tray by dropping into the air, or could climb the pole back up to the roost if that pole is rough wood.
- Do not use containers like buckets with smooth sides to catch guano. Bats falling into this type of container will become entrapped and unable to climb up the slippery surfaces and will be unable to fly directly out of the container.
- Avoid using anything that will retain water. Pups falling out of the bat house may fall into the pooled water below the roost which could result in it drowning.
- Use porous material to catch the guano. Examples are:
    - Window screening attached to a wooden frame (Figure 22).
    - Plastic lid with holes for drainage. Lids can be sliced to allow it to wrap around the pole where the bat house is installed.
    - Use light coloured surfaces to make the guano more visible.

- If it is a bat box mounted on a building, placing some light-coloured plastic on the ground beneath that bat box (guano may also be visible on the wall surface below the bat house).
- Bat guano can be used for research purposes (determine bat species, examine diet, test for pesticides). In some cases, it is important that the guano is freshly collected within hours of deposition (e.g., quantifying/describing virus loads, hormone content), and collection in special storage solution (e.g., RNALater). Increasingly, more research is being done using guano, including surveillance for spores of *Pd*, the fungus that causes white-nose syndrome.
    - If the goal is to collect guano for genetic analysis to determine the species of bat, then one should keep the guano from floating in water which would wash intestinal cells off the surface of the guano pellets (DNA in these cells is needed to identify species of bat). Keep guano pellets dry to prevent breakdown due to microbial/enzymatic processes. Guano pellets are best stored dry at room temperature (e.g., in a paper envelope), but for long term storage (years) they should be frozen. Do not store guano long term in a cooler or fridge as it will degrade in the moist conditions.
    - Not all bat species are easily identified using genetic analysis (Walker et al. 2019) and it depends on the lab that you send to as to what species they can differentiate (depending on what genetic markers they use [e.g., mitochondrial loci like cytochrome b versus nuclear markers], and processes they employ [e.g., sequencing, metabarcoding, length polymorphisms]).
- The relative amount of guano accumulating below a roost can be indicative of the general size of the colony – e.g., daily examinations of guano can reveal whether there are few or many bats roosting in a bat box.
- Guano catchers may need to be cleaned off periodically. Frequency will depend on the goal of the collection (e.g., clean off daily if the goal is to determine occupancy on a daily basis; clean off each season if the goal is to determine annual use).

A.

B.

C.

Figure 22. A guano trap is generally a screen at the base of poles or trees. Mesh window screening works well to catch guano under bat roosts. Mesh allows water to pass through and leave the pellet intact for genetic analysis (bat species identification) if desired. Guano collection trays are useful for monitoring occupancy. Guano trays should be flat and never a container to prevent bats that may fall from the roost from becoming entrapped. These are made of screening, so that the guano trap does not fill with rainwater and thus not become a drowning hazard for bats. Adult females can also theoretically land on the screening to rescue dropped pup. A guano pellet (inset shown on window screen material) looks similar to mouse feces but crumbles easily when crushed with the consistency of a rough powder (composed of bits of insect carapace and moth scales). Photo in B also shows an Anabat Roostlogger (Titley Scientific) above the guano trap facing upwards to acoustically record bats gathering at the bat box entrance, or flying in/out. Note: the large pole in A is wrapped in metal to discourage terrestrial predators. Photos by D. Quamme (A), H. Gates (B and C).

5.2.2. Acoustic Recording

Acoustic recording units (ARUs) or bat detectors, allow one to listen to the high frequency bat echolocation calls that bats use for navigation and finding prey. Most modern bat detectors also allow you to record the sounds to examine later with computer software. At roosts, bats often emit a variety of call types including social calls, which are sounds that are not used for navigating in the dark or finding prey, but instead are thought to be for communication (e.g., Gadziola et al. 2012 – Big Brown bat vocalizations). Typically, species identification is made through the use of echolocation recordings of search phase calls emitted by bats while in flight navigating in the dark in search of prey. Many species can be differentiated using echolocation calls (see Lausen et al. 2022 for acoustic guide to 18 North American species). Social calls may not be useful for identifying bat species, although as more research is conducted, some types of species-specific social calls are being discovered (e.g., Gadziola et al. 2012, Bohn and Gillam 2018, Lausen et al. 2022, silver-haired bat chapter).

Bat detectors come in many different forms, but many are not well-suited to record inside a roost, or even at its entrance because they are designed to detect bats many metres away (up to 100 m depending on bat species and detector settings; see Fraser et al. 2020 for a comprehensive bat acoustics guide). A simple effective detector that can record in or at a roost on internal batteries for months (or even years depending on how you program it), is an Anabat RoostLogger (Titley Scientific, Columbia, Missouri). Roostloggers, which can be deployed near the roost and left for the entire bat season (or even a year or longer if programmed accordingly), run on 4 internal D batteries, are waterproof, and the standard model records bats from 0 - ~8 m away (microphone is directional so it can be aimed at the roost entrance). In Alberta and British Columbia, these units are regularly used mounted just below bat boxes to determine occupancy, which can be extremely informative when paired with microclimate data to assess overheating risk (C. Olson, S. Dulc, pers. obs.); Anabat roostloggers can also be used to record within attic roosts to establish patterns of roost use (e.g., large attic colony of Yuma and Little Brown Myotis, Peachland, BC - BEEPS n.d.).

Monitoring using acoustic recordings can provide information about occupancy (bats being present in a box), and in some cases, the acoustics may allow you to identify the occupants to species (Lausen et al. 2022). If one wishes to record only bats that are emerging from a roost (and not bats that are flying distant to the roost entrance), it is recommended a zero-crossing detector of low sensitivity be used (e.g., Roostlogger as described above) – full spectrum recordings are generally not recommended as even on their lowest gain, most full spectrum detectors will clip as bats echolocate too closely to the microphone (C. Lausen, pers. obs.).

Acoustic monitoring does not indicate the number of bats in a roost, so if a colony count is desired, bats must be counted as they emerge from the roost (**Appendix Five : Citizen Science-based Bat Roost Monitoring Programs**,) or bats can be video-recorded and then counted). If one were to record bats and count them over for long periods of time, it may be possible to use acoustics data to gauge trends in colony size over time -- this method has yet to be tested and may prove useful for large-scale monitoring programs like North American Bat Monitoring Program (www.nabatmonitoring.org) to track changes to bat populations as a way of monitoring broad-scale threats to bats across the continent.

5.2.3. Counting Bats

Techniques that can be employed to determine occupancy include using an acoustic Roost Logger (see **Glossary**) under the box (Dulc. S. pers. comm.) or using infrared cameras to count individuals upon emergence (Kerth et al. 2001, Bartonicka and Rehak 2007). Bat capture at boxes (using mist nets or harp-traps) can be used to confirm species and study morphometrics, health, reproductive rates, and more; however, researchers do not commonly employ this technique as a way of counting bats due to the invasive and time-consuming nature of this method.

5.2.3.1. Visual counts

Bat roosts can be monitored to determine dates of use, and numbers of bats. The best way to gauge the number of bats in the box at any one time is to count the bats emerging at dusk.

- Roost emergence counts
  - If there are multiple exits to the roost, multiple observers should be in place to count bats at emergence. Ideally there would be two per exit so that each exit count is estimated by more than one person.
  - Set up 15-30 minutes before local sunset time so that movement and talking can be completed prior to the emergence of bats, which, in summer months, usually occurs approximately 15-30 minutes after sunset in most areas.
  - Choose a spot to watch the exit point such that the exiting bats will be backlit with either the sky or a light-coloured background (to make it easier to see the silhouettes of bats as they drop from the roost opening).
  - Choose counting nights that are calm and warm with no rain.
  - Watch for at least 60 minutes or until no bat has been seen exiting for at least 15 minutes.
  - Use a hand counter (manual clicker or smart phone app) to keep track of exiting bats (watch for bats that make return flights to the box and try not to double-count – 2 hand counters can be useful to add on one and subtract on the other, combining them at the end of the count).

- Where applicable, observing bats directly during the daytime roost period.
  - Bat Houses
    - Stand under the bat condo (if open chambers can be viewed from below) or box during the daytime and illuminate the interior using a powerful spotlight to view any roosting bats.
      - This should be done infrequently as to minimize disturbance, especially throughout the first season of occupation when bats are not as familiar with their new roost.
      - The duration of time spent illuminating the box should be quick (a couple of minutes at the very most) – if there are a lot of bats to count, a photo might be taken, and a count done later using the photo.
      - If there are many bats and/or the bats exit from a single access point, bats may be video recorded, and numbers can be counted post-exit from video analysis. Use of infrared, and/or thermal imaging may be beneficial in helping to discriminate between individuals to get an accurate count.

        - Conduct observations during the period of use, note dates and expected types of activities at the roost (e.g., pregnant bats, young pups present, pups preparing for volancy, etc.).
    - Building roosts
        - If entering the roost is possible, wear appropriate protective gear (masks, gloves, clothing that can be cleaned).
        - Using a red filter on lights can be less disruptive to roosting bats.
        - Make the visit brief.
        - Use low voices and be as quiet as possible.
        - Make notes and observations of the visit.
        - Follow decontamination procedures for white-nose syndrome.
        - Observe safe practices to prevent spread of COVID19.

5.2.3.2. Counting bats using PIT tags

A passive integrated transponder (PIT) can be used by either gluing the small rice-sized tag onto a bat (temporary monitoring) or implanting it under the skin. PIT-tagging is increasingly being used to monitor bats effectively as it provides a way to passively document presence of a bat repeatedly over the long term. Antennae are set up around a roost opening in such a way as to have the bat pass by the antennae (van Harten et al. 2019), allowing the tag to be scanned much like the scanning of a barcode of an item in a grocery store. The unique barcode of each tag is recorded based on parameters programmed into the PIT tag reader. There are some challenges to this system, including the ability to only scan one tag at a time, therefore if multiple bats pass by the antennae at the same time, only one may be recorded. Although a few different brands of PIT tags have been used, and different systems were needed to read them, many of these issues have been overcome with some readers that will read multiple brands of tags.

5.2.3.3. Laserbeams and Light for Counting bats -- Infrared, Night Vision, Thermal Imaging and Break-Beam Counters

The infrared spectrum of light is that which exists out of the visual spectrum of humans and bats and is associated with heat. Passive infrared sensor technology is found on things like game cameras to trigger pictures or video when a warm animal passes by the camera within range of its sensor. Cameras that have IR flash (active IR) means they can then project infrared (or near infrared) light out in front of the camera and the reflected light comes back to the camera to allow image capture in the dark. IR technology can be useful for counting bats if a video camera is placed outside a roost to record bats emerging in low light conditions.

Night vision works by increasing the sensitivity of a camera to low levels of light – these can be goggles or cameras and as long as there is even a low level of ambient light, they can be extremely helpful to see and/or record bats during emergence from a roost. Night vision scopes can be monocular or have 2 eye pieces and can allow bat emergence counts to continue long past sunset in dark enough conditions that bats would otherwise not be visible to the naked eye.

Thermal Imaging cameras passively record long wave infrared light that is given off as heat. Such cameras can estimate temperature and objects are seen based on their differential temperatures. If a bat is cold (e.g., in deep torpor), it may not be different in temperature from its surroundings and would thus not appear as an object in a thermal image camera. Affordable smartphone-operated thermal devices now allow even citizens to watch and record bats emerging from roosts in complete darkness. The cooler the night and the warmer the bat, the better the contrast and thus the thermal image. For an example of use of these IR and thermal imaging technologies with bats, see Darras et al. (2021).

Simple counting devices can make use of a laser beam, with the breaking of that beam causing a 'count'. If bats fly through a laser beam, the beam cannot reach its receiver, and this break causes a count. These have been used at bat box entrances to count bats as they emerge (e.g., Jason Rae, Wildlife Conservation Society Canada, unpublished data; Shahroukh Mistry, California State University Butte College, unpublished data). Challenges with this approach is that if more than one bat breaks the laser beam, it is only counted as one bat, and if something else were to break the beam, it might also be counted (e.g., wasp).

5.2.4. Monitoring roost microclimates

Interior bat house conditions can be monitored using small devices that passively record both temperatures and relative humidity over extended periods of time. There is a wide range of loggers that will record microclimates – some small logger-tags are affordable and easy to install. This information may provide important insight on whether a bat house is suitable in its current position and gives insight into roosting preferences of bats if the bat behaviour and occupancy is also monitored.

5.3. Reporting

There are a growing number of organizations that are collecting roost occupancy data and monitoring bat numbers at roosts. Throughout Canada and the USA, non-profit organizations, provincial/territorial and state-run programs (often in coordination with university research) have targeted citizen or community science initiatives to monitor bats and their use of bat houses. A list of the currently active programs is available in **Appendix Five: Citizen Science-based Bat Roost Monitoring Programs**. General best practice for reporting data should involve an initial consult with provincial/territorial or state wildlife officials to determine if there is an organized data capture program and to determine what kinds of information are being collected and what can be contributed.

These programs function as a repository for these types of records across the country, but some provinces and states have individual community bat programs that have organized monitoring programs that track bat roost locations and counts. The North American Bat Monitoring Program is soliciting roost location data (buffered locations) and colony counts to help inform modelling of trends in diversity and relative abundance of bats across US and Canada as unprecedented cumulative threats continue to impact bat populations.

5.2.4. Community Bat Programs and the Power of Citizen or Community Science

Community bat programs are emerging across North America, and many will have forms or online reporting opportunities to submit data on monitoring of roosts (see **Appendix Five : Citizen Science-based Bat Roost Monitoring Programs**). Community bat programs that recruit citizen scientists to conduct repeated counts of bats exiting known roost locations (in combination with reporting geospatial data, local site descriptions and submission of a guano sample for species identification) have been successful in both British Columbia (www.bcbats.ca) and Alberta (www.albertabats.ca) and are excellent models for other jurisdictions across North America (Lausen et al. 2023). This citizen-based approach inherently favours bat species that use bat houses and building roosts (such as Little Brown Myotis, Yuma Myotis and Big Brown Bat).

To successfully launch a similar monitoring program in other jurisdictions, one generally needs to find a local person to champion the cause. Look for/apply to funding sources to remunerate a lead/coordinator who can then orchestrate the program. Consider opportunities to leverage monitoring efforts to contribute to bat studies (e.g., collection of guano, carcasses or acoustic recordings to address questions of physiology, diet, disease surveillance, etc.) which can facilitate funding for monitoring, including purchase of suitable equipment and accessories to safely and effectively conduct bat monitoring (e.g., proper lighting, bear spray, bat detectors, tally counters, infrared camera, Tyvek suits, etc.).

The program lead/coordinator will:

- Encourage volunteers to participate in Citizen Science monitoring activities.
- Provide education and public engagement to make citizens aware of the value of bats and the benefits/need for studying these important wildlife species.
- Train volunteers (sometimes referred to as “Bat Ambassadors”) to conduct/assist with public outreach (e.g., bat walks, presentations, bat box building workshops).
- Organize a group of interested volunteers to conduct bat counts.
- Develop an easy and clear monitoring protocol and schedule, including a locally relevant checklist for roost inspection and maintenance procedures and schedules (for community bat program participants to follow and/or distribute to landowners that they engage).
    - Check bat boxes at least once per month between April and October (or the active period for bats for the area in question) for signs of occupancy (guano catchers are helpful, as often it is difficult to determine if a bat box is occupied).
    - Promote visual checks throughout the summer, to confirm occupancy. Remember that bats may occupy bat boxes intermittently and perhaps for only part of the season. These boxes are still providing important habitat, but may require more frequent checks to characterize colony size.
    - Conduct exit counts at occupied boxes at least once during the active period for bats for the geographic area where the bat house is installed. Ideally, two counts early in the active period (during pregnancy) and two counts later in the season (as pups begin to fly) will give a better estimate of the actual number of bats present and any

increases in colony size from pup production. At some sites, bat numbers may highly fluctuate if bats are using several roosts in the immediate area. Only repeated counts will provide evidence of this behaviour.

  - Contact (and expect to have to re-contact) box owners with reminders to monitor boxes. At a minimum – March/April – reminder to install new boxes, ensure older boxes are clean and in good condition. June/July – reminder to monitor for occupancy/annual bat counts, be vigilant for overheating events or other problems that may arise at roosts while young are being raised, and to check for dead fallen pups.
  - Count bats before exclusions.
  - Determine species of bat in the bat box through acoustic recordings or guano analysis if this service is available in your region.
  - Always report monitoring results, whether a bat box is occupied or not. Lack of use is important to know about to improve our understanding of bat preferences.
  - Use a guano catcher or place plastic sheeting or cardboard on the ground or mounted under the bat box to best monitor for intermittent use (see **Section 5: Maintenance, Monitoring and Reporting Practices**). Recall: Bat guano looks like mouse droppings – dark and elongated pellets. Bat guano is easily crushed and contains insect fragments.
  - Consider installing a shade cloth/sheet over the bat box if bats appear too hot and are hanging around the entrance of the box. If mortalities are observed, install a nearby or adjoining box that is cooler, through shading, aspect, or venting. This will provide a safe escape from occasional overly hot (e.g., > 42°C or 108°F inside bat box) temperatures in the main box.
  - Encourage monitoring of roost temperatures (e.g., install a temperature logger, see Appendix 8.6 Measuring Microclimates) and occupancy (e.g., record as often as possible in a field book to later report) in bat boxes, to determine maximum tolerable temperature for bats and situations that create high temperatures. Contact your local bat conservation organization or fish and wildlife department for more information (provide list).

- Solicit, and synthesize all count data and encourage reporting of <u>all unused boxes</u> as well as used boxes, to improve future installation advice. Report all roosts and monitoring/count data to appropriate agencies, and buffer locations and sensitive information as appropriate and/or pre-arranged with landowners via signed forms. (**Appendix Five : Citizen Science-based Bat Roost Monitoring Programs**).
- Provide feedback to bat box owners, Bat Ambassadors, bat counting volunteers, and other community bat members, to enforce value of monitoring and retain interest and enthusiasm of participants. This might be in the form of a regular newsletter.
- Look for partners or form strategic alliances with municipal, regional, and provincial agencies to promote bat conservation in natural areas such as parks.

Section 6: Glossary

Adaptive management: A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form—'active' adaptive management—employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed (BC MOF 2008).

Bachelor roost: A roost used by one or more males during the day.

Bat crack: A type of artificial crevice roost that has been used in some areas of North America to more closely mimic or simulate tree cavities or gaps under bark (e.g., artificial bark: resin bark roosts, Mering and Chambers 2012; BrandenBark, Adams 2015).

Bat detector: Any device used to render the ultrasonic calls of a bat audible to the human ear, and/or records sounds for later listening or spectral analysis.

Bat box: a small rectangular "box" with one or more cavities in which bats can roost. Each cavity, often referred to as a 'chamber' is akin to a hollow or crevice that might exist in a large diameter tree. Bat boxes, especially in North America, are typically constructed of wood and often plywood. This type of bat house is meant to mimic a tree cavity or crevice more closely. See also "Bat house."

Bat condo (condominium): a large bat house, often metres by metres in size, elevated on 4 posts. It may contain chambers like bat boxes, in addition to other crevices that bats will typically use as roosts such as under tin roofing, under cedar shakes or wooden siding. This type of bat house is meant to mimic a building roost more closely. See also "Bat House."

Bat house: An artificial structure built out of materials such as wood, concrete or woodcrete, specifically for bats. These typically refer to bat condos, mini condos, some custom buildings, or bat boxes.

Bat house array. A bat box array is a set of bat boxes installed either back-to-back or side-by-side with features that result in variation of internal microclimates (e.g., varying external box colour or orientation).

Bat mini-condo: a medium-size bat house, often 1-4 m^2 in size, elevated on one or more poles. It typically contains chambers like bat boxes, in addition to other crevices that bats will typically use as roosts such as under tin roofing, under cedar shakes or wooden siding. It will typically offer more microclimate options than a bat box, but less than a bat condo, and is generally better more suitable for a large colony of bats (hundreds) than a typical 4-chamber bat box. See also "Bat House."

Biologically Important Roost: A roost that plays a crucial role in the persistence of local bat populations (Neubaum et al. 2017). Some jurisdictions also refer to significant roosts defined as:

- Any hibernaculum or swarming site.
- A roost used by a nursery colony of any species but especially those that have an elevated status of either endangered or vulnerable, (any number of individuals), or a nursery roost used by more than six females of other species (can include mixed species groups).
- A roost used by a maternity colony of Red- or Blue-listed species (any number of bats), or a maternity roost used by more than four females of other species (can include mixed species groups).

- Any permanent-type (e.g., cave, mine, cliff, rock outcrop, talus, building, bridge) regularly used day roost used by a male or a non-reproductive female of a Red- or Blue-listed species, or >10 males/non-reproductive females/juveniles of other species (can include mixed species groups).
- Any permanent-type regularly used night roost used by a Red- or Blue-listed species or >10 bats of other species (can include mixed species groups).
- Any regularly used roost of a species listed under Schedule 1 of SARA (any number of individuals).
- Any roost deemed significant by an experienced bat biologist.

BrandenBark™: A flex-bark polymer sheet moulded to resemble bark that is typically wrapped around a pole and has been found to successfully create 'artificial tree' type roosts for some bats (Adams et al. 2015).

Crevice: A narrow crack or opening, or a fissure or a cleft, not large enough to admit a human.

Day roost: A roost where bats rest during the day in spring/summer/fall. Day-roost types include maternity roosts, bachelor roosts, and mixed male/non-reproductive female/yearling groups. Use of a specific day roost may be seasonal or variable within a season.

Echolocation: An orientation system based on generating sounds and listening to their returning echoes to locate obstacles and prey (Nagorsen and Brigham 1993).

Ephemeral roost: A bat roost in a feature where the characteristics important to bats (e.g., microclimate) may change quickly and/or unpredictably. For example, an area under sloughing tree bark.

Fertilization: The impregnation of the egg by the sperm cell (Nagorsen and Brigham 1993).

Flyway: Any corridor used by bats commuting between roost and foraging areas. Often delimited by physical structures such as vegetation or buildings (Kunz and Parsons 2009).

Forage: To hunt for food.

Gestation Period: The length of the pregnancy; the time from fertilization until the birth of the foetus (Nagorsen and Brigham 1993).

Goldilocks Approach: This is the concept of offering many different temperature options. This applies to providing a wide selection of roosts of different temperature options when deploying bat houses. This is important for bats as their thermal preferences reflect their energetic needs, and these can vary widely and daily during the active season, especially during reproductive months. This phrase came into wide use as a bat box deployment strategy starting in recent years (Lausen 2019, 2021).

Guidelines: A set of recommended or suggested methods or actions that should be followed in most circumstances to assist administrative and planning decisions, and their implementation in the field. Guidelines may consist of policy statements, procedures, or checklists. They are provided as a broad framework of recommended actions to be taken and, therefore, provide some flexibility for decision-making. Note that guidelines cannot, by definition, be mandatory; such actions are prescribed by regulations or rules (Dunster and Dunster 1996).

Harp-trap: A specialized trap designed exclusively for capturing bats (Kunz and Parsons 2009).

Hibernaculum: A site where one or more bats hibernate in winter (pl. Hibernacula). A specific hibernaculum may be used by bats only part of the winter and may not be used every winter.

Hibernation: A state of lethargy characterized by a reduction in body temperature and metabolic rate (Nagorsen and Brigham 1993).

Lactation: The period of milk production by female mammals nursing young.

Maternity colony: An aggregation of females in spring, summer, or fall. The colony may include pregnant females (may not be visibly pregnant early in the season), lactating females with or without young-of-year, or post-reproductive females. A maternity colony may consist of a group of females within a single maternity roost (e.g., building, cave), or a group of females roosting singly or in small groups in close proximity and maintaining a long-term social relationship, adhering to the fission-fusion model (Metheny et al. 2008; Kerth et al. 2011; e.g., in crevices within a cliff or boulder field, in a forest stand under sloughing bark of trees). A roost used by such a colony is called a maternity roost.

Maternity roost: a roost used outside of the winter period by adult females that are capable of reproduction.

Mitigation: A “mitigation measure” means a tangible conservation action taken to avoid, minimize, restore on-site, or offset impacts on environmental values and associated components, resulting from a project or activity. (Environmental Assessment Office 2013).

Monitoring: Repeated, systematic measurements done with a specific purpose in mind. Monitoring is focused on measurements over time in order to detect the change toward, or away from, a stated standard or objective. Monitoring is part of the cycle of assessment and evaluation that is linked to management activities.

Nocturnal: Active at night.

Night roost: A roost where bats rest at night between foraging bouts. Bats may roost singly or congregate.

North American Bat Monitoring Program (NABat): A program of the US government whose mandate is to monitor bat populations – specifically aimed at tracking trends of species diversity and relative abundance. (Loeb et al. 2015, Reichert et al. 2021; see nabatmonitoring.org).

Nursery colony: A type of maternity colony containing mainly nursing adults with young (summer), or an aggregation of mainly volant pups (late summer/early fall). A roost used by such a colony can be called a nursery roost.

Nursery roost: A roost where females congregate to give birth and raise their young (adapted from Knight and Jones 2009). A nursery roost is a type of maternity roost.

Ovulation: Maturation and release of the egg before fertilization.

Parturition: Birth.

Permanent roost: A roost that is available for bat use over many years and has suitable characteristics (e.g., microclimate, access) that remain stable over time. Examples of permanent roosts include caves, cliffs, mines, bridges, buildings, and large hollow trees of a slow-decaying species such as western redcedar (*Thuja plicata*).

Pup: A bat born during the current year, sometimes also referred to as a juvenile or young-of-year.

Riparian Area: Riparian areas are three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems. They extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the watercourse at a variable width (Ilhardt *et al*. 2000).

Rocket box: A style of bat house built around a central mounting pole. It often consists of two chambers continuous around the central post, thus bats can move around the chamber in all aspects (all four sides of a square post), allowing bats exposure to more microclimates than a traditional bat house with a single aspect.

Roost: A daytime retreat or nighttime resting place.

Roost Logger: a type of zero-crossing bat detector with short range detection best suited for recording acoustic calls of bats in or near roosts. It is waterproof and runs on internal batteries for long periods (months) without maintenance. It is designed and manufactured by Titley Scientific in Columbia Missouri. Recordings are analysed in any software package that reads zero-crossing recordings (e.g., Analook, KaleidoscopePro).

Snag: A standing dead tree or part of a dead tree from which at least some or all of the smaller branches have fallen (BC MOF 2008).

Stewardship: Caring for the land and associated resources so that healthy ecosystems can be passed on to future generations (Dunster and Dunster 1996).

Swarming: Behaviour associated with nocturnal flights that are made by aggregations of bats in late summer or fall. This may be associated with mating and/or preparation for hibernation.

Synanthropic: ecologically associated with humans.

Thermoneutral Zone (TNZ): The ambient temperature range within which a resting animal (not digesting food) uses the lowest amount of energy, consumes the least amount of oxygen and is still able to maintain a constant body temperature. The upper and lower critical limit of this temperature range is relative to body size (i.e., larger animals will have a wider TNZ range while the range will be narrower in smaller animals).

Torpor: controlled physiological lowering of metabolic rate characterized by body temperature (Tb) below the minimum normothermic Tb (Barclay et al. 2001), to conserve energy. Torpor may be in response to adverse environmental conditions and/or low food availability and can operate on multiple temporal scales (hourly, daily, seasonally).

Volant: Capable of flying.

Wildlife Tree: A tree or group of trees that provide wildlife habitat and assist in the conservation of stand-level biodiversity (BC MOF 2008). A wildlife tree is any standing live or dead tree with special characteristics that provide valuable habitat for conservation or enhancement of wildlife. These trees have characteristics such as large size (diameter and height) for site, condition, age, and decay stage; evidence of use; valuable species types; and relative scarcity. They serve as critical habitat for a wide variety of organisms.

Yearling: A bat born in the previous reproductive year.

Young-of-year: A bat born during the current active season (also: pup).

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Section 8: Appendices

APPENDIX ONE: A literature review of bat roosting ecology and physiology, and use of bat houses

To understand what bats need in terms of the microclimates within a bat house, it is essential to understand and evaluate torpor strategies used by bats. These strategies vary by body condition, sex, reproductive condition, age, and time of year.

Bats have the ability to use “daily torpor” to conserve energy during periods of food shortage or cold weather (Racey and Swift 1981, Holroyd 1993, Hamilton and Barclay 1994, Grinevitch et al. 1995, Barclay et al. 2001, Lausen and Barclay 2003). Many mammals, including bats, and some bird species, use torpor which can save up to 99% of their daily energy requirements by lowering both their body temperature and metabolic rate, allowing them to survive periods of harsh conditions (Wang and Wolwyk 1998, Wang 1989, Willis and Brigham 2003). Daily torpor refers to bouts restricted to a single daily cycle versus “hibernation”, which applies to a similar energy-saving state that is maintained for many days at a time (e.g., though the winter period for bats) (Geiser and Ruf 1995, Willis and Brigham 2003). Torpor use and subsequent energy savings can vary depending on the “depth” of torpor, the frequency of torpor use and the length of torpor bouts (Barclay et al. 2001).

Bat energetics and physiology underpin roosting ecology, and although these are complex interactions, some basic principles can be used to help guide our provisioning of roosts for bats (Lausen 2019, Lausen 2020ab). Roosts, as structures that shelter bats, play a critical role in their survival and reproduction.

A.1.1. Bat Annual Cycles (Figure 23)

Female bats emerge from hibernation in spring carrying sperm from mating the previous autumn or early winter -- upon waking in spring, females ovulate, and fertilization may occur (Racey 1982). Body condition of these bats may vary depending on the amount of fat reserves they had when they entered hibernation, the length of time they spent in hibernation and the number of times they roused during the hibernation period. Females who were born the previous summer appear to enter hibernation at a lower weight than older females and this may affect their ability to support a pregnancy in the spring and affect winter survival rates. Low weight females in poor condition may either fail to ovulate or ovulate and produce an embryo which may subsequently be resorbed, or embryos may develop further and spontaneously abort (Barclay 2012). In years with warm early spring temperatures and early availability of flying insects, females that emerge in poor condition may be able to regain enough fat reserves to support a pregnancy. Females that emerge from hibernation in good to fair condition are more certain of success. However, all bats are at a disadvantage if they experience an extended period of cold or rainy weather that prevents bats from foraging, or limits insect production forcing them to spend time in torpor to wait for favourable foraging conditions.

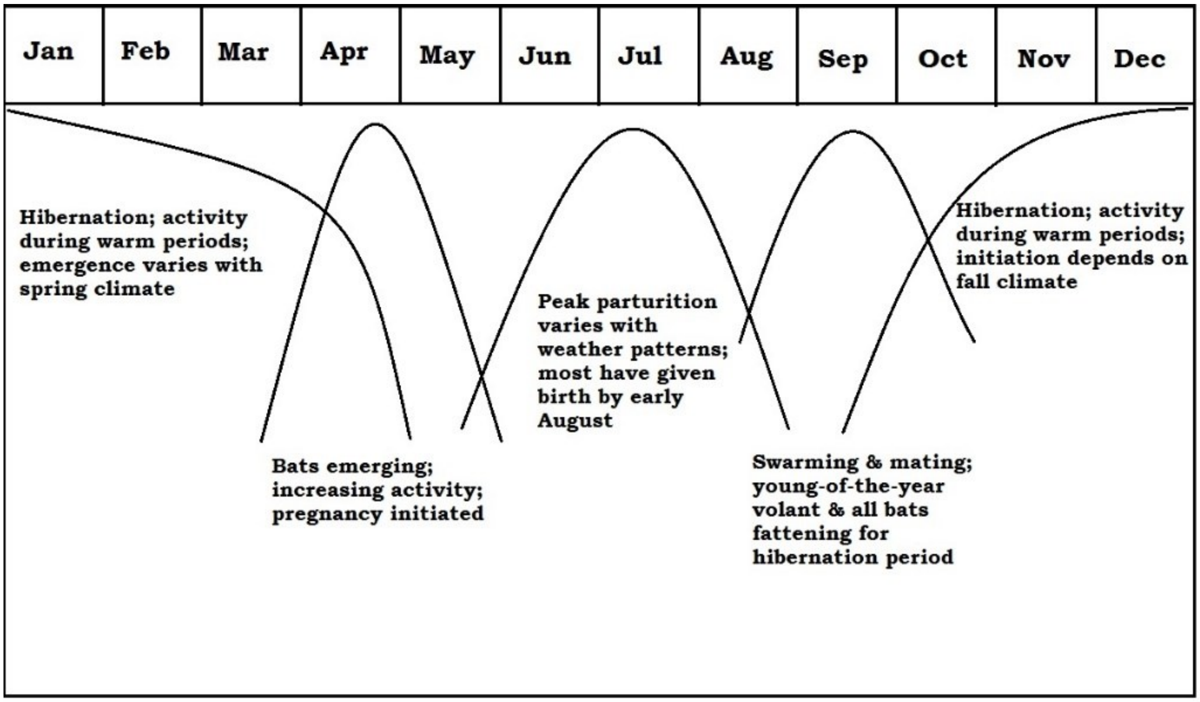

Figure 23. General annual pattern of bat activities. Curved lines represent increasing or decreasing numbers of bats engaging in each activity where the peak of the curve represents the peak numbers engaged in that activity. Figure: S. Holroyd.

In spring, female bats are typically seeking warm roosts which will keep their bodies heated without having to expend much of their own energy. This is increasingly important in eastern reaches of the continent where bats emerging from hibernation, having survived white-nose syndrome (WNS) may be in poor body form. A warm roost in spring may not only provide a jump start on gestation but can help bats heal from the wing damage caused by WNS, allowing body functions like wound repair to occur with less energy expenditure (e.g., Wilcox and Willis 2016).

During pregnancy, use of torpor slows fetal growth rates and can delay the birth of pups by two to three weeks (Racey 1973, Racey and Swift 1981, Racey 1987, Grindal et al. 1992, Holroyd 1993, Lausen and Barclay 2006, Willis et al. 2006, Linton and MacDonald 2018). Spring temperatures are often cooler, rainier, and more variable than in summer forcing pregnant female bats to cope with periods when they cannot forage for insects and maintaining an active body temperature requires additional energy expenditures (Racey and Swift 1981, Grindal et al. 1992, Holroyd 1993). Females use deep torpor more commonly during pregnancy than lactation (Holroyd 1993, Grinevitch et al. 1995, Lausen and Barclay 2006, Willis et al. 2006). This allows females to maintain their pregnancies in a stalled state of development until they can adequately meet the energy demands of the growing fetus (i.e., when warmer environmental temperatures result in both greater prey availability and less energetic demand to maintain their own body temperature) (Barclay and Harder 2003). However, the disadvantage of a late birth date is that it reduces the time available for pups to achieve adult size, master flight and hunting techniques, and store fat reserves for winter hibernation (Lausen and Barclay 2006). Lower fat reserves entering hibernation translates into lower rates of survival (Frick et al. 2010b, Barclay 2012, Czenze et al. 2017).

After pups are born, lactating mothers need to maximize pup growth rates to ensure offspring reach adult size and start flying and hunting on their own as quickly as possible. Females use deep torpor much less during this period (Holroyd 1993, Hamilton and Barclay 1994, Grinevitch et al. 1995, Lausen and Barclay 2002) as it can reduce milk production (Wilde et al. 1999) but shallow torpor may be used more frequently as a way to conserve energetic costs (Lausen and Barclay 2006). Once the young of the year begin to fly, mothers are still nursing their offspring until they learn to hunt for themselves, this is a period known as “peak lactation.” Nursing mothers may be consuming more than their own weight in insects each night to keep up with milk demands. Poor environmental conditions during lactation can force females to use torpor but this will affect their ability to produce sufficient milk for young and may delay weaning and reduce the time available for young to gain enough fat reserves to survive the winter hibernation period (Racey and Entwistle 2000, Barclay 2012). Weaning takes place a week or so after young take flight and colonies soon start to break up and bats may leave the nursery roost site for alternate roosts.

Interestingly, a comparison of reproductive female Big Brown bats using building roosts versus females using natural rock roosts found that torpor use patterns differed significantly (Lausen and Barclay 2006). Females using warmer, more thermally stable, and safe (predator free) buildings used deep torpor more often in pregnancy than bats in rock roosts (where temperatures were cooler and individuals need to be vigilant for predators precluding entering a state where they would be oblivious to risk, (Lausen and Barclay 2006). Building roosting Big Brown bats were able to raise their pups to fledging one to two weeks earlier than comparable colonies roosting in natural rock roosts (Lausen and Barclay 2006). Little Brown Myotis at higher latitudes and higher elevations depend on the stable warm temperatures provided by buildings and because microclimates in bat boxes typically fluctuate more than building roosts, bat boxes may be a less viable roost alternative option for bats in these cool environments (Thomas and Jung 2019, Johnson et al. 2019).

A.1.2. Differences in Roost Use by Age, Sex, and Reproductive Condition

A.1.2.1. Reproductive Females: Pregnancy and Lactation

Bat houses are often constructed to target colonies of breeding females and their young. Selection by bats of a maternity roost with a warm microclimate is an important behavioural strategy to achieve energy balance. In a warm roost, reproductive females may realize energetic saving because they do not have to actively maintain an active body temperature (Lausen and Barclay 2006). Warm roost microclimates can aid in digestion and weight gain, increase prenatal growth rate, support milk production and, if the roost is situated to capture late afternoon solar radiation, can provide passive rewarming prior to evening emergence (Lausen and Barclay 2006).

Typically, large groups or colonies of bats are composed of adult breeding females and may be classified as either a “maternity roost” or a “nursery roost” (see **Section 6: Glossary**). Reproductive females have the highest energy requirements of any life stage due to the energy demands of fetal development and lactation (Kurta et al. 1989, Speakman and Thomas 2003). Reproductive females may also employ clustering to conserve heat and reduce heat loss (Burnett and August 1981). Clustering behaviour also increases the relative humidity within the roost (Kurta 1985, Kurta et al. 1990, Bartonička and Řehák 2007) and the interaction between internal roost temperatures and relative humidity is important when considering the health and safety of roosting bats. Lactating females, who use water to make milk for young, may cluster as an important water-saving strategy, because reduced surface area to volume ratios of a cluster also reduces evaporative water loss (e.g., Boratyński et al. 2015). Roosting in groups can result in a daily energy savings of 53% and in cooler regions of North America may be a critical strategy to meet the energetic requirements of pregnant and lactating females as well as contributing to maximizing growth rates of juveniles (Kurta et al. 1990, Willis and Brigham 2007, Pretzlaff et al. 2010, Olson and Barclay 2013).

- A.1.2.2. Females: Post-Lactation

Once young are weaned, post-lactating females can select roost microclimates more conducive to the use of torpor (i.e., cooler roosts than used during pregnancy and lactation) and will increase the use of deep torpor to prepare for hibernation (Lausen and Barclay 2002, 2006, Solick and Barclay 2006, Johnson and Lacki 2014).

- A.1.2.3. Juvenile Bats

Delayed birth and/or slow growth rates of offspring will result in a later date for both weaning and flight of young bats. This reduces the time available for offspring to learn to hunt and acquire sufficient fat reserves for their first winter. Mortality rates of first year bats is often quite high with only about half of all pups surviving to spring (Tuttle and Stevenson 1982). Bats offset this high juvenile mortality with a long lifespan, however there are limits to the amount of additional mortality that populations can sustain.

Like many temperate zone bats, Yuma Myotis, Little Brown Myotis and Big Brown Bat pups are furless and unable to actively thermoregulate for the first several days following birth (e.g., Little Brown Myotis 9.5 days – Studier and O'Farrell 1972). During this poikilothermic period, the temperature of the roost itself, metabolism (assimilation of milk) and direct contact with mothers or other adults are the only sources of heat for neonates. Thus, pups require warm roost microclimates that will minimize body temperature losses when they are left behind in the roost; a warm roost decreases the likelihood of hypothermia until mothers return from nightly foraging.

Juveniles often huddle together in tight clusters within the roost, which further buffers them from heat loss when adults are absent. Milligan (1993) found juvenile Yuma Myotis huddled in the highest and warmest area in the roost structure when left behind by mothers during nightly foraging. This social thermoregulation has even been found to be more important than roost microclimate in maternity colonies of some tree-cavity roosting species (Willis and Brigham 2007, Kuepper et al. 2016). By huddling together, juveniles decrease the effective exposed surface areas where heat loss occurs and are able to maintain body temperature more than twice as long as a bat roosting solitarily; a decline in skin temperature that occurs after about five minutes for a single roosting pup takes almost twelve minutes for pups roosting in a cluster (Kuepper et al. 2016).

Juvenile growth and development is positively correlated with roost temperature; post-natal weight gain and growth rate increases with a warm microclimate (Tuttle 1976, Lausen and Barclay 2006). These energetic benefits are maintained if roost microclimate does not exceed the critical limits (maximum and minimum) of temperature and humidity, particularly for vulnerable pre-volant young. Advanced juvenile development will increase the likelihood of young surviving their first hibernation period (Frick et al. 2010b). Favourable roost microclimate, together with earlier parturition dates, will give young a longer period to master flight and prey capture, exploit foraging opportunities, and store energy as fat (Linton and MacDonald 2018). For example, Lausen and Barclay (2006) found that parturition and fledging occurred up to two weeks sooner for juvenile Big Brown bats raised in buildings compared to those in rock roosts. With high first-year mortality rates for Little Brown Myotis (0.23 – 0.46), survival probability was positively correlated with parturition date; pups born earlier in the season (in late May) were more likely to survive their first winter than those born later in the summer (mid-July) (Frick et al. 2010b).

A.1.2.4. Non-reproductive Females

Females that failed to support a pregnancy in spring are classed as "non-reproductive" individuals for that season. This may include females that did not become pregnant or females who resorbed or aborted embryos (likely as a result of poor body condition or an inability to support a pregnancy but this can also happen due to stress). Like male bats, they are without the energy demands of fetal growth or lactation and have only basic energy demands (i.e., eat enough to maintain a healthy body condition) through most of the summer season, with increasing demands to enable fattening prior to hibernation in the fall. Non-reproductive females can use daily torpor without restriction. Preferred roost sites for these bats will have cool temperatures during the daytime with late afternoon solar exposure to enable them to passively rewarm in preparation for nocturnal activities. Typically, they do not roost with pregnant or nursing females. Deeper and more frequent bouts of torpor are used during the maternity season by non-reproductive females relative to reproductive females (Lausen and Barclay 2002; Solick and Barclay 2006; Johnson and Lacki 2014). Their choice of roosts, such as in rock crevices, tree crevices or cavities will include sites that offer microclimates that facilitate heterothermy (Solick and Barclay 2006). Non-reproductive females sometimes roost within large maternity roosts if those sites can offer microclimates that are cool enough to allow them to use torpor (e.g., a large building roost but not a bat box). Social organization, cooperative behaviour and roost fidelity may be important explanatory factors in these situations (Kerth and Konig 1999, Kerth et al. 2011).

A.1.2.5. Adult Male Bats

During the spring and summer, male temperate zone bats are generally solitary but may form small bachelor groups (Hamilton and Barclay 1994, Vonhof and Barclay 1996). Occasionally male Myotis can be found day-roosting in the same structure as females (Anthony et al. 1981, Broders and Forbes 2004), particularly in early spring for Little Brown Myotis (Barclay and Fenton 1980). In such cases, males roost alone and not in close proximity to the females, suggesting that they are exploiting different microclimates within the same roost structure that are more favourable to their particular physiological needs (Kurta and Kunz 1988, Hamilton and Barclay 1994). Adult males typically prefer cooler roost microclimates than can be found in a maternity roost during the summer (Barclay and Fenton 1980). The male preference for cooler roosts is at least partially related to the physiological requirements of spermatogenesis.

In temperate bats, spermatogenesis begins in late spring or early summer and is completed by autumn to coincide with the primary breeding season (Racey and Entwistle 2000). For Little Brown Myotis, spermatogenesis occurs between May and August (Barclay and Fenton 1980) and between June and September for Yuma Myotis (Herd and Fenton 1983); Big Brown Bat spermatogenic activity peaks in August in eastern USA and declines in September, but spermatogenesis may begin before June (Christian 1956). Spermatogenic cells are extremely heat-sensitive; temperatures in excess of 37 °C (99 °F)can cause deformation or death of sperm cells and increase the risk of poor fertility (Widlak and Vydra 2017, Yadav et al. 2018). However, cold roost microclimates, such as would occur in a winter hibernaculum, are also not suitable for males in the summer. In most mammals, spermatogenesis occurs at ~ 3°C below body temperature (Yadav et al. 2018). Thus, males require roost microclimates that are warm enough to facilitate spermatogenesis while minimizing energy output to maintain a normothermic body temperature. Roosts such as those found in rock crevices, bridges, and trees in various stages of decay (exfoliating bark, crevices, or cavities) are typically selected by males as day roosts during summer (Broders and Forbes 2004, Jung et al. 2004). Such roosts allow use of torpor, provide passive daytime rewarming (Hamilton and Barclay 1994, Turbill and Geiser 2006) and facilitate the production and storage of viable sperm until mating occurs in autumn/winter.

For adult males, there are additional energetic benefits to using cooler roosts in the summer. Relative to a reproductive female, males have lower energetic demands and are able to use more frequent and deeper torpor to a much higher degree than pregnant or lactating females (Hamilton and Barclay 1994, Johnson and Lacki 2014). Dietz and Kalko (2006) found that males can employ deep torpor for up to two-thirds of the day, but torpor use may inhibit spermatogenesis (Dietz and Kalko 2006). Torpor allows male temperate bats increased flexibility in optimal foraging (avoiding adverse conditions or low prey densities) and efficient energy assimilation/savings as they prepare for mating and hibernation. Frequent use of deep torpor further explains why males are not typically found roosting with females in structures such as bat boxes during the summer maternity period, because maternity or nursery bat boxes would simply be too hot for them.

A.1.3. Thermal Tolerance of Species

Responses to temperature and/or humidity may vary with bat species, and there may be variation in response depending on body size variation within species and the types of roosts used by bats may affect their response (Toussaint and McKechnie 2012, Czenze et al. 2020, Noakes et al. 2021). Larger bat species that typically roost in open, exposed roosts may have a greater tolerance to both high temperatures and evaporative water loss (Noakes et al. 2021). Smaller-bodied species roosting in sites where environmental extremes are buffered (such as inside tree roost hollows) may have a lower tolerance to high temperatures and low relative humidity that results in high levels of evaporative water loss and dehydration (Noakes et al. 2021). A subset of species' thermal preferences and tolerances are listed in **Appendix Four: Bat Species' Thermal Preferences/Tolerances**).

Noakes et al. (2021) found no sex differences in responses to increasing ambient temperature for Little Brown Myotis in terms of evaporative water loss or resting metabolic rate. For Little Brown Myotis in general, resting metabolic rate increased 2.5 times when ambient temperatures rose from 32°C to 46°C (90 °F to 115 °F); evaporative water loss was 6-7 times higher at ambient temperatures of 46°C versus 32°C; and resting metabolic rate increased 2.5 times when ambient temperatures rose from 32°C to 46°C (Noakes et al. 2021). Female Little Brown Myotis in Quebec used torpor 50-70% of the time when the ambient temperature within the roost fell below 20°C (68 °F) during pregnancy or below 22°C (72 °F) during lactation (Henry 2001). When ambient roost temperatures reached 40°C (104 °F), Little Brown Myotis were found to move to cooler parts of the roost to avoid overheating (Henry 2001). Breeding female Little Brown Myotis may prefer roost temperatures that are within the range of 22–40°C (72-104 °F) for maintaining homeothermy with minimal energy expenditure (Henry 2001, Fontaine et al. 2021, Zahn 1999, Ruczyński 2006, Wilcox and Willis 2016).

Thermal tolerance levels are affected by relative humidity in the roost. Kurta et al. (1990) found Big Brown bats in natural roosts were found to consistently cluster with conspecifics with a measured relative humidity of 40-90% in the roost; this behaviour was determined to lower metabolic rate and decrease evaporative water loss for individuals in the cluster. Clustering also influences interior roost temperatures. Clustering bats were found to be warmer in cavity roosts with bigger clusters of bats; and single bats in a small cavity were warmer than a single bat in a large cavity (Kurta 1985). Lactating Big Brown bats in Alberta chose deeper rock crevices with more stable warm temperatures than the shallower crevices used by both pregnant and post-lactating bats (Lausen and Barclay 2003) which indicates both ranges and stability of roost temperatures are important and may vary with reproductive condition.

A.1.4. Social organization and its influence on roost selection

It is unclear how social organization, or the importance of social interactions, influences roost selection (Kerth 2008). Roost selection may be influenced by cooperative or competitive sociality within and between species. For example, Senior et al. (2005) found evidence to support a dominance hierarchy resulting in segregation of male *Myotis daubentonii*, and August et al. (2014) found female social groups to be long-lasting and geospatially discrete for two sympatric *Myotis* species. Interspecies roost sharing is not uncommon in anthropogenic structures (particularly buildings). Little Brown Myotis and Yuma Myotis have been found roosting together, and with other species such as Big Brown Bat, Brazilian Free-tailed, and Californian Myotis, in distinct microhabitats within the same structures (Braun et al. 2015). Through PIT-tagging of bats at mixed species maternity roosts, Rensel (2021) found that Yuma and Little Brown Myotis form strong conspecific social bonds during pregnancy and lactation. The latter species was typically later to arrive back in spring at maternity roosts and earlier to leave than Yuma. Some mixed species roosts would therefore become occupied only by Yuma Myotis early and late in the reproductive season. In late summer, Yuma Myotis mixed with nearby nursery colonies, moving among a larger selection of roosts. Many Yuma Myotis PIT-tagged in early spring at a monitored maternity roost were often not detected again until this fall mixing, in what one might describe as a ‘meta-colony’ (Rensel 2021).

Some mixed species maternity roosts in natural rock crevices -- Western Small-footed Myotis (*Myotis ciliolabrum*) with Big Brown bats, and Little Brown Myotis with Long-legged Myotis (*M. volan*s) – have been reported in Alberta (C. Lausen, pers. obs., Saunders and Barclay 1992), but the extent of mixed species natural roosts does not appear to be well documented, and it is not clear how natural roosts might be partitioned by the different species. In winter hibernation, mixed species clusters have been reported (e.g., Californian Myotis with Silver-haired Bat; Lausen et al. 2022), and this may be due to the importance of clustering during winter, regardless of species; however, whether this interspecies clustering occurs in summer seems to be undocumented in the literature.

A.1.5. Bat Community Structure

Bat boxes are typically used by only a small fraction of species in an area (Griffiths et al. 2017). But if one or two species successfully populates offered artificial structures in an area, can bat boxes cause a shift in bat community structure? In the published literature there are mixed findings when bat boxes are installed as supplementary habitat for enhancement or mitigation in an area where such boxes have not existed previously. In Australia, bat box installations were attributed to Gould’s Wattled Bat dominating a bat community in one area (Griffiths et al. 2018b) but not in other locations under a more regimented experimental design (Griffiths et al. 2020b). Little to no research has been conducted on the impact of bat boxes on bat community structure in North America.

There has been research that has looked at how the development of anthropogenic structures across North America may have artificially increased the number of Little Brown Myotis, resulting in an expanded distribution and higher population numbers than what would have been expected pre-settlement by Europeans (Thomas et al. 2021). That a change in the population size of a bat species in an area can change the ecology of the other bat species in the area, is now known from post-WNS research (Morningstar et al. 2019). Humphrey (1975) showed that species richness and diversity was strongly correlated with an index of physical diversity of an area (the index included measures of topographic complexity, presence of trees and anthropogenic roosting features). High species diversity areas have representation of diverse habitats and many types of roosting features, where low diversity sites are lacking (Humphrey 1975, Findley 1993). However, there is a lack of specific studies to support our understanding of how either anthropogenic or natural roost availability influences bat community structure. Areas supplemented with large numbers of artificial bat roosting structures may have unpredictable effects on local bat species assemblages. Species that respond well to buildings and bat houses may experience success that results in exceptionally large colony sizes that may outcompete other bat species for food resources. Until this has been more rigorously studied, it may be prudent to restrict bat box use to rural and urban areas where building roosts already occur or have potential to occur. Natural landscapes should be managed with the goal of recruiting and maintaining good, natural roosting habitat. Augmentation of lost roosting habitat in natural landscapes should be used only with the purpose of bridging the time required to recruit new natural roosting habitat (e.g., trees). Use of structures that more closely mimic the natural habitat may more closely mimic natural process, but that is a research avenue that needs pursuing (e.g., bark mimics, tree cavity creation; Adams et al. 2015, Griffiths et al. 2018a, 2020a, Mering and Chambers 2012).

The tendency of bats that use artificial roosts to occupy fewer roosts may strengthen social associations (Godinho et al. 2015; Kerth et al. 2011). Webber et al. (2016) compared tree- versus building-roosting Big Brown Bat maternity colonies and found that bats in buildings formed denser, more highly connected social networks than tree-roosting maternity colonies. Over many generations of roosting in the same roof or attic for much of the reproductive season, colonies of building-roosting bats can become heavily dependent on these structures (Schorr and Siemers 2021) and this social structure may be at risk should this roost suddenly be unavailable to them (e.g., eviction, demolition, renovation).

A.1.6. Roosting Behaviour and Roost Habitat

- ### A.1.6.1. Roost Selection and availability

Roost selection is related primarily to the function of the roost (e.g., maternity roost to raise young or night roost to digest food) and the reproductive status of the individual. As a result, selection of a roost structure may vary daily, seasonally, or yearly. Selection of a particular roost structure may involve physical characteristics, at various spatial scales (e.g., individual roost structure or surrounding landscape), or be the result of a complex interaction of several characteristics.

Roost selection is limited by availability. Bats forced to use less than optimal roost sites may experience lower reproductive success and/or survival (Barclay 2012). Roost requirements change over the year largely reflecting availability of insect prey, reproductive status, and seasonal weather. As a coarse guideline, bats must use roosts that do not result in their bodies freezing, or overheating, and are conducive to reproduction, maximizing the likelihood of offspring survival. If the microclimatic conditions within the roost are not ideal, the bats will expend energy to ensure their body temperature is conducive to their physiological needs. Large roosts like building attics not only allow bats to move around to find appropriate temperatures, but allow them to control group size/clustering which influences evaporative water loss (humidity or water vapour pressure in the immediate surroundings) . It is the combination of humidity and temperature that is referred to as microclimate and underpins the heat stress index.

- ### A.1.6.2. Fidelity and Roost Switching

Because roost selection has important implications for reproductive success and survival (Brigham and Fenton 1986, O'Donnell and Sedgeley 2006), roost fidelity, roost switching, and the use of roost areas are key aspects of roosting ecology. Both roost fidelity and switching can vary temporally (daily, seasonally, or yearly) (Kunz 1982).

Bats that switch roosts may use a group of roosts repeatedly and show fidelity to an identifiable geographic roost area. Several studies have found bats exhibiting fidelity to roosting areas both across years and within seasons (Veilleux and Veilleux 2004, Willis and Brigham 2004, Olson 2011). Fidelity to a particular area may promote long-term social connections amongst a group of bats and lead to the evolution of potentially beneficial social behaviours (Kerth 2008, Olson 2011).

Roost fidelity and switching is correlated with roost permanence and with sex and reproductive status (Lewis 1995, Papadatou et al. 2009, Russo et al. 2017). Bats occupying ephemeral roost structures (e.g., wildlife trees that have a typical decay pattern, or roosts under peeling bark) may show less roost fidelity and may switch roosts more frequently than those in more permanent roost structures such as buildings (Lewis 1995, Willis and Brigham 2004). The question is: do bats treat bat houses more like building roosts or tree roosts?

Roost switching behaviours often differ between natural versus artificial roosts. While colonies using natural roosts may spread out and occupy several roosts in a small area ('roosting area'; Willis and Brigham 2004), bats using human-built structures, especially buildings, will typically use fewer alternate roosts and move less frequently between roosts (Webber et al. 2016). For example, maternity colonies roosting within attic roosts will switch roosting locations within the same attic space (Lausen and Barclay 2006; Ellison et al. 2007), and those in bat boxes may switch roosts every one to three days, if such roosts are available, to find optimal microclimates which are critical for reproductive success and development (Slough and Jung 2020; Rensel 2021). Bats in natural roosts typically move among crevice or cavity roosts (e.g., switch trees) every one to two days (e.g., Nixon et al. 2009, Olson and Barclay 2013). It is not unusual for a colony of reproductive female bats to use dozens of natural roosts in a season and sites are likely to be reused as long as the roosts remain available and suitable (Slough and Jung 2020).

Bats typically switch roosts to achieve the most suitable microclimates, facilitate social associations, and/or to avoid predation and parasitism (Kunz and Lumsden 2003). Sedgeley (2001) suggests lactating females may switch roosts to ensure non-volant young are not left in unfavourable microclimate conditions. For bats occupying tree cavities, frequent switching may reduce guano accumulation inside the cavity (Psyllakis and Brigham 2006). Regardless of the motivation behind roost switching, the benefits should outweigh the costs of switching (e.g., energetic output, potential exposure to predators) (Lewis 1995).

Female bats may show a higher degree of fidelity to roosts than males (Papadatou et al. 2009, Russo et al. 2017). Maternity colonies exhibit particularly high inter-annual fidelity to building roosts (Lewis 1995, Gumbert et al. 2002, Willis and Brigham 2004, Lausen and Barclay 2006, Dixon 2011). However, multiannual fidelity to the same roost area (network of roosts) and even to a particular roost tree (Kurta and Murray 2002) has also been demonstrated for bats using natural roosts (Nixon et al. 2009, Johnson et al. 2012ab, Olson and Barclay 2013). If suitable roosts are common on the landscape, roost switching frequency may be higher and fidelity lower, than if roost options are limited (Lewis 1995).

Roost switching behaviour may be limited for pregnant and lactating females due to constraints on flight from late-stage pregnancy litter mass or the mass of growing neonates. These females may be challenged in balancing their energy budget due to decreased maneuverability and foraging efficiency with their increased flight load (Aldridge and Brigham 1988). However, for some bat species mother bats may move pups to new roosts every few days (Kunz and Lumsden 2003). At birth, mass of a Little Brown Myotis pup can be up to 30% of the mother's post-partum weight (Cockrum 1955, Burnett and Kunz 1982) and forearm may be 43% of adult size (Burnett and Kunz 1982). Milligan (1993) found newborn Yuma Myotis pups to weigh 20% of the mother's post-partum weight. Holroyd (1993) found singleton newborns were 20.5% and the total mass of two newborn twin pups was 36.6% of the mother's post-partum mass for Big Brown bats in western Canada; eastern populations of Big Brown bats that produce twins regularly had a total litter mass that was 41% of the mother's post-partum mass (Burnett and Kunz 1982). Neonates grow rapidly and the energetic cost of carrying a pup during foraging flights will increase as the mass of the pup increases.

A.1.6.3. Roost Areas

The size of a roost area may vary depending on the bat species but may also reflect the local availability and density of suitable roosting sites and resources such as available drinking water and insect prey type and abundance (e.g., Elmore et al. 2005, Pauli et al. 2015, Rainho and Palmeirim 2011). Rainho and Palmeirim (2011) specifically found that the size of foraging areas was defined by the distance to the nearest water source. Water sources are important for bats (Korine et al. 2016), especially in the face of overheating events in nursery roosts. In eastern USA, 20-22% of water obtained on a daily basis by breeding female Big Brown bats was through drinking water (Kurta et al. 1990); this is similar to the value determined for Little Brown Myotis (20-26%) in New England (Kurta et al. 1989).

Few studies have determined the total number of trees used by a colony or the size of the "roost area" (the area encompassed by all of the roost trees used by a single colony of bats). Callahan et al. (1997) found colonies of Indiana bats in Missouri used from 10-20 trees per season, and typically used three "main" roost trees. They also determined that the roost area encompassing all of the roost trees ranged from 206-688 hectares (509-1,700 acres); this indicated an estimated tree roost density of 10-35 trees/ha (4-14 trees/ac, Callahan et al. 1997). Little Brown Myotis colonies in Alberta had roost areas that ranged from 20 to 300 hectares (49 to 741 acres, based on 95% minimum convex polygon, Olson 2011). Estimates of the number of tree roosts per roost area were 49 tree roosts/20 ha (49 tree roosts/49 ac) for one roost area and 100 tree roosts/300 ha (100 tree roosts/741 ac) for the second roost area, however not all possible roosts were located, especially for the colony using the larger roost area (C. Olson, pers. comm.). Others have estimated that bat roost areas can vary from 30 hectares (74 acres) or less (Vonhof and Barclay 1996; Silver-haired Bats, Long-legged Myotis, August et al. 2014; UK species, Psyllakis and Brigham 2006; Little Brown and Long-legged Myotis). The work of assessing the size of roost areas is challenging and labour intensive, but clearly an important piece of information for the management of bat habitat. Johnson et al. (2012b) followed female Northern Myotis over two years in West Virginia. They found 32 bats in year one using 64 roost trees; bats were associated into 16 social groups with roost areas that ranged from 0.39 to 14.77 ha (0.96 to 36.50 ac) using 1-11 trees (Johnson et al. 2012b). In year two, 38 bats used 51 trees; eleven associated groups of bats used 1-16 trees in roost areas that ranged from 5.24 to 35.33 ha (12.95 to 87.30); in both years, bats favoured 1-2 primary roost trees (Johnson et al. 2012b). Roost area size results were similar to those reported by Henderson and Broders (2008) for the same species in Nova Scotia (0.3-31.1 ha or 0.74-76.8 ac).

Other species of cavity-roosting bats also seem to exhibit a preference for particular trees labeled as "hubs", "primary roosts" or "nodal roosts" within their roosting area (Baker and Lacki 2006; Rhodes et al. 2006, Callahan et al. 1997, Johnson et al. 2012b) and these roosts may link the larger roost network potentially playing an important role in facilitating social interactions amongst the bat colony (Rhodes et al. 2006).

Interestingly, Olson (2011) also reported inter-roost distance within roost areas. The mean distance between consecutive roosts was significantly greater for bats in the colony with the larger roost area of 300ha (532 ± 389 m, range = 119 – 1729 m, n = 23) than for bats in the colony with the smaller 20ha roost area (198 ± 122 m, range = 50–476 m, n = 18) (Olson 2011). Considering that Little Brown Myotis pups range between 20-25% of their mother's body mass at birth, flying between 0.5-1km with a load that could be up to half your own body weight (for pups a week or two old) is a remarkable feat that involves an enormous amount of energy expended by the mother.

Roost areas may be abandoned by bats if the availability of roosts becomes limited (Silvis et al. 2015; Bondo et al. 2019). Research with Northern Myotis (*M. septentrionalis*) and Big Brown bats concluded that maternity colony social networks remain intact only until 20% of the colony's roosts have been removed, after which the social networks become fragmented. Both Bondo et al. (2019) and Silvis et al. (2015) determined that roost loss can occur up to ~20% although tolerance limits to roost loss may be dependent upon local forest conditions and differ among species, thus continued research on this topic is needed. Big Brown bats in Saskatchewan were found to use progressively fewer tree roosts as roost trees were removed in their home range, until the entire colony relocated (at 46% roost loss), despite there being 33 roost trees still remaining in the roosting area (Bondo et al. 2019). While 33 natural crevice roost structures sound like a lot of roosts for a colony of bats, other studies have shown that a Little Brown Myotis colony used more than 60 tree roosts (Olson and Barclay 2013) and a Big Brown Bat colony of approximately 40 females used more than 70 rock crevice roosts throughout the reproductive season (Lausen and Barclay 2002) -- this emphasizes the importance of providing many roost options for a colony of reproductive female bats. If roost-switching is common for tree-roosting species that also use bat boxes, then it might be important to consider "roost areas" and the distribution of bat houses within the roost area to create a network of useable roosting structures for bats. Multiple bat house roosts on the landscape will provide flexibility to choose sites based on the microclimates available. Roosts need to be located close enough together within the roost area to be feasibly reached by a female carrying a load (either in late pregnancy or during lactation when burdened with a non-volant pup).

A.1.6.4. Physical Features of Preferred Natural Roosts

Natural (non-anthropogenic) day roosts for Big Brown Bat, Little Brown Myotis, and Yuma Myotis most commonly include crevices and cavities (often created by a primary cavity excavator such as a woodpecker, (Bonar 2000), but also cavities that result from tree rot) in coniferous or deciduous trees; however, rock crevices are also used, and the Myotis may use spaces under exfoliating bark (Barclay and Fenton 1980, Kurta and Baker 1990, Crampton and Barclay 1998, Parsons et al. 2003, Willis et al. 2003, Braun et al. 2015, Lausen et al. 2022). Maternity roosts in hydrothermally heated rock features/caves have been documented for Myotis in coastal BC (Firman et al. 1993, Nagorsen and Brigham 1993) and in Alaska (West and Swain 1999).

At the individual tree level, both live trees and snags (dead trees) are used by both Big Brown bats and the Myotis species, but cavities in living trees tend to be preferred, likely due to differential decay processes and the resulting roost quality and longevity (Parsons et al. 2003, Psyllakis and Brigham 2006). The decay class of a tree may influence the quality of a roost through the proportion of bark or cavity roosting opportunities available (Parsons et al. 2003, Psyllakis and Brigham 2006). Hardwoods are preferred by primary cavity nesters and provide favourable excavating conditions at younger ages than softwoods (Bunnell 2013). However, coniferous trees are longer-lived and therefore provide habitat (for both birds and bats) longer on the landscape (Bunnell 2013). Availability of appropriate trees for excavation by primary cavity nesting birds (such as woodpeckers who create cavities later used by bats), also depends on the distribution of fungal heart rot species in forest ecosystems which create the conditions that allow a tree to be excavated (Parks et al. 1996, Bull et al. 1997).

Larger trees can provide larger cavities which have been found to support larger colony sizes (Kalcounis and Brigham 1998, Olson and Barclay 2013, Parsons et al. 2003). Evelyn et al. (2004) also found that female Yuma Myotis in California selected roosts in the largest diameter trees as maternity roosts. Trees used by bats tend to be large in diameter (greater than 30 cm or 12 inches DBH), and tall (Betts 1996, Vonhof and Barclay 1996, Rabe et al. 1998, Lacki and Schwierjohann 2001, Weller and Zabel 2001, Olson and Barclay 2013, Kalcounis-Ruppell et al. 2005, Lacki 2018). Many Myotis bats prefer old-growth forests (that offer higher densities of large diameter, tall and senescing trees, that can offer larger cavities) over young forest stands (Brigham et al. 1997, Crampton and Barclay 1998, Ormsbee and McComb 1998, Vonhof and Wilkinson 2000, Kalcounis-Ruppell et al. 2005, Psyllakis and Brigham 2006, Barclay and Kurta 2007, Olson and Barclay 2013). Stand density (tree stems per unit area), prevalence of standing dead trees (snags) and canopy cover may also influence the quality or abundance of natural roosts (Fabianek et al. 2015).

Little Brown Myotis in western North America showed a definite preference for tall trees (Lacki 2018). In forested areas where the dominant tree species tend to be smaller in diameter (e.g., less than 30 cm or 12 inches DBH, lodgepole pine or small diameter aspen with flaking bark), tree-roosting bats may use deformities, such as crevices or peeling bark and these sites are often only used by one or two bats as they are unable to physically contain a large group (Rasheed and Holroyd 1995, J. Hobbs pers. comm.).

Crevice dimensions employed in bat houses have been designed to mimic the size of crevice habitat used by bats in natural features such as found in trees and rock formations. Deep, narrow crevices (generally in the range of 1.9-2.5 cm (¾-1 in.) wide and at least 30 cm (12 in.) deep) are preferred as roosting sites for bats (Keeley and Tuttle 1999). Several radio-tagged Little Brown Myotis in British Columbia used rock crevices that were on average between 2-3.5 centimetres wide (Rasheed and Holroyd 1995). Low rock outcrops with crevices and splits and other geological formations or features, such as ‘hoo-doos’ and crevices created by erosion of streambank sediments along steep-sided rivers provide important summer roosting habitat used by many bat species including Big Brown Bat, Yuma

Myotis, and Little Brown Myotis (Vaughn 1980, Rasheed and Holroyd 1995, Holloway 1998; Chruszcz 1999; Holloway and Barclay 2000; Lausen 2001; Chruszcz and Barclay 2002; Lausen and Barclay 2002; Lausen 2003; Lausen and Barclay 2003).

Physical characteristics of the natural roost itself such as aspect, height (roost entrance), surrounding canopy cover, tree decay class and internal cavity volume may influence the microclimate of a roost (Fabianek et al 2015). Natural roosts will vary in their ability to buffer occupants from ambient temperatures; it is this cavity quality and microclimate stability that are often key to occupation (Sedgeley 2001). The availability and quality of natural roosts, particularly in forests, are likely to change over time due to poor silvicultural practices, senescence, forest pest outbreaks, wildfire, increasing urbanization and climate change impacts (Machmer and Steeger 1995, Edworthy et al. 2018). Bat populations of some species may be influenced by the availability of these cavities (Kalcounis and Hecker 1996, Kalcounis and Brigham 1998). Bat colonies using natural roosts often use several roost structures within a roost area rather than depending on a single isolated feature (Kerth and Konig 1999, Willis and Brigham 2004, Garroway and Broders 2007). Structural characteristics such as canopy closure, sub-canopy characteristics, and understorey vegetation may also influence habitat selection (Jung et al. 1999).

- #### A.1.6.5. Roost microclimates

Roost microclimates are typically characterized by measures of temperature and (less often) relative humidity, compared to local ambient conditions. Critical minimum and maximum limits, for both temperature and humidity, will dictate the suitability of a particular roost microclimate at a given time or for a particular life stage for bats. Bat roost microclimates are directly influenced by the regional climatic variables typical of a location. A natural roost in an arid, interior landscape may offer significantly different interior microclimate regimes than would the same roost in a damp, maritime environment (Dillingham et al. 2003). Suitable microclimates within bat houses will vary regionally; general concerns vary from issues of overheating in hot or arid regions, to concerns focused on heat retention in northerly regions, especially in cool coastal areas or at higher altitudes (Dillingham et al. 2003). However, there may be considerable microclimatic variation within regions; for example, low valley bottom habitats in what might generally be classified as a “northerly region” may have “hot spots” that can produce over-heating events in bat houses placed in very warm aspects (e.g., in British Columbia: S. Dulc, pers. obs.), and even bat boxes at latitudes north of 60° (Yukon, Canada) can overheat (Leung et al. 2022; Tom Jung, pers. comm.).

Poorly insulated roosts (e.g., made of materials that are low density and high thermal conductance) are more variable in temperature and, thus, could be more likely to experience extreme temperatures (Larson et al. 2018). For example, in Australia, the maximum temperature recorded from small nest boxes deployed for arboreal marsupials was 52°C (126 °F) compared to a maximum of 38°C (100 °F) recorded by a natural tree hollow (Rowland et al. 2017). Materials that artificial structures are made of, and their thicknesses, of course impact their thermal properties. However, much variability in measured microclimates stem from context; bat boxes are often placed in direct sunlight, and thus they can overheat at some points in the summer, and yet it is those same boxes that warm more quickly in spring and allow females to get a jumpstart on gestation and/or heal from damaging effects of WNS.

Factors influencing roost microclimate conditions include:

- Solar exposure (hours per day of direct sun, amount of shade and aspect; Kerth et al. 2001, Flaquer et al. 2006, Baranauskas 2007, Bideguren et al. 2019, Fontaine et al. 2021)
- Number of bats occupying the structure, as group size can increase the roost temperature by several degrees (Kurta 1985, Willis and Brigham 2007, Olson and Barclay 2013) and this may also influence relative humidity in the roost (Kurta et al. 1990)
- Colour, due to albedo effect (Lourenço and Palmeirim 2004, Bideguren et al. 2019)
- Ventilation (number and placement of vents) (Tuttle et al. 2005)
- Insulating properties of roost walls (construction materials for bat houses, Bideguren et al. 2019; natural materials, e.g., rock crevice vs tree cavity vs under tree bark; Lausen and Barclay 2002, 2006, Olson and Barclay 2013)
- Installation location (internal temperatures are more stable for houses mounted on buildings; Thomas and Jung 2019, Johnson et al. 2019, Fontaine et al. 2021); pole mounted bat houses may be cooler. Convective cooling may be an issue in sites with little wind protection.
- Design of bat house (number of chambers – large single chambers can significantly overheat, C. Olson, unpubl. data); chamber volume, interior volume of a roost structure will contribute to the microclimates that are available; structures with larger interior volumes afford the greatest range of microclimate, Hoeh et al. 2018).

A.1.6.7. Characteristics of Geographic Locations of Preferred Natural Roosts

The type, abundance, and quality of natural roosts and/or roost networks will vary based on geographic location (e.g., latitude, altitude, ecosystem type), landscape type (e.g., urban vs rural) and management regime (e.g., intensive timber harvest or pristine old-growth forest). Depending on the bat species, other attributes such as distance to water sources or forest edge may also influence roost choice.

Proximity to water or quality foraging areas have been linked to roost selection, especially for Yuma and Little Brown Myotis, and Big Brown Bat (Brigham et al. 1997, Ormsbee and McComb 1998, Rabe et al. 1998, Evelyn et al. 2004, Kalcounis-Rüppell et al. 2005, Syme et al. 2001). Water and prey availability are especially important for reproductive females as their energy and water needs are higher during lactation (Adams and Hayes 2008, Adams 2010, Korine et al. 2016, Lintott et al. 2014, Patriquin et al. 2019). Availability of water will likely be more important in arid areas and as climate change progresses (Adams and Hayes 2008). For Yuma Myotis in suburban California, natural day roosts were found within 150 m of water 70% of the time, and 80% occurred near or within areas of high forest cover (Evelyn et al. 2004).

The location of roosts on the landscape is also important. In Kentucky, selected roost trees were not distributed equally across the landscape; roosts were located on upper and mid-slope sites rather than on lower sites (Lacki and Schwierjohann 2001). Similar patterns have been reported for other snag-dependent bat species (Brigham et al. 1997; Ormsbee and McComb 1998; Rabe et al. 1998).

Accessibility to roosts is important as well. Roosts on the edge of roads or clearings have good, open access (Waldien et al. 2000). The amount of vegetation clutter that is acceptable around roosts varies by bat species. Smaller, more manoeuvrable, bat species, like Little Brown and Yuma Myotis will roost in more cluttered habitat than that used by larger species, such as Big Brown bats. Because juveniles and pregnant females have reduced manoeuvrability, females may choose maternity roosts in less complex habitat because they are easier to access (Kalcounis and Brigham 1998). However, there is a trade-off in having a roost that is easy to access because it may also be situated such that it gives predators easier access as well (Hutchinson and Lacki 2000). Bats may choose natural roosts within forested areas but the distance to forest edges may be a factor in roost selection. Interior forest sites may provide protection from wind and reduced the energy loss associated with convective cooling in unprotected roosts (Willis and Brigham 2005).

Roost selection may be influenced by landscape scale characteristics that include:

- Habitat composition and fragmentation.
- Forest age and stand-level heterogeneity: mature forests support a greater abundance of roosting options due to the increased density of living or dead (snag) trees with structural deformities (cavities, sloughing bark) (Brigham et al. 1997, Crampton and Barclay 1998, Ormsbee and McComb 1998, Vonhof and Wilkinson 2000, Kalcounis-Ruppell et al. 2005, Psyllakis and Brigham 2006, Barclay and Kurta 2007, Olson and Barclay 2013).
- Vegetative cover: roosts may be selected based on the percent of canopy due to connectivity with foraging habitats, protection from predators, (Silvis et al. 2015) or the influence of canopy closure on the microclimate of the roost itself.
- Elevation: selection of roosts may be influenced by elevation due to species composition of available roost trees or by differences in ambient temperature that ultimately impact roost microclimate (Kellner 1999, Lacki and Schwierjohann 2001).

A.1.7. A Deep Dive into the Use of Bat Houses

Bat houses have a long history of use as a habitat compensation tool in the event of natural roost loss (Flaquer et al. 2006) or eviction of bats from buildings (Arias et al. 2020). The effectiveness of this practice, however, is still widely debated (Mering and Chambers 2014). The truth is that bats will roost in just about anything that provides a safe hiding spot but the goal in providing bat houses for bats is to provide a structure that is safe and one that functions both safely and effectively for that bat (depending on its sex, reproductive condition, and activity).

Bat house uptake after loss of a building-roost has mixed success, with some bats occupying boxes readily (Brittingham and Williams 2000), while others prove unsuccessful (López-Baucells et al. 2017). Big Brown Bat colonies excluded from buildings have commonly moved to another nearby building and the colonies moved as a socially linked group (Brigham and Fenton 1986). In areas where natural roosting options exist, bats may not choose to occupy bat houses as readily (White 2004, Ciechanowski 2005).

Bat houses may not represent equivalently suitable roosting habitat as compared to building roosts due to differences in thermal stability, microclimates, size, and capacity to house large numbers of bats or other qualities that may be important to bats (such as light levels or avoiding parasites and predators). The fact that this disparity remains is a sure indicator that there is still room for improvement for how bat houses are used to replace building roosts.

The effectiveness of bat boxes used to replace a building roost hinges on three main things:

- design/style of houses,
- number of houses and capacity to hold bats,
- and placement.

While there has been much focus on design, one can argue that it is in fact the number and placement of bat houses are the most important factors that influence successful occupation by bats.

Advanced designs of bat boxes can increase the range of microclimates that a single box roost can provide, theoretically reducing the overall number of bat boxes that would be needed to meet the needs of a colony of bats over the reproductive season. But it is a trade-off of cost and time as to whether one invests in a more technologically advanced bat box (e.g., one with additional insulative properties or solar powered heat mats or other additional feature), and erect presumably less of them, or to build and deploy many more standard style bat boxes. Some additional features like insulation may be relatively inexpensive and benefit bats by providing more stable microclimates. It might be that the environment in which the boxes are being deployed dictates the need for more advanced boxes, as would be the case in an open grasslands or rural area lacking alternative roost or anthropogenic roost options. In such places, condos or mini condos might be a better option, especially if a small plot of land can be secured, rather than trying to arrange for multiple bat box placements in the area. Budget, land availability, landowner buy-in, heterogeneous versus homogeneous environment, shady vs sunny options all play into deciding how best to replace a lost building roost for bats.

Bat houses have a high value as a research tool, allowing the study of typically cryptic species. They can be used to study a variety of questions relating to roosting ecology, community structure, life-history strategies, diet, disease monitoring and more. This is in part due to the ease of access of bat boxes as a study site and the high concentration of individuals present at each site. However, typical bat houses (condos, mini condos, and bat boxes) do not provide roosting habitat for all bat species (see Appendix Table 2). There have been recent innovations to create other types of artificial bat roosting habitat by creating "bark mimic" roosts using synthetic materials.

Bat house design has evolved over time and recent use of new materials, and the development of design features to stabilize fluctuations in both temperature and relative humidity are being tested for effectiveness and safety for bats. Current research measures success by counting the numbers of bats occupying a bat house, which surely measures preferences at that place and time, however, the ultimate measure of success for bat houses of all types is the ultimate reproductive success of the females using that structure. Researchers continue to move towards that goal.

It is useful to examine where bat house design began and to review the current state of design innovation for these structures.

▪ A.1.7.1. Design History

Bat houses were first deployed in North America around 1907 by Dr. Charles A. Campbell who believed he could eradicate malaria from Texas with the help of mosquito-eating bats (Storer 1926, Murphy 1989). Dr. Campbell's most famous bat house design would be labeled a "bat condo" today with its high tower and roosting shelves, after a few modifications, it eventually housed an estimated 250,000 Mexican Free-tailed Bats (*Tadarida brasiliensis*) (Storer 1926, Murphy 1989, Figure 24). Dr. Campbell's "Municipal Bat Roosts" were subsequently built in various locations across the southern US and the design was even adopted in Italy (Murphy 1989). This pioneering work led to the recognition of the contribution of bats to human health, their value, and legislation to protect bats.

Bat houses had a resurgence in popularity after promotion in the early 1980s by Bat Conservation International who touted them as a conservation and pest management tool (Tuttle and Hensley 1993).

BCI's "Bat House Builder's Handbook" has been the essential guide to bat house building (Tuttle et al. 2005) and while the fundamentals of bat house design have not changed significantly in the past 35 years, there have been changes in bat house sizes, materials and there have been shifts between crevice-style boxes and cavity-type boxes.

Designers of bat houses generally strive to mimic natural roosts by creating chambers that resemble large cavities, small crevices, or exfoliating bark. Older bat box designs (see Figure 24) included a single chamber, either resembling a large cavity or a small crevice. Single chamber, crevice-style boxes may not have the capacity to host large maternity colonies and may be prone to overheating when placed in very warm aspects or painted dark colours (Brouwer and Henrard 2020). Cavity-style boxes with large openings, such as the European-designed Schwegler 1FS box are commonly occupied by non-target species such as birds, which can effectively evict bats from boxes (e.g., Aughney 2008, Dodds and Bilston 2013). A design by Brittingham and Williams (2000), featured a bat house with a closed bottom with a small slit entrance for bats to enter. These boxes resulted in the accumulation of ectoparasites, which can negatively impact bat health (Brittingham and Williams 2000). Other reports in the literature exist that suggest colonization of bat houses by bat bugs could cause box abandonment (Bartonicka and Ruzickova 2012; Chytil 2014). Newer style boxes used in North America are typically crevice-style with multiple chambers (Figure 25).

Recommendations regarding the appropriate aspect for bat houses has not changed significantly and it was recognized very early on that east to southeast facing bat houses have optimal exposure to morning sun resulting in faster heating in the morning (the coolest part of the day) and a higher daily heat gain versus other aspects (Hodgkins 1985). Bat houses attached to buildings and larger bat houses were observed to have temperature profiles with better stability (Hodgkins 1985). And generally, nursery colonies were found to prefer a stable temperature range of 27-32˚C (80-90°F, Hodgkins 1985). Other key factors identified in determining bat house success include:

- Using dark coloured material such as tarpaper or shingles on the roof to increase heat absorption and retention.
- Placing bat houses in sites sheltered from wind; and,
- Using installation sites near bodies of water (Hodgkins 1985, Korine et al. 2016).
- Recommended materials for bat houses include cedar, redwood, or other untreated, roughened wood materials (Hodgkins 1985).

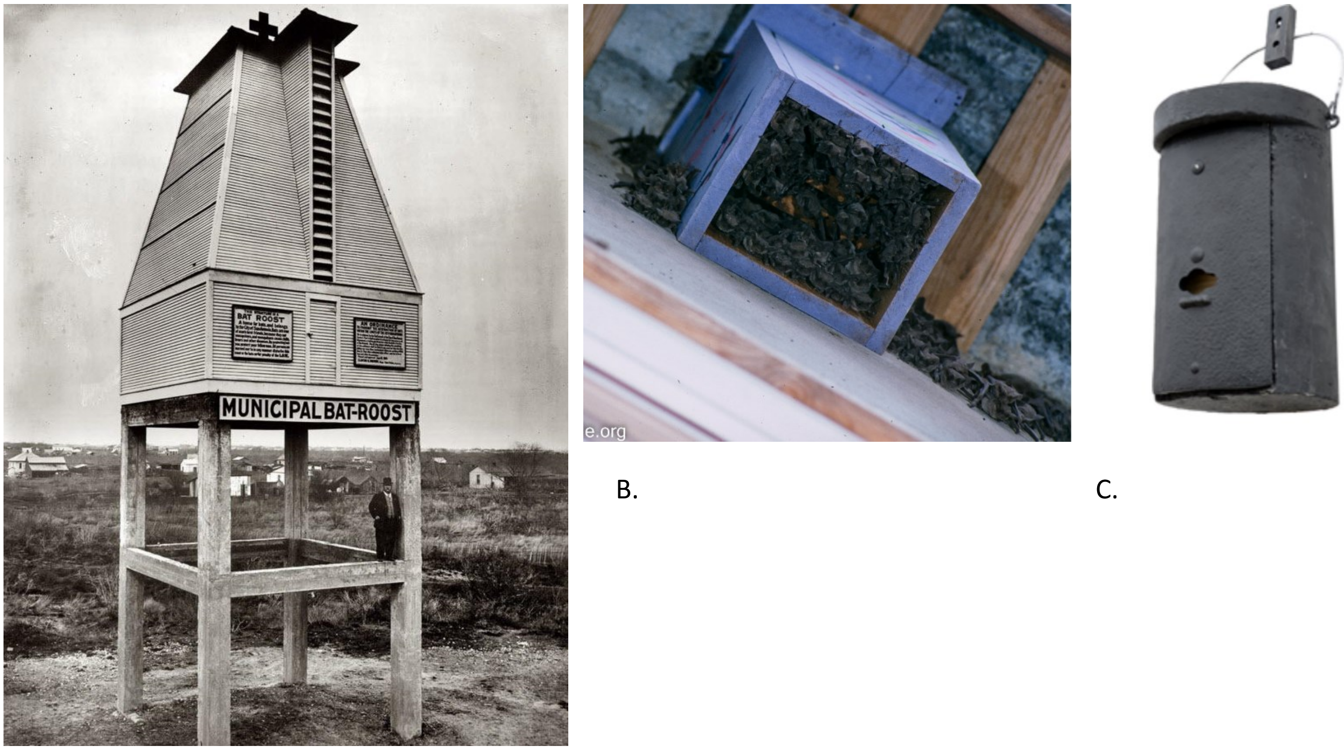

Figure 24. Old style bat houses. A. Municipal Bat Roost, erected by the City Council of San Antonia, Texas, March 17, 1916 (San Antonio Express News); B. From Tuttle and Hensley (1993) showing bats using a cavity-style box. Photo is taken looking from the ground up into the bottom of the box. Bats are visible roosting on the outside and within the box, possibly showing signs of overheating. C. Schwegler cavity-type bat house (metal Schwegler 1FS Box) is used in Europe but uncommon in North America and not recommended for use here. Photo from https://www.nhbs.com/1fs-schwegler-large-colony-bat-box .

Figure 25. Modern crevice style bat house. Looking upwards into a bat house full of Yuma Myotis at Colony Farm, lower mainland, British Columbia (photo by J. Saremba).

- A.1.7.2. Current Bat House Design

Research on the effectiveness of Rocket Boxes in comparison to the equally popular 4-chamber maternity box has produced conflicting results. Some research has shown bats have a preferential use of rocket boxes over four-chambered standard style maternity houses (de la Cruz et al. 2018, Hoeh et al. 2018), while others have found bats preferring the four-chamber maternity boxes (Weier et al. 2019). The variation in response may reflect a number of possible factors including regional differences in roost preferences, or there may be an inability to distinguish between the desirable characteristics attributed to both the rocket box and other large, maternity-style boxes (Hoeh et al. 2018).

Success has been reported in North America at several bat condos (Finn 1997; Pennisi et al. 2004), but as with many bat houses, condos may take time to become occupied by large numbers of bats – for example, the Creston Condo in B.C. (Figure 2) started out with only a few hundred bats, but has increased in occupancy each year, and now 10 years later, based on banding and emergence counts, this condo is estimated to be used by well over 7000 Yuma/Little Brown Myotis (C. Lausen, unpublished data). Large bat condos can be difficult to install because of their size. Bracing support poles and installing cement pilings is necessary to support these structures and local building permits and building inspections may be required. Hoisting the actual "house" portion onto the support beams may also require the use of an industrial lift truck for safe installation. Mini condos are often small enough to avoid these requirements, and some groups have even built these structures "in place" to avoid the requirement of a hoist. Bat condos of either size are unique projects that require considerable planning to execute safely and successfully. Often they also require a sizeable amount of funding. To date there are few construction plans available for the construction of bat condos, and many have not been thoroughly tested with enough species in enough geographic areas to recommend a particular style. For example, some condo designs provide a fly-in window (necessarily large to accommodate flight) that has been found to be a source of entry for predators in some areas (anecdotal reports of small owl entry). Generally, having several landing platforms for bats to grab onto with their claws and then crawl through small cracks into a roost structure is a safer entrance plan (restricting entrance size to exclude avian predators or those that can move on vertical rough surfaces like squirrels). The general concept of a condo is to provide many crevices/gaps for bats to roost in. Varying the width of the gaps may accommodate multiple species. It is also a good idea to include multiple types of roosts in the condo, such as corrugated tin roofing on the top to provide hot roosting locations early in spring, gaps under planked siding (closely mimicking loosened bark), and multiple chambers inside the structure that mimic large tree cavities or building attics in that they are likely to provide warm stable microclimates that won't overheat during the critical mid-summer lactation period. Bat Conservation International has a plan for a condo that has many of indoor roost chambers, and it can be adapted to include gaps under the external siding, and a set of doors to enclose the roost boxes in cooler climates.

Landowners have been encouraged to construct and erect bat boxes as habitat enhancement (Agnelli 2011, Kaarakka 2018, Kellner 2019a) and that may be appropriate in some areas where roosting habitat is lacking. It might also be most appropriate to try to more closely mimic natural roosts if this is not an urban or rural area.

In some areas, members of the public are often encouraged to become "citizen scientists" who monitor and report population sizes of bats occupying their bat houses by conducting emergence counts (Kellner

2019b, **Appendix Five : Citizen Science-based Bat Roost Monitoring Programs**). This citizen science monitoring approach encourages bat stewardship and allows researchers to monitor long term bat house use and provides important data that can be used for management of certain bat species. Bat houses installed by homeowners can also be used as an effective outreach tool as they often provide a talking point. Homeowners who take on the role of supporting bat conservation can act as important social influencers who affect the attitudes towards bats of their family and friends.

A.1.7.3. Some Cautionary Notes about Bat Boxes

Some structures built for bats may never be used by bats and that may be due to design, placement, or lack of maintenance (e.g., occupancy by other animals such as wasps) or potentially because there is an alternate, more preferable roost nearby. When bats do use a structure, this could be an indication that the structure has some optimal features but could also be a function of low roost availability in that area. While bat boxes could be detrimental to bats (see below), this will not always be the case. Unfortunately, there is no one particular design, colour, placement, or number of boxes that can be recommended for all situations. Instead, it is important that the persons undertaking any evictions and roost replacement be aware of the potential problems and are observant following eviction to ensure that roosts are monitored, and mitigation actions adapted as needed to respond to any concerns that arise. Use of the attached best practices for bats using bat houses should help minimize potential negative impacts to roosting bats.

A.1.7.4. Historical recommendations for exterior paint colour for bat houses

For many years, Bat Conservation International suggested the idea of using different paint colours for various parts of the USA (i.e., with lighter exterior treatments for bat houses situated in the hottest areas and dark treatments for cooler regions; map in Tuttle and Hensley 1993, Tuttle et al. 2005, Tuttle et al. 2013). Generally, this is a good rule of thumb. However, there may be significant variation within any given region depending on local topography, or other features that may influence the microclimate of a particular site. The BCI map would indicate that all of Canada should be using the darkest treatment colours for their bat houses, however, this has not been found to be suitable for sites like the Okanagan Valley in British Columbia that gets excessively hot in July, and even bat boxes in Yukon have been found to overheat, with white roofs having been shown to alleviate reduce this problem (Leung et al. 2022).

The hottest bat box temperature threshold for the most common bat box species is estimated to be approximately 40°C (104 °F) as this is when bat behaviours have been noted to change (Lourenço and Palmeirim 2004), and this value has been used for assessment of the risk of heat stress in bat boxes (Flaquer et al. 2014, Griffiths et al. 2017, Rueegger 2019). However, bats are likely to be metabolically adapted to different geographic climates (e.g., Dunbar and Brigham 2010), and the amount of solar exposure required to generate appropriate internal temperatures within a bat house are likely vary with many factors including location, topography, elevation, time of year, weather, humidity and bat behaviour and species' ecology. This complex interaction makes it difficult to generalize how bat boxes should be differentially designed/painted, stressing once again the importance of installing multiple bat boxes of different types (and colors) to best meet the needs of bats in a given area.

▪ A.1.7.5. Heat Stress

Bats must make trade-offs when selecting day roost sites. Choosing a warm roost can reduce energy use (Sedgeley 2001; Doty et al. 2016; Wilcox and Willis 2016) and speed up pup development (Zahn 1999; Lausen and Barclay 2006); thus, bats tend to seek out warm roosts, particularly during the periods when females are pregnant or nursing their young. However, if a bat uses a roost that is prone to extremely high temperatures, both adult bats and pups could succumb to the heat (Licht and Leitner 1967; Welbergen et al. 2008; Flaquer et al. 2014; Alcalde et al. 2017). Heat stress for bats using bat houses is a major concern associated with the future deployment of bat boxes for conservation as there is a substantial risk of subjecting bats to uncomfortable or lethal conditions if not enough roost options are present or made available. Recent studies have tested complex and/or expensive designs, but these are not commercially available and in some cases, not easily replicated by others. Of the few microclimate studies of bat houses available, most documented overheating events in some or all of their artificial structure designs (e.g., Brittingham and Williams 2000, Lourenço and Palmeirim 2004, Bartonička and Řehák 2007, Mering and Chambers 2012, Flaquer et al. 2014, Griffiths et al. 2017, Bideguren et al. 2019, Hoeh et al. 2018, Tillman et al. 2021).

The upper thermal tolerance threshold for most bat species is likely near 40°C (104 °F) but see **Appendix Four: Bat Species' Thermal Preferences/Tolerances**), and this value has been used for assessment of the risk of heat stress in bat boxes by others (Flaquer et al. 2014; Griffiths et al. 2017; Rueegger 2019). In a lab setting, three bat species (Yuma Myotis [*Myotis yumanensis*], Brazilian Free-tailed Bat [*Tadarida brasiliensis*], and Pallid Bat [*Antrozous pallidus*]) showed signs of heat stress when temperatures reached 40°C and many died after a few hours of exposure to these high temperatures (Licht and Leitner 1967). Further, Little Brown Myotis (*Myotis lucifugus*) and Soprano Pipistrelles (*Pipistrellus pygmaeus*) shift to cooler roosting positions when roost microclimates are near or above 40°C (Burnett and August 1981; Lourenço and Palmeirim 2004). While heat tolerance may vary among species and individuals (e.g., Davis and Reite 1967), and some species in fact may seek and benefit from slightly higher temperatures, 40°C seems to be a suitable upper ambient temperature at which to evaluate bat box microclimates. We know that bat boxes typically exceed this upper temperature level more often than building roosts (**Appendix Six: Microclimate of Attic Building Roosts Versus Bat Boxes – A Case Study from British Columbia.**).

Relative humidity complicates our understanding of the effect of temperature on bat behaviour and physiology. Heat stress is a combination of the effects of temperature and humidity because the cooling mechanisms used by bats depend on evaporation. At high levels of relative humidity, evaporation is reduced, and heat can build up in the body to the point of being lethal. A cluster of bats can raise humidity levels in a bat box to nearly 100%, even in an arid environment (S. Dulc, pers. obs.). However, a lone bat or a small group of bats in a bat box may tolerate roost temperatures higher than 40˚C, as they would more easily be able to dump heat through evaporative water loss through wings and ears. Small groups of bats may also be able to easily move to the bottom of the box at the opening where temperatures are often significantly cooler. Bats will often lick themselves to induce evaporative cooling (Licht and Leitner 1967), but they will also fan their wings (Reeder and Cowles 1951; Welbergen et al. 2008), increase blood flow to the wings (Reeder and Cowles 1951) or large ears (Betts 2010), or they may abandon their day roost in search of a cooler alternative (e.g., Burnett and August 1981, Bondarenco et al. 2014).

A.

B.

Figure 26. Crowding of bats at the openings of bat boxes (A) -- Tadarida species crowding a bat box in Florida. Photo by L. Finn. B. Little Brown Myotis in British Columbia. Photo by S. Latour.

One should avoid removing or modifying any bat box roosts that may have experienced overheating events (e.g., bat seen bulging out the bottom of the bat box, Figure 26; or dropping out the opening in hot weather), as these boxes are clearly being used by bats who have chosen to use these structures. The action needed at these sites is the installation of more boxes to provide optional cooler microclimates, whether these are in the exact same location as the others (e.g., back-to-back) or nearby (e.g., in the shade of a tree or building a few metres away) or add a temporary shade element to get through short periods of extreme heat (Figures 15 to 18). In other words – supplement, don't remove or permanently modify.

It is accurate to say that a 'hot roost' is desirable for reproductive females and their young. However, roosts can overheat. It is a fine line between being optimally warm to facilitate reproduction and being too hot. Overheating can cause bats to expend energy in trying to cool themselves, including behaviours such as fanning themselves with their wings (e.g., Inkster 2011), or urinating on themselves and moving to areas with airflow such as the outside of a bat box (e.g., Figure 26). Bat boxes are more likely to overheat than building attic roosts (e.g., **Appendix Six: Microclimate of Attic Building Roosts Versus Bat Boxes – A Case Study from British Columbia.**). Both natural and artificial crevice roosts can overheat (Lausen 2001, Brack and Sparks 2021), and this is important to remember when considering how many roosts are needed by a colony of bats to successfully raise young. For example, Lausen (2001) reported Big Brown Bat rock crevice roosts that could exceed 50°C (122 °F) but were never occupied by bats at these extreme temperatures.

A.1.7.6. Bat Houses as Potential Ecological Sinks

An ecological trap occurs when an animal preferentially selects suboptimal habitat and then experiences lower fitness than what would have occurred in higher quality habitat (Battin 2004; Robertson et al. 2013). Ecological traps can be created by rapid landscape change due to human activities (Robertson et al. 2013). In many cases, animals may be tricked into using an ecological trap if land use changes make low quality habitats appear attractive (Schlaepfer et al. 2002; Hale and Swearer 2017). Mitigation and conservation efforts may fail if managers provide habitat with visual and environmental signals indicative of optimal habitat but that are actually poor quality (Hale and Swearer 2017). Ecological traps are not well studied for most animals (Robertson and Hutto 2006; Hale and Swearer 2016), but it is clear that ecological traps may lead to rapid extinction or extirpation for animal populations (Donovan and Thompson 2001). Animal density alone is not an appropriate indicator of habitat quality (Van Horne 1983). To distinguish quality habitat from an ecological trap, we must measure habitat preferences and measures of fitness, such as reproductive success and survival (Battin 2004, Robertson and Hutto 2006). Bat boxes, which are often provided as surrogates for natural roosts, may function as ecological traps by supporting unsuitably hot microclimates (Flaquer et al. 2014, Bideguren et al. 2019), though many other facets of bat boxes could also result in the development of an ecological trap.

Bat boxes could function as ecological traps if they are prone to thermal extremes and offer bats no safe temperatures during heatwaves. Three studies noted heat stress events in artificial roosts that resulted in mortality (Flaquer et al. 2014; Alcalde et al. 2017; Griffiths et al. 2021), though these types of events are undoubtedly more common than reported in the published literature. In British Columbia for example, overheating of monitored bat boxes has been implicated in the death of bats observed dropping out of bat boxes during heatwaves in recent years (e.g., Lausen et al. 2023).

Bats are opportunistically preyed upon by a variety of animals (e.g., raccoons, snakes, cats; Hopkins and Hopkins 1982; McCracken et al. 1986; Ancillotto et al. 2013); therefore, bat boxes could also function as ecological traps if they allow easy access by predators. To date, there are no studies on the baseline risk of predation at bat boxes. Many bats select natural roosts that are short lived, typically lasting for only a few seasons (Britzke et al. 2003; Whitaker et al. 2004; O'Keefe and Loeb 2017), whereas bat boxes can be long-lasting (Chambers et al. 2002; Rueegger 2016) and could be easily recognized by potential predators and serve as routine sites for predation. Guano accumulation could be an obvious cue to predators of the presence of bats, as predators in Australia visit bat boxes treated with guano more frequently than bat boxes not treated with guano (Threlfall et al. 2013). Compounding this, many bat boxes are small (Mering and Chambers 2014) and if a large colony occupies a small box then upward movement may be precluded and bats will have no safe haven to avoid predation.

Bat boxes could also function as ecological traps if they support unnaturally high parasite loads compared to natural roosts. Parasite density is directly correlated with relative roost permanence (Patterson et al. 2007). Because bat boxes are not as ephemeral as natural roosts in dead trees, bats could potentially be exposed to higher parasite loads in bat boxes, thereby leading to higher energetic expenditures, declines in body mass, and compromised immune function (Christe et al. 2000; Giorgi et al. 2001; Lourenço and Palmeirim 2007). Sometimes bat boxes host colonies of hundreds of bats (Brittingham and Williams 2000; Hoeh et al. 2018; Bergeson et al. 2020); large aggregations of bats facilitate the transmission of parasites and, thus, roosting females and their pups could be more susceptible than in natural roosts with smaller colony sizes. Pups may also be at a greater risk of ectoparasite accumulation than adults in bat boxes, as pups have poor motor function early in development (McLean and Speakman 1997) and may be less capable of grooming in the event of a large ectoparasite infestation. Poor grooming capabilities and larger infestations of parasites within bat boxes could therefore reduce pup fitness and survival.

If the comprehensive needs of an animal are not considered, restored habitats may function as an ecological trap and mitigation efforts may fail (Hale and Swearer 2017). Provisioning bats with boxes on altered, low-quality landscapes could result in decreased fitness due to bioaccumulation of toxins and a generally poor diet. When used to mitigate natural roost loss, bat boxes could function as an ecological trap by drawing bats into suboptimal landscapes that do not fully meet their dietary and safety needs. For instance, providing bats with bat boxes near areas where insects are treated or exposed to chemicals could result in bats bio-accumulating toxins within body tissues as they consume insects near their roosts (Gerell and Lundberg 1993; Bayat et al. 2014), potentially decreasing survival (Frick et al. 2007). Bats may be unable to meet their dietary needs on altered landscapes, such as in urban or suburban areas, as arthropods may have insufficient nutrients due to land use practices (Schowalter et al. 1981) or because of lower arthropod diversity in areas with more development (Marini et al. 2009; Merckx and Van Dyck 2019) or homogeneity. For example, bats that forage over agricultural lands have lower dietary breadth than bats foraging over forest fragments (Clare et al. 2011). For a broader discussion of use of bat boxes ("thinking beyond the box") and avoidance of ecological sinks, see Lausen et al. (2023).

Climate change is an under-researched concern associated with the future deployment of bat boxes (Flaquer et al. 2014; Bideguren et al. 2019). Climate change may increase both the frequency and intensity of heat waves (Meehl and Tebaldi 2004) and has already had devastating impacts on larger pteropodid bats (Welbergen et al. 2008) and predictions are that it will significantly affect North American bat species (Adams and Hayes 2008, Adams 2010). Because many temperate region bats choose dark colored roosts over cooler options due to increased energetic savings of generally warmer conditions (Kerth et al. 2001; Lourenço and Palmeirim 2004; Doty et al. 2016), the risk of heat stress could increase substantially if these roosts do not adequately buffer lethal temperatures (Bideguren et al. 2019). Combining poor landscape placement with few bat boxes (or boxes all with similar placements) could be a recipe for disaster for bats; this is especially true if the bat boxes small with thin walls and exposed to solar radiation. In areas where extreme heat events are more likely, bat boxes might operate as ecological traps that seem attractive to bats, but which cause death for pups or adults. Immediate action is needed to recognize areas where bats do not have enough roost choices and thus maybe be prone to overheating as climate change continues.

In these areas, if more bat boxes cannot be installed in cooler nearby placements, then more sophisticated and/or larger vented bat boxes that are less likely to overheat (e.g., made of wood-crete or concrete, or insulated walls) need to be installed. More study and innovation of affordable box designs, and more widespread access to new bat box designs is needed to better respond to the rapidly changing climate that many bats are now facing.

A.1.8. Other types of artificial roosting habitat: bark mimics

A more recent innovation is BrandenBark™, an artificial roost structure that mimics the natural roosting habitat for species that use the spaces under exfoliating bark of trees (Adams et al. 2015). BrandenBark™ is a sheet of polyurethane elastomeric Flex-Bark© wrapped around a pole to create an artificial roosting structure (Figure 27) for bats that prefer to roost under peeling bark (Adams et al. 2015). The roost depicted in Figure 27 was used immediately in its first spring after being erected. Metal flashing is installed as a predator guard, and a wooden frame holds mesh around the pole to catch guano for monitoring occupancy (via presence of guano, and genetic identification of bat species). A flat "roof" was installed above the BrandenBark to keep the roost dry, and although easily visible, bird spikes on top of this roof prevent potential avian predators from perching.

Bark patterns can mimic a variety of tree species (Adams et al. 2015), and a typical installation involves an untreated 7.6 m utility pole, placed 1.5 m into the ground and packed with gravel, with the buried portion of the pole treated to prevent decay (Figure 27). A 1.0m by 1.3m sheet (approximately) of sheet of BrandenBark™ is screwed onto the pole leaving a gap at the bottom to allow bat access (Adams et al. 2015). This material has successfully provided roosting habitat for Indiana Myotis (*Myotis sodalis*), and sites have also been used by Little Brown Myotis (Lausen et al. 2022), Northern Myotis (*M. septentrionalis*) and Big Brown Bat (Adams et al. 2015).

Bark mimic structures are typically used to provide roosting habitat for species that do not use bat houses but rather rely on old growth tree features. But these structures do not come without problems. Recent work has indicated that this material may be a problematic when attached to fast growing trees as the tree growth can interfere with the function of the bark mimic feature (C. Lausen, pers. comm.). Lifespan of these structures may also be limited in some cases due to wood decomposition. Trees and poles wrapped with this material may not be stable over periods of 10 years or more.

Ideally, bat roosting habitat should be managed on forested landscapes so that stand structure is naturally variable enough to support bats over time. For example, when older age-class trees are lost, there are older-aged green trees growing on site to eventually replace these lost wildlife trees. In cases where there are gaps in management and stand structure in managed forests fails to provide the roosting habitat needed for local bat populations, bat houses, tree modifications, and bark mimic-type roosts could be used to bridge the time gap until natural roosts are again available (e.g., Griffiths et al 2018a, 2020a; Rueegger 2017, Mering and Chambers 2012, Adams et al. 2015). Installing a variety of artificial roost types may benefit more bat species. However, providing artificial roost habitat for bats in managed forests should not be the normal approach. Cases that necessitate this strategy indicate a failure on the part of forest managers to retain features to support wildlife.

Figure 27. BrandenBark™ wrapped around a pole (blow-torched for preservation) created a bark-mimic roost for a maternity colony of Little Brown Myotis near Golden, British Columbia. Top circle of wood prevents water from entering the artificial bark roost, and bird spikes have been added to this top to keep avian predators from perching. Photo by C. Lausen.

A.1.9. Advances and innovations in bat house design

A.1.9.1. Bat Box Design and Placement

Bat houses installed for the purpose of housing a maternity or nursery colony of bats should always be of some type of large multi-chamber design as these designs have been found to provide the largest range of internal microclimates to meet the changing needs of the bats using it. Single chamber bat houses (either large or small) may be useful as shelter for non-reproductive females, males, or transient bats, but these simple structures should not be installed facing very warm aspects and should not be used to house maternity or nursery colonies due to their propensity to overheat. Providing a variety of structure types in various aspects creates a roosting area that may meet the needs of bats over the active season. But beyond basic structure (multi-chamber versus single chamber), other aspects of bat houses can be modified to influence internal temperature profiles. Researchers have been looking at ways to innovate and there have been tests in three areas to affect internal temperature profiles of bat houses, specifically looking at the:

- Effect of building materials.
- Effect of passive design add-ons.
- Effect of active design add-ons.

A.1.9.1.1. Materials

Classic style bat boxes (not insulated, typically made of wood), by their very nature, are likely to track ambient more closely than roosts like building attic roosts that are built with both insulation and venting options. In general, darker boxes with thinner walls, and chambers that are most exposed to solar incidence, will produce the hottest microclimates (Rueegger et al. 2019). Using unique materials to insulate the walls that absorb or dump heat (e.g., phase-changing insulation, composite wood like woodcrete or other materials) can produce a change in typical internal microclimates within a bat house.

Woodcrete bat boxes (Brouwer and Henrard 2020) are made from a durable, composite material formed by mixing wood and concrete (see Figure 21 for an example). Woodcrete bat boxes are rot-resistant and more durable (25-30 years) than typical plywood-constructed boxes (5-10 years; reviewed in Rueegger 2016). Woodcrete has a higher specific density than plywood, which gives it better insulative properties (Van der Wijden et al., 2014; Baranauskas, 2009). Others have manipulated this material and added polystyrene or styrofoam in bat box material to reduce the overall weight of the bat box and to reduce the magnitude of extremes during heat waves and to improve insulative properties (Andrusiak & Sarell, 2019; Larson et al., 2018).

A.1.9.1.2. Passive modification

A passive modification is a design element added on to a bat house that requires no active management to maintain it. For example, changing paint colour or changing the dimensions that affect the volume and mass of the bat house can significantly change the internal temperature profile of a bat house. Increasing the mass of a bat box may make a more stable microclimate as increased insulation and a larger thermal mass take longer to heat up and cool down (Tillman et al. 2021).

The ideal bat box provides a gradient of temperatures to bats so that they can shift to lower, cooler positions if the top part of the box begins to overheat (Flaquer et al. 2014). Taller boxes with more chambers provide larger ranges of microclimates, and this affect can be modified by reducing or adding vents, (e.g., Tillman et al. 2021). Small volume roosts, or ones that are particularly wide and short rather than tall and narrow, offer much smaller gradients of temperatures. Providing as large a roost as possible, and particularly a tall roost, provides bats with more microclimate options.

Brittingham and Williams (2000) determined that bats prefer to roost side by side, thus wide boxes are preferred over narrow boxes. Recent designs have also incorporated “escape hatches” for bats at the top of tall, large volume roosts (J. Saremba, pers. comm). In bat houses with large numbers of bats, individuals can get trapped on hot days in the uppermost (and hottest) portions of the structure. Ideally bats would be able to easily access different chambers within the box without having to exit and re-enter (e.g., crawl spaces between chambers), thus easily taking advantage of a larger range of temperatures (Hoeh et al. 2018; Tillman et al. 2021). Not only do escape hatches and crawl spaces between chambers improve the availability of the range of microclimates for bats, but it can also make it safer for mother bats and pups (Rueegger 2019). A female with a large pup may otherwise have to resort to flying with a load that could be half her own body weight. Not only is this energetically expensive, but it is also risky as there is a potential for bats to become grounded at this stage (making them vulnerable to predation). The added benefit to additional openings is improved ventilation. Bat boxes lacking ventilation will have higher internal temperatures and could be more prone to overheating on warm weather days (Bideguren et al. 2019; Tillman et al. 2021).

Painting a bat box roof white versus black can substantially alter its microclimate and pairing one type next to the other to meet the wide range of microclimate needs of a maternity colony has been recommended by Leung et al. (2022). There are methods of changing the thermal properties of bat boxes. Dark paint colors can enhance the absorption of solar radiation and increase the risk of overheating (Lourenço and Palmeirim 2004; Griffiths et al. 2017; Bideguren et al. 2019; Rueegger 2019).

A.1.9.1.3. Active modification

Recent advances in testing of bat box designs has described strategic modifications that can be made to alter microclimates of the boxes that require supervision and have components that either respond to temperature changes (such as fans or heaters) or require active monitoring. These include:

- Adding an external water jacket (Tillman et al. 2021). Tillman et al. (2021) demonstrated that a bat box can provide more stable microclimates by outfitting it with a water jacket sleeve.
    - A water-jacket box is a rocket box surrounded by an empty wooden jacket which adds a 1.9-cm (3.4 in.)-wide air space adjacent to the outermost chamber. The jacket contains 12 water-filled packets (28 x 28 x 1.9 cm or 11 x 11 x ¾ in.); each packet is a heat-sealed freezer bag filled with 750 ml of water. Because of the addition of this outer jacket, the box has no vents. Conceptually, a water jacket can be added to the outside of virtually any box design; however, the efficacy of the water-jacket for retaining heat will vary with surface area, volume, color, orientation, and solar exposure of the box.

Following work showing the benefits of heated bat boxes (Wilcox and Willis, 2016), the goal of the water-jacket design was to decrease energy expenditure for roosting bats with high energy demands, such as bats in the early stages of reproduction or those recovering from white-nose syndrome. By increasing the thermal mass of the box with water packets, the water-jacket box reduces the risk of overheating at the top of the box and provides the benefit of warmer nighttime temperatures via phase lag (i.e., heat retention longer into the night). Pups will benefit from the absence of injuriously high daytime temperatures at the top of the boxes. This may be particularly important during heat waves, given the tendency of pregnant and lactating mothers and their pups to occupy the warmest part of the box where crowding may impede escape from lethal or injurious conditions (Lourenco and Palmeirim, 2004). Analyses (Tillman et al. 2021, Bakken et al. 2022, and Crawford et al. 2022) indicate that the extra cost and effort needed to construct the water-jacket rocket box is justified, and suggest it is worth pursuing the development of other bat box designs intended to create thermal phase lag and thus warmer and more stable conditions.

- Adding a heating element. Bat boxes can be insulated for greater thermal stability and heated in a wide range of ways such as installed heating sources (Kiser and Kiser 2004), or capturing solar (e.g., NCUBE Figure 28; Fontaine et al. 2021). Heated bat boxes have been used to contend with variable and cool temperatures (Slough and Jung 2008, Wilcox and Willis 2016). Insulated bat houses with passive solar heating were found to retain temperatures in the optimal range (between 22-40C) 13% longer than classic bat house models and provided bats with an estimated average daily energy savings of up to 7.8% when mounted on a building (indicating that innovations in combination with beneficial mounting locations can significantly benefit bats; Fontaine et al. 2021). For example, Fontaine et al. (2021) designed a new style of bat box which increases the amount of time the box offers optimal temperatures for reproduction, thus saving bats energy. Their new design, dubbed Ncube PH1 (Figure 28), incorporates plexiglass to increase solar radiation into the box, while retaining heat within the box using insulated walls, incorporation of non-wood building materials (clay brick, cement panel), and a reduced entrance/exit opening.

A unique design by students at Northern Alberta Institute of Technology (NAIT), led by Dave Critchley designed and tested a box using Infinite R™, a Phase Change Material (PCM), as an insulation material and determined that its ability to absorb excess heat and release it (thermal cycling) through a phase change between liquid and solid, allowed their custom bat boxes to offer more stable microclimate designed with a specific target temperature (Hlewka et al. 2018; see **Appendix Seven: Innovative New Bat Box Design – A Case Study from Alberta by Northern Alberta Institute of Technology.**). Their box designs also included optional addition of a photovoltaic panel that runs a small fan that dumps heat when a maximum temperature is exceeded. Testing of these bat boxes and monitoring for occupancy is ongoing (D. Critchley, pers. comm.).

Ncube PH1 (3-chambers)		92x41x24 cm wood, 5 cm thick styrofoam insulation, plexiglass, and clay brick, light cement panel

Figure 28. Ncube PH1 (3 chamber) bat box design by Fontaine et al. (2021, supplemental Table S1). This design proved to offer temperature ranges well aligned with bat reproduction and was modelled to potentially save bats up to 8% of their daily energy if mounted in an east-facing location on a building. Selection of this style of bat box by bats has yet to be tested.

A.1.9.1.4. Observations on Occupancy and Reproductive Success by Bats

In most instances, we still know very little about reproductive success for bats using artificial roosting structures. Observing bats in a bat box does not mean they are reproductively successful (i.e., offspring reach adult size and successfully produce young) and, even if pups are observed, it is difficult to determine what percentage of adult females are successfully raising young. To assess reproductive success requires bat capture over a long enough time frame to properly measure reproductive rates. Even with capture, however, one can only determine how many young have been born or fledge. It is far more difficult to quantify how many young survive to hibernate and then survive their first winter. The timing of birth, first flights by young bats, and the condition of the juvenile bats as they enter hibernation may all be influenced by roost habitat quality and will directly affect survival rates through their first winter (Barclay 2012). Actual measures of success will require long-term datasets from several sites over a range of environmental conditions. Capture-recapture data in combination with marking, population monitoring, and tracking reproductive rates of bats at specific colonies will be required to make an educated assessment of the actual success of a particular bat house design.

Clearly, it is a priority to understand the factors that influence bat house use by bats (Mering and Chambers 2014, Rueegger 2016). However, we are only beginning to see research emerge in North America and have been looking to European bat research that has examined occupancy of bat houses (Boyd and Stebbings 1989, Baranauskas 2007, Biderguren et al. 2018).

The biggest challenge in developing best management practices for a large geographic area and multiple species is that artificial structures may not be equally effective at all sites due to variation in both environmental factors and bat behaviour (e.g., effects of group size on roost microclimate and relative humidity). As such, guidance must necessarily be broad in scope, pointing to underpinning fundamentals that need to be understood and considered, rather than be highly prescriptive. And we must all be prepared to engage *adaptive management* as we learn what does and does not work in some areas with some species.

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APPENDIX TWO: List of bat species of Canada and the USA

Table 2. A list of the bat species of Canada and the USA with a summary of their roosting preferences. Lasiurines (Lasiurus genus; note that taxonomy is evolving but we have opted for older more recognizable names for this genus here) are all considered to be foliage-roosting species, unlikely to be found in a bat house. Sources used to populate this table follow below the table.

Common Name (Family; IUCN Status)[1]	*Scientific Name*	Uses Buildings Yes/No	Uses Bat Houses Yes/No	Region[2]	Other roost types used
Pallid Bat (V; LC)	*Antrozous pallidus*	Yes	Yes	CAN/US/MEX	Rock outcrops, tree hollows, behind signs, caves, crevices
Mexican Long-tongued Bat (P; NT)	*Choeronycteris mexicana*	Rarely	No	US/MEX	Mountain canyons (rock crevices), caves, mines
Rafinesque's Big-eared Bat (V; LC)	*Corynorhinus rafinesquii*	Yes	?*	US	Large hollow trees, bridges, culverts, leaf piles
Townsend's Big-eared Bat (V; LC)	*Corynorhinus townsendii*	Yes	Yes* (but only large structures, not bat boxes)	CAN/US/MEX	Tree hollows, caves, mines
Hairy-legged Vampire (P; LC)	*Diphylla ecaudata*	?	?	US/MEX	Caves, mines, hollow trees
Big Brown Bat (V; LC)	*Eptesicus fuscus*	Yes	Yes	CAN/US/MEX	Rock crevices, tree cavities, bridges
Velvety Fruit-eating Bat or Harts Little Fruit Bat (P; LC)	*Enchisthenes hartii*	?	?	US/MEX	?
Spotted Bat (V; LC)	*Euderma maculatum*	Yes (but rarely)	No	CAN/US/MEX	Crevices in cliff faces (but also caves, mines buildings-rare)
Florida Bonneted Bat (M; LC)	*Eumops floridanus*	Yes	Yes	US	Cavities in pine trees, under roofing tiles, palm fronds
Greater Bonneted Bat (M; LC)	*Eumops perotis*	No	No	US/MEX	Cliff faces, outside tall buildings
Underwood's Bonneted Bat (M; LC)	*Eumops underwoodi*	No	No	US/MEX	Hollow trees
Allen's Big-eared Bat (V; LC)	*Idionycteris phyllotis*	No	No	US/MEX	Mines, lava tubes, boulder piles, under bark

Silver-haired Bat (V; LC)	*Lasionycteris noctivagans*	Yes	No?	CAN/US/MEX	Tree hollows
Western Red Bat (V; LC)	*Lasiurus blossevillii*	No	No	US/MEX	Tree foliage
Eastern Red Bat (V; LC)	*Lasiurus borealis*	No	No	CAN/US/MEX	Tree foliage
Hoary Bat (V; LC)	*Lasiurus cinereus*	No	No	CAN/US/MEX	Tree foliage
Southern Yellow Bat (V; LC)	*Lasiurus ega*	No	No	US/MEX	Trees, palm trees
Northern Yellow Bat (V; LC)	*Lasiurus (Dasypterus) intermedius*	Rarely	No	US/MEX	In moss, in palm fronds, open foliage
Seminole Bat (Seminole Yellow Bat) (V; LC)	*Lasiurus seminolus*	No	No	US/MEX	Spanish moss, oak trees
Western Yellow Bat (V; LC)	*Lasiurus (Dasypterus) xanthinus*	No	No	US/MEX	Open foliage roosts, trees, yucca
Mexican Long-nosed Bat (P; EN)	*Leptonycteris nivalis*	Yes (occ.)	No	US/MEX	Caves, mines, cliff faces, culverts, tree hollows
Lesser Long-nosed Bat (P; NT)	*Leptonycteris yerbabuenae*	No	No	US/MEX	Caves, mines
California Leaf-nosed Bat (P; LC)	*Macrotis californicus*	Yes	No	US/MEX	Caves, mines
Pallas's Mastiff Bat (M; LC)	*Molossus molossus*	Yes	Yes	US/MEX	Under roof materials, attics, palm leaves, rock crevices, caves, bridges
Peter's Ghost-faced Bat (Mormoopidae; LC)	*Mormoops megalophylla*	Yes	?	US/MEX	Caves, tunnels, mines
Southwestern Myotis (V; LC)	*Myotis auriculus*	Yes	No	US/MEX	Tree hollows, under bark, mines, caves
Southeastern Myotis (V; LC)	*Myotis austroriparius (V)*	Yes	Yes	US	Hollow trees, caves, bridges, culverts

California Myotis (V; LC)	*Myotis californicus*	Yes	Yes	CAN/US/MEX	Tree crevices, under bark, rock crevices, bridge, roofs
Western Small-footed Bat (V; LC)	*Myotis ciliolabrum*	Yes	?	CAN/US	Rock-type roosts, erosion crevices, under loose tree bark
Long-eared Myotis (V; LC)	*Myotis evotis*	Yes	Yes	CAN/US	Tree crevices and cavities, rock crevices
Gray Myotis (V; VU)	*Myotis grisescens*	Yes	No	US	Caves, occ. mines
Eastern Small-footed Myotis (V; EN)	*Myotis leibii*	Yes	?	CAN/US	Caves, mines, bridges, tree crevices
Little Brown Myotis (V; EN)	*Myotis lucifugus*	Yes	Yes	CAN/US	Trees, rock roosts, bridges
Dark-nosed Small-footed Myotis (V; LC)	*Myotis melanorhinus*	See western small-footed			
Southwestern Little Brown Myotis or Arizona Myotis (V; LC)	*Myotis occultus*	Yes	No?	US/MEX	Caves, mines, tree hollows and crevices, bridges
Northern Myotis (V; NT)	*Myotis septentrionalis*	Yes	Yes (east?) Brandenbark	CAN/US	Tree crevices, cavities, under bark
Indiana Myotis (V; NT)	*Myotis sodalis*	Yes	Yes	US	Loose bark, tree hollows, bridges
Fringed Myotis (V; LC)	*Myotis thysanodes*	Yes	?	CAN/US/MEX	Caves, mines, rock crevices, bridges, wildlife trees (snags)
Cave Myotis (V; LC)	*Myotis velifer*	Yes	Yes	US/MEX	Caves, mines, barns, bridges, abandoned cliff swallow nests
Long-legged Myotis (V; LC)	*Myotis volans*	Yes	Yes	CAN/US/MEX	Tree crevices and cavities, rock crevices
Yuma Myotis (V; LC)	*Myotis yumanensis*	Yes	Yes	CAN/US/MEX	Tree cavities, bridges, caves, abandoned mines
Evening Bat (V; LC)	*Nycticeius humeralis*	Yes	Yes	US/MEX	Tree cavities, under bark; prefers rocket boxes
Pocketed Free-tailed Bats (M; LC)	*Nyctinomops femerosaccus*	No	No	US/MEX	Rock crevices, canyon cliffs, caves,

					anthropogenic roosts
Big Free-tailed Bat (M; LC)	*Nyctinomops macrotis*	Yes (occ.)	?	US/MEX/CAN?	Rock-type roosts, cliff crevices
Canyon Bat (V; LC)	*Parastrellus hesperus*	No	No	US/MEX/CAN?	Rock-type roosts, cliffs, crevices
Tricolored Bat (V; VU)	*Perimyotis subflavus*	Yes	Yes	US/MEX/CAN	Rock crevices, caves, tree foliage
Mexican Free-tailed Bat (M; LC)	*Tadarida brasiliensis*	Yes	Yes	US/MEX	Tree cavities, caves, mines

[1]Family codes: V = Vespertilionidae; M = Molossidae; P = Phyllostomatidae; Mor. = Mormoopidae. Codes from IUCN Status: LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered.
[2]Country codes: US = United States of America; MEX = Mexico; CAN = Canada; ? = accidental or vagrant.
**A few species such as those in the genus Corynorhinus, prefer open roosts and do not use tight crevices -- artificial roosting structures can be built specifically for them but they will have different characteristics from 'standard' bat boxes and successful roost replacement has been achieved through renovation of old buildings or construction of new ones (e.g., BC MOE 1998; Erikson-McGee and Englesoft 2019; Firman 1998). Building roost mitigations for Townsend's Big-eared Bat have been successful in British Columbia (e.g., Firman 2003; Tim Ennis, pers. comm.; and Mandy Kellner, pers. obs.) and entail construction of replacement building(s) with temperature regulation.*

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APPENDIX THREE: Species Accounts for Little Brown Myotis, Yuma Myotis and Big Brown Bat

Little Brown bats (*Myotis lucifugus)* and Yuma bats (*Myotis yumanensis*) are very similar in outward appearances and captured bats in some populations are almost indistinguishable (Figure 29). Further complications arise because these two species will often share roost locations. The best method for distinguishing the two species is using a combination of morphological features (such as forearm length) and confirming that identification by using an ultrasonic bat detector and observe echolocation call frequency (Weller et al. 2007). This is best done with the bat in the holding bag in what has been called a 'bag test' (Lausen et al. 2022; Luszcz et al. 2016). Often relying solely on a subjective assessment of fur sheen and length, forearm length, and ear color will produce less reliable identifications (Luszcz et al. 2016).

For the layperson, Big Brown Bat may also easily be confused with these two myotis species. All are regular users of building roosts and without experience, Big Brown Bats may also look small and definitive identification does require handling and close assessment. For experienced bat personnel, a photo that gives good detail of the face of the bat may provide enough information to identify Big Brown bats. Bat species can be identified through the use of DNA analysis of bat guano (a test that is now relatively cheap, easy, and reliable). Many species can be definitively identified, however there are still challenges with the Myotis species in some cases, but research is ongoing to refine this technique.

Figure 29. The three focal bat species for this document include Yuma and Little Brown Myotis, and Big Brown Bat. Photos (furthest left and right, J. Hobbs, middle, C. Olson).

Table 3. A comparison of morphological measures of Little Brown Myotis, Yuma Myotis and Big Brown Bat.

Descriptor	**Little Brown Myotis (*Myotis lucifugus*)**	**Yuma Myotis (*Myotis yumanensis*)**	**Big Brown Bat (*Eptesicus fuscus*)**
Longevity	Average 6-10 years Record: 39 years	Average 6-10 years (20-30 years possible)	Average 10-15 years Record: 19 years
Sexual maturity (both sexes)	210 days	One year	One year
Gestation	49-89 days	55 days	60 days
Birth dates	Late May to end of June	Late May through July	Late May to early July
Juveniles Take Flight	21 days	21-28 days	28-35 days
Weaning	25 days	35-42 days	32-40 days
Litter Size	1	1	Eastern populations 2 Western populations 1
Litters per Year	1	1	1
Weight at birth	2.5 grams	1.4 grams	3.3 grams
*Echolocation Frequency**	35-45 kHz	45-50kHz	30kHz
Lo f	44-48kHz	35-40kHz	26-30kHz
fc	48-53kHz	40-53kHz	27-31kHz
fmax	47-61kHz	41-39kHz	>65kHz
*Forearm length***	36 millimetres (33-40 millimetres)	34 millimetres (30-38 millimetres)	47.5millimetres (43-52 millimetres)
*Body length***	86 millimetres (70-108 millimetres)	82 millimetres (60-99 millimetres)	116 millimetres (98-131 millimetres)
*Wingspan***	248 millimetres (224-274 millimetres)	238 millimetres (205-260 millimetres)	328 millimetres (205-393 millimetres)
*Mass***	6-11 grams	4-8.5 grams	8.8-22 grams
Keeled Calcar?	No	No	Yes

Pelage	Brown, long and glossy; belly often lighter fur than back	Light-gray fur to almost black; belly is lighter than back	Pale to dark brown, wings and ears dark to black

**summary data from Nagorsen and Brigham (1993)

*frequencies of *full spectrum* reference calls: lo ƒ: lowest apparent frequency (kHz); ƒc: characteristic frequency, i.e., the frequency of the call at its lowest slope, or the lowest frequency for consistent FM sweeps (kHz), ƒmax: the frequency with the greatest power (kHz), from: sonobat.com (http://www.sonobat.com/download/RockyMtn_Acoustic_Table-Mar08.pdf)

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A.3.1. Little Brown Myotis

Little Brown Myotis (*Myotis lucifugus)*

Reproduction: "Swarming" occurs in the fall, usually near hibernation sites. Males and females congregate in an area, flying, foraging, and mating until environmental conditions force them into hibernation (Fenton and Barclay 1980). Females enter hibernation before males; however, males may continue to mate with females while females are hibernating (Thomas et al. 1979, Fenton and Barclay 1980). Males risk using up precious fat reserves with this strategy, but it may ultimately result in successful fathering of young. Females store sperm in their uterus over winter; ovulation occurs as they wake from winter hibernation and pregnancy starts at this point (Fenton and Barclay 1980). A female's body condition will determine if she can successfully maintain her pregnancy. Low fat reserves or unfavourable environmental conditions in spring can result in either failure to ovulate, resorption or abortion of the embryo (Jonasson and Willis 2011).

Adult morphology: Little Browns can vary in fur colour across their range. Typically, brown in colour, their fur can range from yellowish to olive and gray-brown to almost black depending on the population but usually they will have a paler belly (Nagorsen and Brigham 1993). Their fur is often described as long and glossy. The wings are darker brown to black. Little Brown bats have long hairs on their toes (Feldhamer 2015). Little Brown Myotis can be difficult to distinguish from Yuma Myotis; some populations of these two species are morphologically almost identical (Weller et al. 2007). However, generally, species may be distinguished using a combination of both features of their respective echolocation calls and forearm length (Weller et al. 2007, Luszcz et al. 2016).

Diet: *Myotis lucifugus* is a small to medium sized bat and prey is often smaller in size than that of larger bats. They are generalists, feeding on both emergent aquatic insects and a variety of other insects (Feldhamer 2015). Aquatic insects include midges, mosquitoes, mayflies (Ephemeroptera), flies, (Diptera) and caddisflies (Trichoptera); as well, small beetles (Coleoptera), lacewings (Neuroptera) and moths (Lepidoptera) are all included in their diet (Anthony and Kunz 1977, Belwood and Fenton 1976, Clare et al. 2011, Feldhamer 2015, Fenton et al. 1980, Herd and Fenton 1983, Rainey 2005, Saunders and Barclay 1992, Whitaker and Lawhead 1992). Little Brown Myotis are aerial insectivores, capturing their prey while in flight. They are nimble flyers, often found about one metre above the surfaces of still ponds and above the shrub layer in upland areas.

Distribution: Historically one of the most widespread and abundant bat species in across Canada and the United States, however they do not occur in Mexico and are absent from the central southern United States. Little Brown Myotis have experienced significant population losses in the eastern part of the range as a result of white-nose syndrome (Frick et al. 2015). Small populations remain in white-nose syndrome affected areas; unaffected areas have strong populations in the interim (WNS 2021).

Summer roosts: Little Brown bats use large diameter trees, buildings, rock crevices, bat houses, bridges, hollows, and cracks in large tree snags of older stands and woodpiles. Males and nonbreeding females roost separately from maternity colonies. Maternity colonies will seek out roosts that will hold a large population (Maxell 2015, Hayes and Wiles 2013).

Home Range and Movements: Little Brown Myotis have an estimated home range size of about 143 hectares (353 acres) or 13-26 hectares (32-64 acres) for a lactating bat (Coleman et al. 2014, Henry et al. 2002, Slough and Jung 2013). Home range of a colony is an estimate of the area that bats may travel for food each night. Other radio-telemetry studies have tracked bats moving up to 15 kilometres from their home roost (Falxa 2005, Towada and Falxa 2007). Generally, Little Brown Myotis are classified as "mid-range flyers" that are expected to fly more than 2 kilometres from their roost to forage, but generally range between 5-8 kilometres from their day-roosts (BC Ministry of Environment 2016, Anthony and Kunz 1977; Fenton and Barclay 1980; Rainey 2005, Kunz and Reichard 2010). In New England, Little Brown Myotis adults flew 37 kilometres from a release site to their day-roost a behaviour labelled "homing" by Davis and Hitchcock (1965). Juvenile Little Brown Myotis were not capable of this homing behaviour and would either find an alternative day-roost at the release site or disperse elsewhere (Davis and Hitchcock 1965). Distances moved between summer and winter habitats were 50–200 kilometres in Ontario (Fenton and Barclay 1980) and 1.6–80.5 kilometres in New England (Davis and Hitchcock 1965). In Manitoba, seasonal movements between summer roost habitat and winter hibernation sites ranged between 10-647 kilometres (Norquay et al. 2013). In New England, one female travelled 128 kilometres in three days (averaging 43.5 kilometres per night) (Davis and Hitchcock 1965).

Hibernacula/Winter roosts: Little Brown Myotis use both caves and mines with high relative humidity and temperatures slightly above freezing. Some of these bats have also been found hibernating in deep rock crevices in some states (Tholen et al. 2018). During hibernation, Little Brown bats hibernate in clusters and wake often to adjust. Little brown bats use caves and mines as hibernacula, where they form groups of a few to hundreds of thousands of individuals (Fenton and Barclay 1980, Keen and Hitchcock 1980).

Fidelity: Female bats are known to exhibit high levels of long-term fidelity to summer maternity roosts especially if the roost location is a "permanent" feature (Lewis 1995, Fenton and Barclay 1980). Bats may switch roosts in response to a change in roost microclimate or condition, to reduce parasite load, to relocate closer to favourable foraging areas, in response to disturbance or predation risk, or so that young will become familiar with alternative roost sites (Lewis 1995; Rabe et al. 1998). Bat species that use permanent roosts exhibit less roost-switching behaviour than species that use ephemeral roosts, such as trees (Lewis 1995).

Little Brown Myotis also show strong fidelity to winter hibernation sites; however, roost relocation has been observed for both males and females between hibernacula with movements ranging between 200-300 kilometres between seasons (Norquay et al. 2013).

Threats:

Overwintering populations have experienced losses up 90-95% due to effects of white-nose syndrome in some location (Frick et al. 2010a); populations in Canada are now listed as federally endangered as of 2014 and a recovery strategy subsequently was developed (Environment and Climate Change Canada 2018, WNS 2021).

Increased fidelity to permanent roost types makes Little Brown Myotis more vulnerable to local extirpation if there is a limited number of roosts available or known to them, and especially if the roosts are removed from the landscape or made ineffective as a result of human disturbance or modification (e.g., destruction of cliff faces or caves, modification of cave environments, disturbance at roost sites, or capping of mines). Deforestation, urbanization, pesticide use (direct and indirect effects), water pollution, vandalism, disturbance at cave hibernation sites, and the removal and/or mismanagement of forest resources such as snags and fallen trees all represent threats to Little Brown Myotis. Loss of old buildings and/or exclusions from building sites used as maternity roosts by Little Brown Myotis may also have significant effects on local populations. Predation by housecats on bats occurs in some areas; natural predators include owls and raptors like goshawk that are active in the early evening.

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A.3.2. Yuma Myotis

Yuma Myotis (*Myotis yumanensis*)

Reproduction: Mating occurs in the fall, females store sperm overwinter, ovulation occurs when they emerge from hibernation and fertilization and the initiation of pregnancy begins (Dalquest 1947). If the female’s fat reserves are low or other stressing conditions exist, she will not ovulate, or she may resorb or abort the embryo (Braun et al. 2015). As pregnancy progresses, females congregate in maternity colonies in roosts with warm or even hot, but stable temperatures. Females give birth to single pups between May and July, depending on latitude (Braun et al. 2015). Females bear young in the summer following their birth (Herd and Fenton 1983). Older mothers tend to give birth earlier than younger mothers, which may result in higher survival rates for earlier born offspring (Milligan and Brigham 1993). Males captured in June, July, and August may show signs of spermatogenesis (Herd and Fenton 1983).

Adult morphology: A medium-sized Myotis with bi-colored fur (tips are light-colored while closer to the skin is a dark brown color however, brown shades can differ from region to region). The under-belly coat is whitish to buff while the back can range from pale brown to nearly black. The fur has a duller appearance than the Little Brown Myotis. Ears may reach the nostrils when pushed forward, the tragus is blunt and about half the length of the ear (Nagorsen and Brigham 1993). The wings are darker brown to black (Bradley and Hickman 2013). The calcar is not keeled.

Diet: Yuma Myotis are small bats and therefore seek out smaller, soft-bodied insects as prey. This species is more closely associated with water than most other North American bat species, foraging closely above the surface. Their diet is thus dominated by aquatic emergent insects such as flies like chironomids (Diptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera) but small beetles (Coleoptera) and moths (Lepidoptera) are also found in their diet (Kellner and Harestead 2005, Braun et al. 2015). However, representation of insect species groups in the diet may vary regionally (Braun et al. 2015). Yuma Myotis also repeat hunting paths nightly (Braun et al. 2015).

Distribution: Yuma Myotis is a western bat species with occurrences reported in a broad swath from British Columbia, Canada to central Mexico, and east to Oklahoma (Nagorsen and Brigham 1993, Bradley and Hickman 2013).

Summer Roosts: Yuma Myotis are closely associated with water. They regularly forage over water and roost sites are often found nearby. Roost habitat will be found within riparian habitats near lakes and tributaries, wetlands, ponds, or in areas near water sources within scrublands, deserts, and forested habitats (Braun et al. 2015). These bats use rock crevices, trees, buildings, caves, and mines for roosting. Tree roosting bats prefer large living conifer and hardwood trees in areas with high forest cover near water (Evelyn et al. 2004). Some bats also roost under bridges and in abandoned swallow nests. (Maxell 2015, Braun et al. 2015). Maternity colonies can mass in the thousands, sometimes with other species (often with Little Brown Myotis); the largest colonies are often found in buildings. They are regular users of bat houses.

Roost conditions required by pregnant and lactating females include warm, stable temperatures, protection from wind, rain and predators, high relative humidity, and nearby sources of drinking water. Females may seek lower elevations to take advantage of warmer climates for gestation and maternity colony conditions; characteristically, roosts have high ambient temperatures (36-39C) and bats cluster together to conserve heat (Betts 1997). However, Yuma Myotis will exhibit physiological stress at ambient temperatures near 41°C (106 °F, Licht and Leitner 1967) and may die if their body temperatures rise above 42°C (108 °F) if they are restricted from fanning their wings (Reeder and Cowles 1951). Death is also a risk if they experience 40 minutes of exposure to an ambient temperature of 44.5°C (112.1 °F, O'Farrell and Studier 1970); temperatures between 45 and 50°C (113 and 122 °F) represent a potential lethal threat (Licht and Leitner 1967). Bats will take measures to avoid overheating including avoiding the hottest parts of the roost, salivating, and licking for heat dissipation in combination with panting (Licht and Leitner 1967, O'Farrell and Studier 1970). Licht and Leitner (1967) observed Yuma Myotis with open-mouth panting and a wet muzzle at body temperature of 41.5–42°C (106.7-107.6 °F).

Yuma Myotis was found to have a low tolerance to water and food deprivation and animals were found dead after two days of deprivation-testing suggesting they are unable to survive 2 successive days without rehydration (Studier et al. 1970). Betts (1997) noted that high humidity of more than 90% seems to be of utmost importance to reduce evaporative moisture loss for Yuma Myotis maternity colonies.

As is the case with many other bat species, males tend to roost individually (Texas Parks and Wildlife n.d.) compared with reproductive females, and males and juveniles may seek higher elevation roosts where they can find cooler daytime temperatures and have greater opportunity to use torpor (Dalquest 1947).

Home Range/Movements: Yuma Myotis are considered "mid-range" flyers and tend to fly more than 2 kilometres to forage but generally range 5 – 8 kilometres from their day-roosts and have been observed to travel up to 13 km searching for food (G. Falxa, n.d.; Maxell, 2015). In Squilax, B.C., Yuma Myotis were observed flying 4 kilometres between roosting and foraging areas (Nagorsen and Brigham 1993). In California, lactating females were captured an average of 2 kilometres from their day-roost sites (Evelyn et al. 2004).

Hibernacula/Winter roosts: Yuma Myotis are hibernators and are assumed to winter at sites near their summer roosting habitat; however, winter hibernation sites are not well known, and it is possible that some populations make lengthy flights to find suitable hibernation habitat (Braun et al. 2015).

Fidelity: Yuma Myotis may have high fidelity to permanent-type maternity roost habitat (such as in buildings) and return to the same location year after year (Kellner and Rasheed 2001). Within a single season, these bats may use natural roost sites (like trees) for several days (a California study found Yuma using tree roosts for an average of 4.8 days with an average between roost distance of about 2 kilometres (Evelyn et al. 2004).

Threats: A Myotis was detected in Washington State in 2016 with visible signs of white-nose syndrome; this was the first record of WNS in this species. The disease continues to spread; however, the extent of mortalities is unknown, primarily because there are few hibernation sites known and mortality rates remain unknown. Yuma Myotis are susceptible to roost abandonment after human disturbance (Verts and Carraway 1998). This species may be affected by ill-timed exclusions of colonies from buildings, sealing of abandoned mines, and poor management practices of forests and riparian areas.

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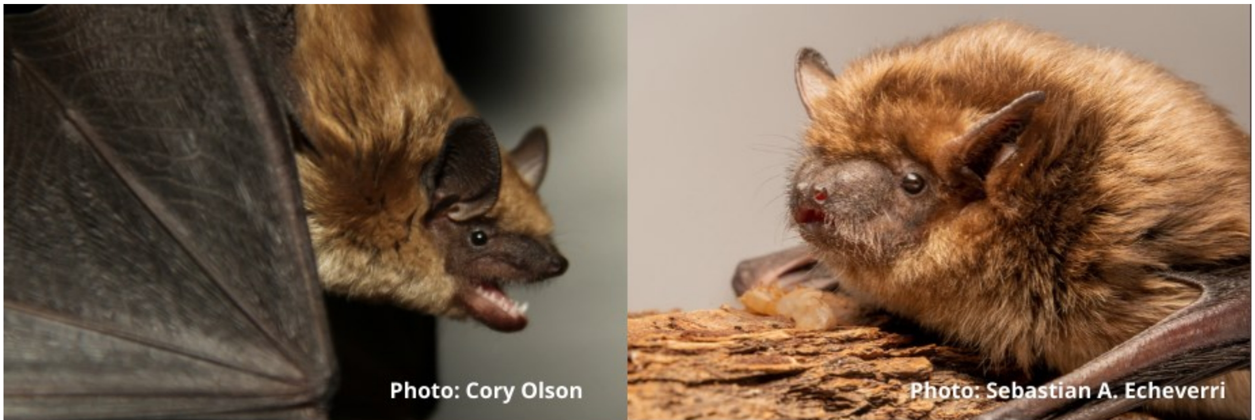
A.3.3. Big Brown Bat



Big Brown Bat (*Eptesicus fuscus)*

Annual timeline: Big Brown bats give birth between mid-June to late July in southern Alberta (Holloway 1998, Lausen and Barclay 2006a, Barclay 2012). Environmental conditions, temperature and precipitation can influence the timing of birth and length of gestation (Grindal et al. 1992, Holroyd 1993, Barclay 2012). Mothers nurse their pups for 4-5 weeks (Kunz 1971); juveniles begin flying between mid-July through until the end of August. Hibernation lasts between November to April (Nagorsen and Brigham 1993), but these bats periodically become active throughout the winter, roost switching or flying for unknown physiological reasons (Lausen and Barclay 2006b, Klüg-Baerwald et al. 2016, 2017, 2021).

Adult Morphology: A relatively large bat, this species has a large, broad head and nose, and long fur that varies in colour from pale to dark brown that tends to be slightly oily (Nagorsen and Brigham 1993). Ears, face, and membranes are very dark to black; ears just reach the nose when pushed forward, the tragus is short and blunt (Nagorsen and Brigham 1993). The calcar has a prominent keel.

Diet: Big Brown bats are flexible, generalists. Their diet often is dominated by beetles, but they will eat most types of insects that arise in a variety of habitat types (riparian, upland, farmland, and pasture areas). They will also hunt patches of insects that collect around outdoor lights. Insects in the diet include true bugs (Hemipterans), flies (Dipterans), moths (Lepidopterans), Hymenoptera (flying ants, some bees) and aquatic emergent insects like caddisflies (Trichopterans) (Kurta and Baker 1990, Perkins 1990, Whitaker 1995). Big Brown bats are often associated with areas near rivers (Brigham and Saunders 1990, Wilkinson and Barclay 1997, Holloway and Barclay 2000); roosting sites are likely to be found near rivers or some type of water. They are strong flyers that can move up to 26 kilometers away from maternity roosts to hunt in a night (Wilkinson and Barclay 1997). They are an aerial insectivore that hunts at around tree height and above foliage (Brigham 1991).

Distribution: Big Brown bats are widely distributed across North and Central America and even from parts of South America (northern Columbia, northwestern Venezuela and northern Brazil) (Kurta and Baker 1990). Big Brown bats are one of the most common and widespread bat species in North America (Kurta and Baker 1990) however, the abundance of Big Brown Bat decreases in regions dominated by coniferous forests (Kurta et al. 1989).

Summer Roosts: Their natural roosts include cavities in large old trees and warm rock crevices; however, they will also readily use both buildings and bat houses (Schowalter and Gunson 1979, Agosta 2002, Lausen and Barclay 2003, Willis et al. 2003). In some areas, human structures may represent their primary roosting habitat (Schowalter and Gunson 1979, Grinevitch et al. 1995, Agosta 2002).

Home Range/Movements: Compared to some other bat species, Big Brown bats are considered fairly sedentary and likely remain within 50 kilometres of their birthplace (Barbour and Davis 1969). Big Brown bats rarely move more than 80 kilometres between summer and winter roosts, though there is evidence that some individuals in the Midwest migrate south for winter (Barbour and Davis 1969. Big Brown bats are considered "long-range" flyers that tend to make foraging flights that are generally 10 kilometres or more from their day roosts, but this distance can be much further while other populations seem to travel only short distances. Big Brown bats have been recorded travelling up to 53 kilometres between day-roosts and foraging areas in Minnesota (Beer 1955). In northeastern Oregon, Big Brown Bat roost trees were 0.45–3.8 kilometres from capture sites, and the maximum recorded distance between roosts for two individuals that used four different tree roosts was 2.1 kilometres (Betts 1996). In South Dakota, the mean distance between capture and roost site was 1.5 kilometres (Cryan et al. 2001). In the Okanagan, B.C., commuting distances between day-roost and foraging areas ranged from 1 to 4 kilometres (Brigham 1991). In this same region, the average distance between roost sites and foraging areas was 1.8 kilometres ± 0.1 (mean ± SD; n = 163 flights); in Ontario, it was 0.9 kilometres ± 0.09 (mean ± SD; n = 85 flights) (Brigham 1991). In Alberta, reproductive female Big Brown bats foraged 20–25 kilometres from their day-roosts along the South Saskatchewan River Valley before returning to the roost (Wilkinson and Barclay 1997).

At an urban-rural interface in Indiana, reproductive Big Brown bats (including pregnant and lactating females) had foraging areas of 2.70 ± 0.49 km^2 (mean ± SD; n = 4), whereas non-reproductive females had larger foraging ranges of 19.03 ± 5.58 km^2 (mean ± SD; n = 7) (Duchamp et al. 2004). Big Brown bats appear to tolerate urban development; they readily fly through these areas or use them for foraging habitat (Duchamp et al. 2004).

In Oregon, Big Brown bats moved 0.83 ± 0.81 kilometres (mean ± SD; n = 5) between successive tree roosts; the longest distance between roosts was 2.1 kilometres (Betts 1996).

Distances travelled between winter hibernation sites and summer foraging areas can be up to 300 kilometres but are usually no more than 80 kilometres (Nagorsen and Brigham 1993). In Minnesota and Wisconsin, this distance ranged from 0.8 to 98.2 kilometres (average 11.9 kilometres, n = 25) (Beer 1955). In Ohio, winter roosts tended to be within 32 kilometres of summer roosts (Brenner 1968).

Hibernacula/Winter Roosts: Big Brown bats will hibernate in buildings (Schowalter and Gunson 1979, Perkins et al. 1990, Whitaker and Gummer 1992, Nagorsen and Brigham 1993). Studies of natural hibernation sites have found that deep rock crevices in river valleys appear to be important hibernacula for Big Brown bats in prairie environments (Lausen and Barclay 2006b, Klüg-Baerwald et al. 2017).

Fidelity: Big Brown bats often use multiple natural roosts in summer (Willis and Brigham 2004) but show high fidelity to building roosts (Lewis 1995, Barclay 2012).

Threats: Annual adult survival rates can be high (e.g., 0.79 for Big Brown Bat), and longevity can reach 19 years (Hitchcock 1965, Holroyd 1993). However, these estimates may represent unusual circumstances. For example, life expectancy for Big Brown Bat in some studies ranges between 5.65 and 6.65 years (O'Shea et al. 2011).

Big Brown Bat has been shown to be affected by white-nose syndrome but less so than other species. One study from New York state found Big Browns to be resistant to the fungus that causes WNS (Frank et al. 2014) but another study in the northeast found a 41% decline in Big Brown Bat populations five years after WNS had arrived in that area (Turner et al. 2011). Other threats to this species include habitat loss (loss of old, mature trees for roosting), and wetlands and other productive habitats for foraging. Widespread use of pesticides may impact prey populations; global observations of insect population declines will affect this species. Destruction of colonies, especially in anthropogenic structures like buildings is probably the leading cause of mortality for this species. Big brown bats are also affected by wind turbines, but less so than migratory bat species. Climate change may affect all bat species; bats are highly responsive to environmental temperatures and survive winter by enduring predictable, stable temperatures, while during summer, bats require warm temperatures to ensure maximum growth rates of pups, and warm, calm, dry nights for hunting insects. Disruption of local weather patterns will impact bats.

Of particular concern for Big Brown Bat is their tendency to hibernate in buildings in winter. Generally, for bats, hibernation sites are considered critical habitat. It is unclear whether winter building use by this species is an adaptation to a new habitat resource (buildings) or if it reflects a loss of habitat (natural winter hibernation sites) or both. The status of the species needs to be re-examined to ensure that loss of summer and/or winter roosting habitat in anthropogenic structures does not result in significant population losses. In some areas, human structures may represent their primary summer roosting habitat (Schowalter and Gunson 1979). Living in close proximity with humans puts them at risk of deliberate or accidental disturbance or mortality from human activities. Bat populations have historically not been monitored, so it is unclear what the impact is from the loss of anthropogenic roosting structures on this species.

Big Brown bats were tested to determine if they were capable of being infected by the SARS-CoV-2 virus as this novel coronavirus was seen as not only a potential threat to humans if bats could become a new reservoir for the disease in North America, but it could also be a threat to bat populations (Hall et al. 2020). Exposure tests determined that Big Brown bats were not affected by the SARS-CoV-2 virus and therefore not a threat to humans, but anyone handling bats or working in close proximity with bats has been advised to use appropriate PPE (Hall et al. 2020).

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APPENDIX FOUR: Bat Species' Thermal Preferences/Tolerances

Table 4. This table is not an exhaustive list but provides some examples of what is known for thermal preferences/tolerances of some species and/or reproductive stages.

Bats	Thermal Notes
Generally – all bats	● Normothermic (active) body temperatures (Tb): 31-38 °C (88-100 °F, McKechnie and Wolf 2019) ● Max Tb (lethal upper): 42-45 °C (108-113 °F, McKechnie and Wolf 2019) ● Leave roosts when temperatures exceed 40 °C (104 °F, Lourenço and Palmeirim 2004) or show behavioural changes such as crawling to openings, urinating, fanning, etc.
Bats (sex/reproductive condition not indicated)	● Max ambient temperature (Ta) before visible signs of heat stress – 42 °C (108 °F)– Little Brown Myotis (Ta-max: Noakes et al. 2021); experimental cut off Tb at Ta-max of 41.6 ± 1.6 °C (106.9 °F) ● Tolerated a Tb = 4 2°C (108 °F) when exposed to Ta-max of 45 °C (113 °F) in cave-dwelling Little Brown Myotis in KY (Henshaw and Folk 1966) ● Speakman and Thomas (2003) found 36 °C (99 °F) to be the upper critical temperature limit for Little Brown Myotis ● If bats were unable to fan wings or use other behavioural avoidance strategies, ambient temperatures of 42 °C (108 °F) were lethal for Yuma Myotis and signs of heat stress were evident for this species at ambient temperatures of 40-41 °C (104-106 °F, Licht and Leitner 1967). ● Thermal neutral zone (TNZ) for Yuma Myotis was defined between 32.5 – 36.5 °C (90.5 - 97.7 °F, Braun et al. 2015) ● TNZ of Little Brown Myotis is Tb = 32-37 °C (90-99 °F, Studier and O'Farrell 1976)
Pregnant Females	● Yuma Myotis – up to 98 °F/36.7° C (Hodgkins 1985 – nursery roost) ● Big Brown Bat – less than or equal to 90 °F/32.2 °C (Hodgkins 1985 – nursery roost)

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APPENDIX FIVE: Citizen Science-based Bat Roost Monitoring Programs

A.5.1. Safety for Public / Volunteers

Ensure private landowners and volunteers are aware that wildlife, particularly bats, should not be handled. If a bat must be moved, wear gloves and follow guidance on rabies prevention. If collecting or cleaning up, ensure appropriate respiratory protection is used when in enclosed spaces. For example:

- As with the handling of any animal feces, ensure gloves are used.
- Guano is an excellent fertilizer but should not be transported away from the roost site, due to the possible persistence and transport of *Pd*, the fungus responsible for WNS, in guano.
- Promote using guano as fertilizer ONLY in the immediate surroundings (typically <10 km from source).
- Wear a mask when cleaning up, sweeping or scooping guano, especially in enclosed spaces like building attics, as particles can be irritants, there may be other irritants like insulation, and in some places of the continent there is the risk of inhaling fungal spores that can cause histoplasmosis (see 4.5.8 Human Health Cautions*).*

Why consider public involvement with bat boxes? As discussed in other sections, many bat species live in close association with people. In urban and rural areas, bat boxes can provide safe, secure roost sites for a variety of bat species, and can be an essential part of managing bats and providing habitat in these altered habitats.

For bats that roost in anthropogenic structures, bat boxes installed by private landowners may be part of a bat-friendly exclusion strategy. Bat boxes provide conservation-minded members of the public an avenue to 'do something' for bats, through habitat enhancement on private or public land.

Bat boxes can also provide a way to engage with the public, either through workshops where people make boxes, or through on-one conversations about installation, maintenance, and monitoring. The process of learning about bat box characteristics and installation, plus how to monitor a bat box, certainly play a role in increasing awareness and knowledge of bats, and in recruiting people who may become roost stewards. As such, bat boxes can have a conservation value well-beyond just protecting the bat colony they house.

Finally, public monitoring of bat boxes, either casually or through an existing Citizen Science program, offers a method to achieve large-scale monitoring of use of boxes and may be useful to develop a dataset to analyze bat preferences. For all these reasons, it is essential to consider public involvement with bat boxes and conservation of species that use bat boxes.

Who IS 'the public'? Public involvement may range from individual landowners who are interested in an exclusion or habitat enhancement, to community groups such as young Girl Guides or knowledgeable local naturalist groups. Consider the public you are working with and determine what an effective use of their time and resources may look like, so as to use conservation funds and resources effectively *and* to benefit the public.

As with any bat box installation, however, a key step before initiating any bat box project with the public/ a private landowner is to consider if a bat box is necessary or appropriate in the situation. See below for best practices specific to each of these situations.

Because recommendations are for multiple (ideally 4+) bat boxes, consider a neighbourhood or community approach, with multiple boxes installed in relatively close proximity to provide a roost area (e.g. install multiple boxes within ~100 m in the neighbourhood or at local parks). This community stewardship model will help provide a range of temperature options for bats.

Clearly communicate the best management practices that are outlined in this document when working with the public or groups that are engaged with roost stewardship/bat-conservation. Always ensure public, including organizations such as conservation land trusts, are aware that there are alternatives to bat boxes. Bat boxes are not effective mitigation for loss of complex natural habitats that provide abundant natural roosts and foraging habitat, so *restore and protect natural habitats where possible*.

A.5.2. Follow-up -- Tracking Bat Houses

Publicly installed bat boxes offer a potential data source for research into bat preferences and present an opportunity to monitor bat populations through local/regional/national or continental programs (e.g., North American Bat Monitoring Program, www.nabatmonitoring.org). To track roosts appropriately, certain information should be solicited.

It is recommended to:

- Encourage bat box owners to register their bat box with a Citizen Science monitoring program (see Table below).
- Bat programs should keep a list of all contacts who receive or build or install a house for follow-up.
- Confirm if bat box owners give permission for data on their bat house (location, box characteristics, and installation information) to be shared provincially for research.
- Always collect standard information on bat house characteristics and installation details, to aid in determining bat preferences. This should include:
    - Type and size (e.g. nursery box, rocket box, condo)
    - Number of chambers
    - Colour
    - Aspect
    - Mounting surface (pole, wall).
- During site visits, record basic characteristics of successful and unsuccessful bat houses (e.g., evidence of use, location, bat box type, mounting method, height, aspect, colour).

Table 5. Bat monitoring and conservation programs currently active in Canada and the USA (list courtesy of Gabriel Reyes). Protocols refers to ability to report roost information and location, or emergence count data, or both. Some websites/programs also provide Roost Monitoring forms that can be filled in to provide details such as bat box styles, colours, mounting details, reasons for placement/eviction, a description of the surrounding habitat, etc. Some community bat programs provide other opportunities for citizen science involvement such as submitting guano samples to identify species of bats using a roost through genetic processing of the guano (e.g., Alberta Community Bat Program).

Country	State/ Province/ Area	Website	Protocols
USA	Nation-wide	North American Bat Monitoring Program www.nabatmonitoring.org	
USA	California	https://wildlife.ca.gov/Conservation/Mammals/Bats/Report-Colony	roost reporting
USA	Connecticut	https://portal.ct.gov/DEEP/Wildlife/Learn-About-Wildlife/Bats-in-Connecticut	roost reporting
USA	Delaware	https://dnrec.alpha.delaware.gov/fish-wildlife/conservation/bats/	Emergence
USA	Georgia	https://georgiawildlife.com/bat-roost-monitoring#:~:text=Set%20up%20and%20be%20ready,the%20roost%20to%20count%20bats.	Emergence
USA	Illinois	http://www.illinoisbats.org/?page_id=314	Both
USA	Louisiana	No website Found (email nanderson@wlf.la.gov)	
USA	Maine	http://www.byrnebatbiology.com/#contact-1	Both
USA	Massachusetts	https://www.mass.gov/service-details/bats-of-massachusetts	Both
USA	Minnesota	https://www.dnr.state.mn.us/reportbats/index.html	Both
USA	Missouri	https://www.facebook.com/pg/MissouriBatCensus/about/?ref=page_internal	
USA	New Hampshire	https://www.wildlife.state.nh.us/surveys/bats.html	Both
USA	New Jersey	http://www.conservewildlifenj.org/protecting/projects/bat/bat-count/	Emergence
USA	Ohio	https://www.facebook.com/yourwildohioexplorer/posts/citizen-science-ohio-bat-roost-monitoringare-you-interested-in-helping-with-our-/2182992248443990/	
USA	Pennsylvania	https://www.pgc.pa.gov/InformationResources/GetInvolved/Pages/AppalachianBatCount.aspx	Emergence
USA	South Carolina	https://www.dnr.sc.gov/wildlife/bats/batwatch.html	Emergence
USA	Tennessee	http://www.tnbwg.org/TNBWG_Citizen%20Science.html	Emergence
USA	Vermont	Vermont's Got Bats? https://vtfishandwildlife.com/learn-more/living-with-wildlife/got-bats https://anrweb.vt.gov/FWD/FW/BatColonyReporting.aspx?_ga=2.18316089.1858133693.1609814625-746235048.1605217714	Emergence
USA	Wisconsin	Wisconsin's Bat Program https://wiatri.net/inventory/bats/ http://www.wiatri.net/Inventory/Bats/Volunteer/Roosts/	both
CAN	Alberta	Alberta Community Bat Program www.albertabats.ca	both

		https://www.albertabats.ca/citizenscience/ and https://www.albertabats.ca/wp-content/uploads/ACBP_CitSci_Form.pdf and guano sampling at https://www.albertabats.ca/wp-content/uploads/ACBP-DNA-Sampling-Protocol.pdf	
CAN	British Columbia	Community Bat Programs of British Columbia https://bcbats.ca/ and https://bcbats.ca/got-bats/report-your-bats/ and https://bcbats.ca/bat-boxes/register-your-bat-box/	Both
CAN	Nationwide	Batwatch https://batwatch.ca/	Both
CAN	Nova Scotia	http://www.batconservation.ca/index.php?q=node/add/batreport	roost reporting
CAN	PEI, Nfld and Labrador, New Brunswick, and Nova Scotia	http://www.cwhc-rcsf.ca/docs/bat_health/CWHC%20Atlantic%20Bat%20Hotline.pdf and http://www.cwhc-rcsf.ca/bat_health_resources.php#population-monitoring	Both
CAN	Saskatchewan	https://www.naturesask.ca/useful-resources/news/2020/375	Both

Figure 30. Volunteer bat counters settle in at a location where bats will be backlit against the night sky enable easy counting as they emerge from a bank of bat boxes in Port Coquitlam, British Columbia. Having multiple independent counters per bat box is recommended, so that a range of estimates can be obtained – counting bats emerging, especially from large colony roosts, can be tricky! Photo by M. Edmonds.

A.5.3. Bat Box Building Workshops

▪ A.5.3.1. Construction – Recommended Approaches for Organizations

Construction of high-quality, multi-chamber, bat boxes is time-consuming. Several approaches are recommended, based on experiences (C. Olson, S. Holroyd, M. Kellner, pers. obs.):

- Use experienced woodworkers: Consider partnering with an individual, organization, or institution with construction or woodwork experience, who can build bat boxes for distribution (e.g., prison, disabled woodworker business, high-school woodworking programs, keen community volunteers with woodworking shops, rod, and gun clubs).
- Volunteers or students: If volunteers are interested in building bat boxes, ensure they have the necessary carpentry skills or can acquire them (e.g., in a high-school woodworking class) to build high-quality bat boxes. Poorly constructed boxes have less likelihood of occupancy and do not last as long, so are not an optimal use of resources. As a result, most Community Bat Programs have moved away from volunteer bat house building workshops and use experienced carpenters instead.
- Supply builders with optimal plans or links to plans online. Some boxes, such as small, single chamber boxes are not recommended. However, do install a variety of boxes if possible, including deep and shallow boxes, wide and narrow chambered boxes, etc. as this will provide varying microclimates and appeal to bats of different stages in reproduction, different sexes, and different species. All boxes need standard components including a long rough landing platform, and ways for bats to move between chambers inside the box without having to exit the box.
- Consider partnering with local hardware stores when possible, for material cost-reduction.
- Bat-box building workshops: These are *a lot* of work. If you are doing a workshop, due to the length of time to make a multi-chamber box, do as much preparation as possible (e.g., pre-cutting and roughening all pieces) to ensure projects can be completed in the allotted time. Combine a workshop with an educational presentation and provide instructions on installation and monitoring.

▪ A.5.3.2. Distribution (who gets a bat box and how to distribute bat boxes)

- Boxes given away for free are less likely to be installed, installed correctly, and monitored. This can be a large drain on limited budgets and reduce effectiveness of the program. Consider:
    - A refundable deposit, returned after installation and/or three years of monitoring (proof of installation and/or occupancy count data required). If unoccupied after several years (verified through monitoring), move the box.
    - Pricing that covers materials and installation costs.
    - Pricing that contributes funds to the bat project.
- Prioritize who will receive bat boxes and ensure they commit to installing enough to suitably mitigate a lost roost or enhance an area depauperate of roosts (e.g., eviction is planned, landowners can commit to monitoring including annual bat counts and/or that are centrally located for volunteers to do roost counts and guano collections; Figure 30). It is wise to ensure recipients provide consent to share roost installation information with provincial/state or

national databases. In most cases, it is best if the recipient signs a consent form to share this information, and thus this information sharing process should be set out ahead of time (see Organizational Gaps5.5 Organizational Gaps).

- Hand-deliver bat boxes if possible, and review installation criteria, select a site, and promote monitoring. Ideally include installation by a trained person.
- Maintain a contact list of all bat house recipient and/or workshop participants and obtain permission to share data for research purposes, and/or ensure recipients all register bat boxes on a central website/database.
- Ensure that installation, maintenance, and monitoring advice is provided to all bat house recipients, regardless of how the boxes are built/sourced.
- Follow up -- ensure bat boxes get installed. Many donated (free) bat houses do not get installed or may be installed in suboptimal locations. Maximize effectiveness of bat boxes by ensuring that boxes are sited in optimal locations. Consider:
  - Site visits to assist with siting and installation by trained staff/ volunteers.
  - Financial incentives to encourage installation by homeowners (e.g., a deposit returned after installation).
  - A fee-for-service model including a site visit, bat boxes, and install.
- Provide a regional instruction sheet, including recommended colour of bat box, facts about local bats, maintenance recommendations, and your contact information.
- Record details about the installation. Share these details with state/provincial repositories of these types of data. Be sure to obtain consent for some specified level of information sharing.

A.5.4. Measuring Microclimates

There are a variety of temperature and temperature/humidity data loggers available on the market that are suitable for use in bat houses and bat mini-condos and are reasonably affordable ($50 - $325). Some allow you to download/launch/program them wirelessly via mobile devices, such as smart phones, making them relatively easy to use and allow wireless download of data. Some are small sealed (waterproof) units that can be placed inside the roost (e.g., "pendant" style), and these can be handy to wash/decontaminate between roosts. One should always verify whether such units are emitting high frequency ultrasound while they are logging, as some units have been found to do so (e.g., Willis et al 2009) and this could deter bats from the roost. This is likely only to be a problem in small roost sites like bat boxes where bats may not be able to roost far enough away from the logger. To avoid this problem, one can instead just insert a sensor tip on the end of a cable into the roost, such as into a bat box chamber. The body of the logger with the bulk of the circuitry that could potentially emit the ultrasound can then be mounted on the outside of the bat box instead. Some examples of loggers that have long sensor cable(s) include those produced by Onset Corporation (HOBO; e.g., Model MX2300 series). When planning to use any of these data loggers it is best to install them during construction of the bat house. If you install them on an existing bat house that is mounted on a post, in most cases you will have to drill a hole to insert the sensor probe into the warmest part of the bat house.

If installing a data logger in a bat mini-condo, consider installing them in three different locations, such as at the top of the interior ceiling, inside one of the roosting chambers and on the bottom of the condo floor. When measuring microclimates in a bat box, one should often try to measure the temperature at the tops of the front and back chambers and measure the outside temperature (a datalogger encased within a solar shield). This will provide you with the hottest location in the bat box, which may or may not be the front chamber (depending on whether it is building- or pole-mounted and what direction it faces). The range of temperatures in a bat box will always range from some warm temperature at the top of the chambers to whatever the ambient temperature is at the opening. It is a good idea to get a sense of what the microclimate options are within roosts that you install to know if they provide a wide enough range of microclimates for a colony to raise young throughout the entire reproductive season.

Ideally, one would collect occupancy data to pair with the microclimate data – on other words, was the roost being used at a particular point in time when you have a measure of the microclimate. This can be useful to learn what temperatures might be too cold or too hot for bats in your area. Occupancy can be determined using multiple methods (see Determining Occupancy).

APPENDIX SIX: Microclimate of Attic Building Roosts Versus Bat Boxes – A Case Study from British Columbia.

Author: Susan Dulc

The following data are unpublished data from Master of Science candidate Susan Dulc (Thompson Rivers University, Kamloops, B.C.) showing the differences in microclimates of roosts (bat boxes and building attics) used by mixed colonies of Yuma and Little Brown Myotis in the Creston, British Columbia area.

Table 6. Daily roost microclimate characteristics, by site and structure type (i.e., bat box or building roost), over a three-year period (2019-2021) between May 23 to July 10 (all roosts were monitored for 49 days; with the exception of Box R in 2020 which was monitored 0 days due to HOBO datalogger failure [n/a]). All roosts are in the West Kootenay region of British Columbia. Temperatures inside (roost) and outside (ambient) at 3 building roosts and 3 bat box roosts, used by bats to raise young.

**indicates years where the comparison period coincided with a heatwave. ŧRoost T1 was occupied for 17/49 days in 2019, 8/49 days in 2020 and unoccupied in 2021 during the comparison period; all other roosts were continuously occupied during the monitoring period.*

YEAR	Characteristic	Roost Type and ID					
		Building A	Building C	Building S	Box R	Box T1 ŧ	Box T4
*2019**	Ambient Temp Max (°C)	35.0	33.5	31.0	35.0	31.5	31.5
	Roost Temp Max (°C)	39.0	32.4	30.0	43.2	39.5	41.7
	# Days Roost 20-40°C	48	42	49	49	33	13
	# Days Roost exceeded 40°C (proportion of days monitored)	0 (0)	0 (0)	0 (0)	8 (0.16)	47 (0.96)	49 (1.00)
	# Days Roost 100% RH	0	0	0	49	11	4
2020	Ambient Temp Max (°C)	37.8	35.3	34.7	35.6	35.0	35.0
	Roost Temp Max (°C)	38.3	33	35.7	*n/a*	31.5	49.5
	# Days Roost 20-40°C	47	40	21	*n/a*	41	47
	# Days Roost exceeded 40°C (proportion of days monitored)	0 (0)	0 (0)	0 (0)	*n/a* *n/a*	0 (0)	2 (0.04)
	# Days Roost 100% RH	0	0	0	*n/a*	0	33
*2021**	Ambient Temp Max (°C)	44.2	41.3	41.8	44.7	40.6	40.6
	Roost Temp Max (°C)	48.6	37.6	47.5	48.8	52.9	52.2
	# Days Roost 20-40°C	49	35	35	48	45	49
	# Days Roost exceeded 40°C (proportion of days monitored)	15 (0.31)	0 (0)	3 (0.06)	13 (0.27)	21 (0.43)	16 (0.33)
	# Days Roost 100% RH	20	0	22	49	0	43

APPENDIX SEVEN: Innovative New Bat Box Design – A Case Study from Alberta by Northern Alberta Institute of Technology.

Author: Dave Critchley

The following bat box was designed by students Jenna Hlewka, Véronique Caron, Cyril Kaderabek, Hafida Aissiou, Krystal Hartog, Bianca Unrau, and Csilla Harsasi under the supervision of Dave Critchley (Figure 31). It won the Quarry Life Award – Heidelberg Cement and was supported by InsolCorp. For full project details: www.quarrylifeaward.com/download-final-report/57131/ruling_the_roost_final_submission.pdf.

While there has been some bat occupancy, thorough monitoring has yet to occur, and temperature set-points have yet to be optimized and will vary with context.

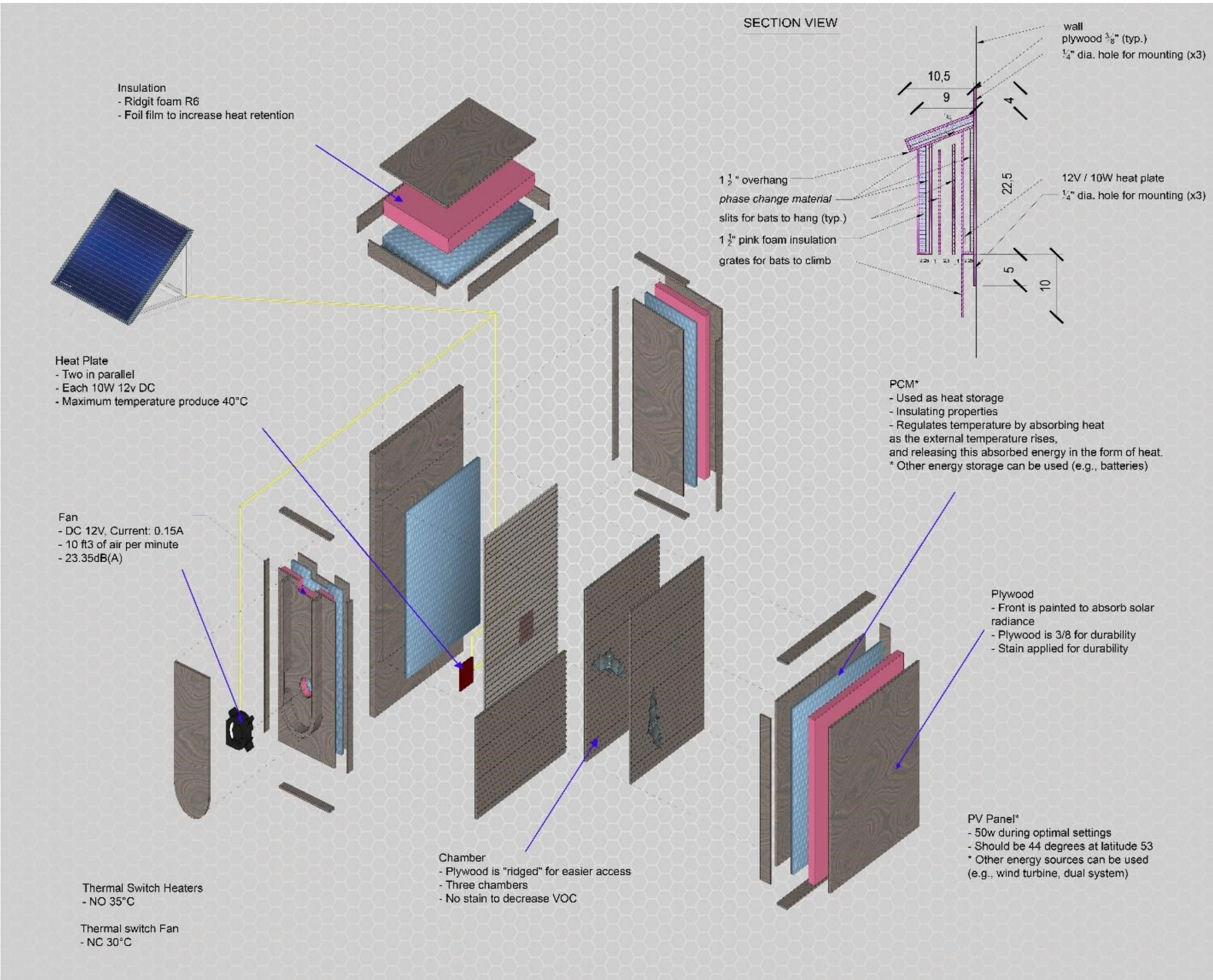

Figure 31. Novel bat box design by students at Northern Alberta Institute of Technology, using additional insulation and heaters. Figure: Dave Critchley, NAIT.