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Altitude- and Sex-Specific Variation in Roosting Ecology and Thermoregulation of *Myotis lucifugus* in Yellowstone National Park

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ALTITUDE- AND SEX-SPECIFIC VARIATION IN ROOSTING ECOLOGY
AND THERMOREGULATION OF *MYOTIS LUCIFUGUS* IN
YELLOWSTONE NATIONAL PARK

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Alexandra Christina Slusher

Lexington, Kentucky

Director: Dr. Michael J. Lacki, Professor of Wildlife Ecology and Management

Lexington, Kentucky

2017

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ABSTRACT OF THESIS

ALTITUDE- AND SEX-SPECIFIC VARIATION IN ROOSTING ECOLOGY AND THERMOREGULATION OF *MYOTIS LUCIFUGUS* IN YELLOWSTONE NATIONAL PARK

Fifty-nine female and six male little brown myotis (*Myotis lucifugus*) were radio-tagged during the summers of 2012, 2013, 2014, and 2015 in Yellowstone National Park. The grand models for daily maximum skin temperature ($F_{98,154} = 1.55$, $P = 0.007$), daily minimum skin temperature ($F_{98,154} = 1.33$, $P = 0.05$), and daily variation in skin temperature ($F_{98,154} = 1.56$, $P = 0.006$) were significant across roost type and reproductive condition class for adult females. Roosts were classified into Types A (warmest roosts), B (roosts with largest daily temperature variance), and C (stable and cool roosts) depending on differences in mean maximum, minimum, and variance in temperatures per day ($P < 0.001$). A total of 347 torpor bouts were recorded from 38 females across the 2012 to 2015 summer seasons. Bats across different reproductive classes and roost types used torpor at different hours of the day. My research suggests that adult female little brown myotis at high elevations in the Park extensively use and rely on building structures for roosting sites during the reproductive season, whereas males used primarily natural roosts.

KEYWORDS: building roosts, little brown myotis, reproductive females, skin temperatures, torpor, Yellowstone National Park

Alexandra C. Slusher

4/19/2017

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Chapter 1: Introduction

Bats are the second largest mammalian order with 1,116 species currently recognized (Altringham 2013). Compared with other mammals, bats have exhibited little variation in ecology, morphology, and physiology since their appearance in Eocene fossil records (Barclay and Harder 2003). Recent molecular phylogeny studies have suggested that bats originated in Laurasia, more specifically North America; however, the sum of missing fossil history is estimated at 61% (Teeling et al. 2005). The oldest known bat *Icaronycteris index* is at least 53 million years old, and was already capable of true flight based on skeletal analysis and likely possessed echolocation capabilities (Simmons and Geisler 1998; Altringham 2013). Bats live relatively long lives, reproduce at low rates, develop slowly despite their small body sizes, and are placed at the slow end of the fast-slow life history continuum (Barclay and Harder 2003). Bats thrive on every continent except Antarctica, exhibit different foraging preferences and strategies, live in social systems ranging from strictly monogamous to highly polygynous, and yet are a strictly homogenous taxonomic Order (Barclay and Harder 2003).

Bats are broadly divided into two suborders: Mega- and Microchiroptera (Pettigrew et al. 1989). The Megachiropteran bats are limited to the Old World tropics; usually have a diet of fruit, nectar and pollen; simple echolocation skills; improved vision; and, are larger than Microchiropteran bats. Microchiropteran bats have a worldwide distribution, a varied diet ranging from frugivory to sanguinivory, complex echolocation skills, and typically weigh less than 30 g (Pettigrew et al. 1989; Barclay and Harder 2003; Altringham 2013). In 2005, Teeling et al. (2005) established new suborders better fitting to results from molecular phylogenies. The new suborders are Yinpterochiroptera and

Yangochiroptera. Yangochiroptera includes all of the species previously classified as Microchiroptera, with added families that were previously classified in the Megachiroptera. The basic differences between the suborders remain largely the same.

Being the only documented mammals capable of true flight, bats occupy an essential, global niche as pollinators, seed dispersers, and insect/arthropod-eaters (Patterson et al. 2003). Globally, bats exhibit a wide range of feeding behaviors including animalivory, herbivory, and folivory. Animalivory defines the diet of animals that eat invertebrates (arthropods) and vertebrates. The vertebrate-eating bats are further separated into piscivorous (fish-eating) and sanguinivorous (blood-feeding) (Patterson et al. 2003). All piscivorous bats supplement their diet with arthropods and other small vertebrates (Ferrarezzi and Amaral Gimenez 1996). Sanguinivorous bats have also been documented supplementing their diet with insects (Ferrarezi and Amaral Gimenez 1996). Herbivory describes the feeding habit of over half of the extant bat species, and includes the frugivorous, nectivorous, and folivorous bats. Frugivorous bats predominantly feed on fruits, nectivorous bats on nectar as well as plant petals, and folivorous bats consume the leaves, buds, and other green parts of plants (Ferrarezzi and Amaral Gimenez 1996). Most bats in North America are classified as insectivorous, and eat a variety of arthropods (Patterson et al. 2003; Altringham 2013).

Chapter 2: Species Account

Section One: Taxonomic Classification

Bats have a greater range of behaviors, diet, and morphology than any other mammalian order (Lacki et al. 2007). The *Myotis* genus includes approximately 103 species within the Order Chiroptera, Family Vespertilionidae (Wilson and Reeder 2005). Little brown myotis (*Myotis lucifugus*; LeConte 1831) occupy most of North America with five subspecies currently recognized (Wilson and Reeder 2005; Vonhof et al. 2015). In the original report on little brown myotis by Fenton and Barclay (1980), six subspecies were listed and can still be found in most literature on the species. It is important to note, however, that the Arizona myotis (*Myotis occultus*; Hollister 1909) was recognized as *M. lucifugus occultus* until 2002 (Piaggio et al. 2002).

Section Two: Distribution

While the exact distribution among subspecies of little brown myotis is in dispute due to overlap and limited hybridization (Laussen et al. 2008), the specific subspecies being studied in this project is *M. l. carissima* (Thomas 1904; Fig. 2:1). The original samples for determining this subspecies within the Park were taken in 1980 from Lake Hotel, YNP; 1.6 km from the Fishing Bridge study site. Vonhof et al. (2015) confirmed that *M. l. carissima* is the only subspecies that occurs in the inter-Rocky Mountain Range and the Greater Yellowstone ecosystem. Through mtDNA sequencing and nuclear microsatellite genotypes, Vonhof et al. (2015) found that western populations of little brown myotis are characterized by significant isolation by distance, whereas eastern populations are characterized by low mitochondrial differentiation and high levels of interaction. The

Alaskan populations of little brown myotis are highly differentiated from all of the western and eastern metapopulations, and require more data before fully understanding their population trends and relationship with other regional metapopulations. The trend toward isolation by distance might suggest that the four western subspecies of little brown myotis may have a higher survival rate if exposed to white-nose syndrome (WNS), due to the limited interactions among regional populations. This assumption, however, is untested and may not hold up considering humans are capable of transferring spores of the *Pseudogymnoascus* fungus; evidenced by the most recently infected individual of little brown myotis just south of Seattle, Washington (whitenosesyndrome.org). Although spelunking is not allowed as a recreational activity within YNP, these activities are permitted throughout other caves in the Rocky Mountain region including Montana, Wyoming, Idaho, and Utah. Because the hibernacula of little brown myotis in western North America are largely unknown, and previous studies on eastern populations suggest little brown myotis typically travel up to 300 km to reach hibernacula (Kunz and Reichard 2010), transmission of WNS to Yellowstone's cave-dwelling bat populations remains a potential threat.

Section Three: Morphological Characteristics

While all subspecies of little brown myotis are broadly grouped together, each subspecies has its own specific physical and likely physiological traits (Vonhof et al. 2015). The *M. l. carissima* subspecies can be recognized by the following: dark brown head with a brown-yellow backside; lighter colored belly; small, black ears; hairs on the hind foot

extending beyond the toes; and, a lack of a keeled calcar (Barbour and Davis 1969; Fenton and Barclay 1980).

Adult body mass for all subspecies usually ranges between 6-9 g; however, females can gain 30% or more of their body mass during pregnancy (Kurta and Kunz 1987; Hughes and Rayner 1993). Forearm length is another metric for identifying subspecies because each subspecies has different range and mean forearm lengths within a broader species range of 31 to 41 mm (Kalcounis and Brigham 1995; Kunz and Reichard 2010). Adult little brown myotis in YNP have body mass values ranging from 4.5 to 13 g and forearm lengths ranging from 27 to 41 mm. In little brown myotis, adult males typically weigh less than females and have smaller forearm lengths (Fenton 1970).

Body mass of adult females recorded during this study demonstrated values between 5 to 13 g. Females at the higher elevation site had a greater body mass and longer forearms than females at the lower elevation sites. Lactating females from Fishing Bridge had an average body mass of 8.5 g (± 0.5 SE; $n = 5$) and an average forearm length of 39 mm (± 0.2 ; $n = 5$) compared to a body mass of 8.2 g (± 0.2 ; $n = 17$) and average forearm length of 37.7 mm (± 0.2 ; $n = 17$) for females at lower elevation sites. Pregnant females at Fishing Bridge had an average body mass of 10 g (± 0.5 ; $n = 9$) and an average forearm length of 38.5 mm (± 0.4 ; $n = 9$), whereas females at lower elevations had an average body mass of 8.8 g (± 0.2 ; $n = 43$) and an average forearm length of 38.4 mm (± 0.2 ; $n = 43$). Non-reproductive females at Fishing Bridge had an average body mass of 7.9 g (± 0.09 ; $n = 16$) and an average forearm length of 38.8 mm (± 0.4 ; $n = 16$), whereas the non-reproductive females at lower elevations had an average body mass of 6.8 g (± 0.2 ; $n = 70$) and an average forearm length of 37.6 mm (± 0.2 ; $n = 70$). The

larger body mass values recorded here compared with *M. l. lucifugus* females elsewhere in the species distribution, may indicate populations in YNP may be responding to environmental stressors, such as severe cold and a shorter reproductive season, not affecting bats at lower elevations elsewhere in the distribution.

Section Four: Survival Rate

First year survival of female little brown myotis ranges from 23 to 46% (Kunz and Reichard 2010), and is higher for young born earlier in the summer (Frick et al. 2010). Adult annual survival rate before WNS was estimated at 63 to 90% (Kunz and Reichard 2010). After the arrival of WNS, adult survival rates for little brown myotis dropped to 0 to 20% (Frick et al. 2010; Kunz and Reichard 2010). For bats exposed to shorter reproductive seasons at higher elevations, being born earlier in the year is even more crucial for winter survival. For females to induce pregnancy, they must regain a healthy body condition after losing body mass during hibernation (Racey and Entwistle 2000; Willis and Wilcox 2014). Warm, stable, and safe environments significantly increase the chance of quickly regaining lost body mass and, thereby, increases the chance of a healthy male:female offspring sex ratio (Willis and Wilcox 2016).

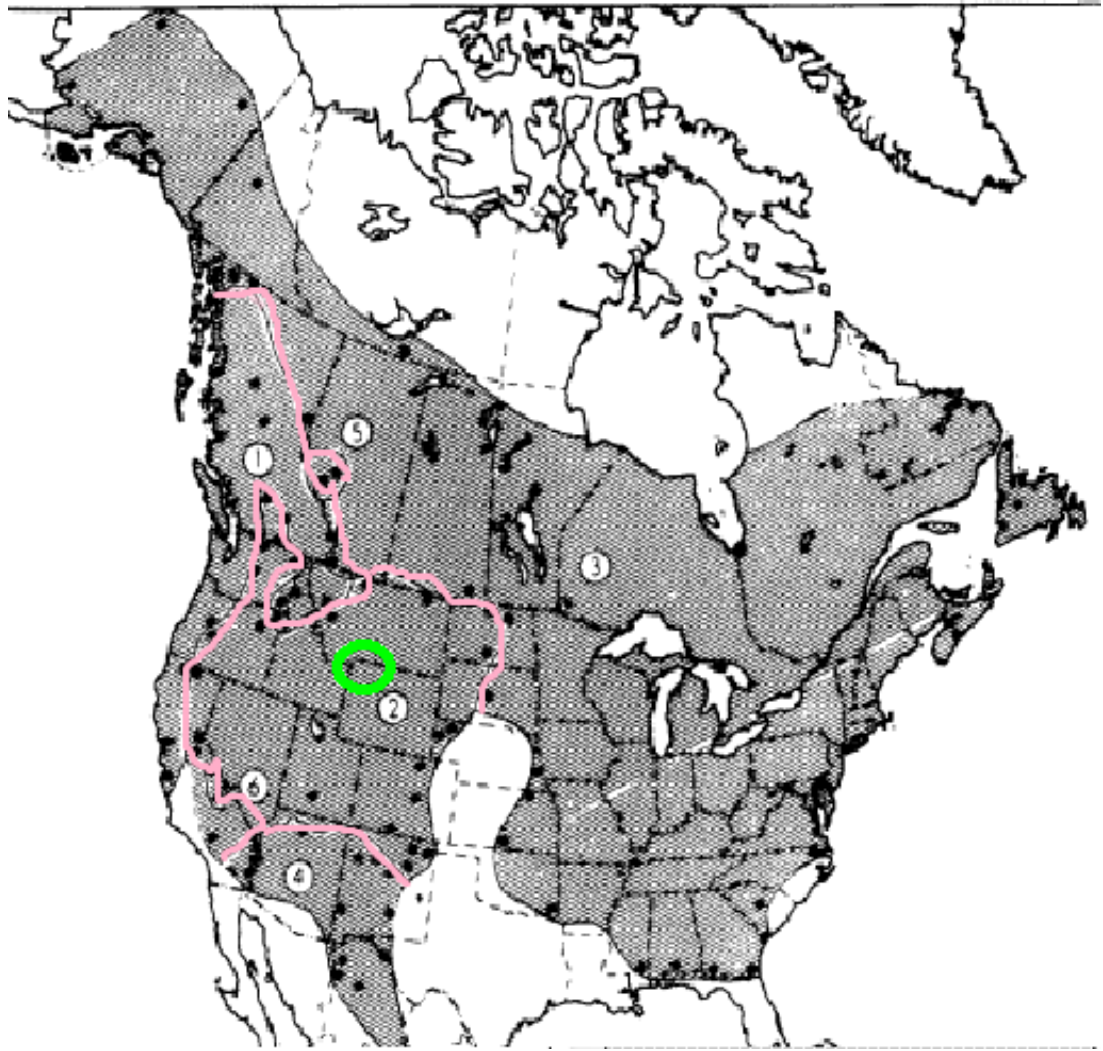


Figure 2.1. *Myotis lucifugus* subspecies range map adapted from Brock and Fenton (1980). *M. l. carissima* is shown as #2 with Yellowstone circled in green. *M. l. lucifugus* (#3) has been found further west and south into Montana than is shown on the map. Exact range is unknown and areas of hybridization are unknown.

Chapter 3: Overview and Significance of White-Nose Syndrome

Section One: Introduction

White-nose syndrome is an emerging infectious disease of cave-hibernating bats associated with a skin and metabolic infection from the fungus *Pseudogymnoascus destructans* (Zukal et al. 2014). Severe skin damage results in disruption of hibernation patterns, premature depletion of fat reserves, dehydration, and mortality in affected bats in eastern North America (Warnecke et al. 2012; Zukal et al. 2014). The annual survival rate of bats in populations in the northeastern United States following exposure to WNS is below 25% over a two-year period (Blehert et al. 2009). The fungus actively grows between 0 and 15.8 °C, indicating that cave systems in colder climates are prime habitat for *P. destructans* (Raudabaugh and Miller 2013; Reynolds and Barton 2014). The fungus shows no reaction to extreme pH levels or inhibitory sulfuric compounds (Reynolds and Barton 2014). Lorch et al. (2013) found that *P. destructans* is capable of surviving in caves no longer populated with bats, indicating that *P. destructans* is now a permanent resident of North America. The impact of WNS on diversity of bats and on affected agricultural economies remains unclear, but will most likely be of major significance (Boyles et al. 2011; Wibbelt et al. 2013). Boyles et al. (2011) estimated that bats are worth approximately \$74/acre/year to farmers in the United States, equating to over \$3.7 billion dollars annually (Fig. 3.1).

Section Two: Distribution

WNS has been spreading outwards from the initial detection site in New York since 2006, and was recently confirmed just outside of Seattle, Washington, in 2016. WNS has

affected most of eastern United States and Canada (except Louisiana and Florida), with new states and provinces seeing infected bats each winter/spring as the disease spreads south and west (Fig. 3.2). With WNS now affecting most of the eastern half of North America, and recently arriving to Washington State, the fungus is likely to eventually reach YNP.

Section Three: Affected Species and Clinical Signs

Thus far, *P. destructans* has been found in hibernacula of thirteen bat species in eastern North America, with seven of the twelve species exhibiting clinical signs of WNS and the remaining five species testing positive for the fungus (whitenosesyndrome.org). Species showing clinical signs of WNS are: big brown bat (*Eptesicus fuscus*), little brown myotis, eastern small-footed myotis (*Myotis leibii*), gray myotis (*M. grisescens*), Indiana myotis (*M. sodalis*), northern long-eared myotis (*M. septentrionalis*), and tri-colored bat (*Perimyotis subflavus*). Species testing positive for *P. destructans* but not yet exhibiting clinical signs are: southeastern bat (*M. austroriparius*), silver-haired bat (*Lasionycteris noctivagans*), Virginia big-eared bat (*Corynorhinus townsendii virginianus*), eastern red bat (*Lasiurus borealis*), Rafinesque's big-eared bat (*C. rafinesquii*), and the cave myotis (*Myotis velifer*). Clinical signs of WNS are first characterized by cutaneous surface layer dermatomycosis (i.e., fungal infection caused by a dermatophyte fungus requiring keratin for growth) and a white fungus visible on the nose and wings. *P. destructans* quickly penetrates the skin and invades the dermal layer, causing tissue infarction and necrosis (Cryan et al. 2010). Severe skin lesions and cutaneous necrosis in hibernating bats disrupts wing blood circulation, causing cutaneous respiration and promoting hypotonic

dehydration, hypovolemia, and metabolic acidosis (Cryan et al. 2010; Wibbelt et al. 2010; Raudabaugh and Miller 2013). Bats with severe skin lesions and necrosis exhibit a much higher frequency of arousal from torpor, but the exact mechanisms for this arousal pattern are unclear (Boyles and Willis 2010; Reeder et al. 2012; Warnecke et al. 2012). Bats with increased arousal frequency during winter months often exhibit premature depletion of fat stores, resulting in death by starvation and/or dehydration (Cryan et al. 2010; Warnecke et al. 2012). Restoration of immune responses during torpor arousal in WNS-positive bats early in hibernation may also result in immune-mediated destruction of infected tissues, leading to death (Meteyer et al. 2012; Zuka et al. 2014). Despite high mortality rates, some individuals in affected populations appear to survive and recover as evidenced from scars on the wings the summer following infection (Reichard and Kunz 2009; Fuller et al. 2011; Willis and Wilcox 2014).

Risk factors of hibernating bats associated with WNS mortality in North America include: distance from the first WNS-affected site, cluster size, species diversity, and composition and Type of hibernacula (Wilder et al. 2011; Zuka et al. 2014). Clustering behavior in cold, high-humidity areas of hibernacula could increase, especially in little brown myotis, susceptibility to *P. destructans* growth as well as increase the bat to bat transmission of infective conidia. Little brown myotis is severely affected by WNS because this species selects hibernacula with high levels of humidity, the preferred habitat condition of *P. destructans* (Zuka et al. 2014). Population viability analyses predict that all populations of little brown myotis could become extinct in 16 to 20 years due to WNS susceptibility (Frick et al. 2010; Wibbelt et al. 2013).

Section Four: Historical Account

Pseudogymnoascus destructans is thought to be introduced from Europe (Warnecke et al. 2012; Raudabaugh and Miller 2013; Khankhet et al. 2014). Infected bat species in Europe are ecologically diverse, and exhibit a wide range of hibernating and feeding strategies (Zukal et al. 2014). Twelve European countries have reported visible white fungal growth on bats in winter hibernation counts (Puechmaille et al. 2011a; Wibbelt et al. 2013; Zukal et al. 2014). A recent study conducted in the Czech Republic showed eleven bat species tested positive for *P. destructans* and exhibited slight clinical signs of WNS, bringing the total number of affected European bat species to twenty-two (Zukal et al. 2014).

Despite a long-standing tradition of annual hibernacula census in a number of European countries, no fungus-associated mass mortalities have been recorded. Furthermore, bats noticeably colonized with the fungus left their hibernacula uneventfully in spring alongside other unaffected colony members (Puechmaille et al. 2011a; Wibbelt et al. 2013). In contrast to the invasion of dermal connective tissue in North American bats, the inflammatory reactions of bats in Europe seem limited to the epidermis and do not extend beyond the epidermal basement membrane (Wibbelt et al. 2013). The one exception was a single greater mouse-eared myotis (*Myotis myotis*) hibernating in the Moravian Karst, Czech Republic (Pikula et al. 2012).

Reasons for the difference in response to WNS between North American and European bats are unclear, but existing evidence supports the hypothesis that bats in Europe might have co-evolved with the fungus whereas bats in North America have only recently been exposed (Wibbelt et al. 2010; Puechmaille et al. 2011a; Puechmaille et al.

2011b; Warnecke et al. 2012; Wibbelt et al. 2013). Co-evolvment with *P. destructans* might have allowed European bats to develop an unspecific epidermal immune response, restricting *P. destructans* from colonizing beyond the epidermis (Wibbelt et al. 2013). European bats also roost in smaller group sizes and exhibit more solitary behavior than North American bats, which could be a survival mechanism against WNS (Langwig et al. 2012).

Section Five: Behavioral Impacts and WNS

Myotis species typically form clusters during hibernation, and such behavior promotes frequency-dependent transmission of *P. destructans* infection independent of population size of bats in infected caves, leading to further loss of individuals to infection (Frick et al. 2010; Zukal et al. 2014), unless bats change their social behavior as has recently been documented for little brown myotis and the Indiana bat (Langwig et al. 2012). Langwig et al. (2012) observed little brown myotis and the Indiana bat exhibiting more solitary behaviors after a few years of exposure to *P. destructans*. Bats surviving the initial die-off, usually two years after WNS is first observed in the hibernacula, began forming smaller colonies or became completely solitary. Langwig et al. (2012) propose that bats changed their clustering behavior in response to WNS, much like behaviors observed in European bats, resulting in a survival strategy for those individuals choosing to remain solitary when roosting in infected sites. Of course, the counter argument could be made that these solitary individuals were never exposed to WNS during hibernation because they were solitary to begin with and are now only noticed because the larger colonies have disappeared. *Myotis l. carissima* in YNP already exhibit some tendency to roost in

smaller numbers or solitarily, as opposed to forming large hibernating colonies typical of many eastern populations of little brown myotis (Johnson et al. 2016). This raises the possibility of whether some populations of western subspecies will be able to survive long enough to build up immunity to WNS as the European Myotis seem to have done. The availability of suitable roost microclimates following emergence from hibernation, i.e., spring staging, will be a key survival determinant for *M. l. carissima* once the WNS fungus arrives.

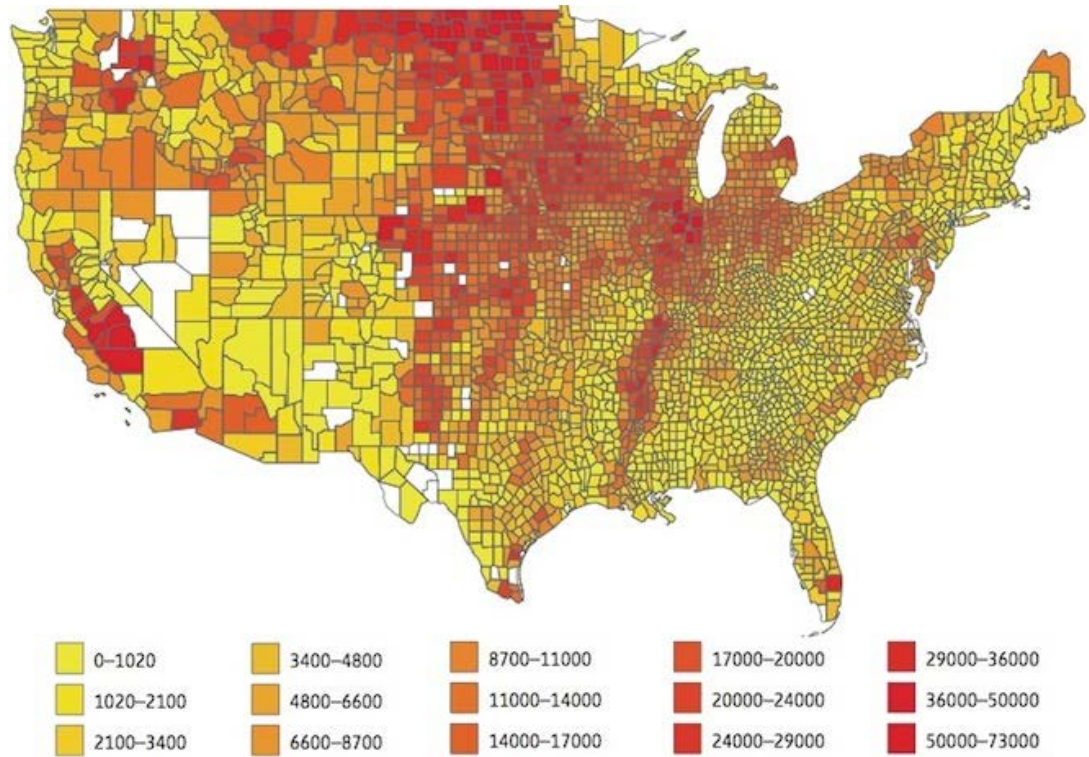


Figure 3.1. From Boyles et al. (2011) which demonstrated a single insectivorous bat is worth \$74 per acre of farmland per year. Values in figure have been divided by \$1000.

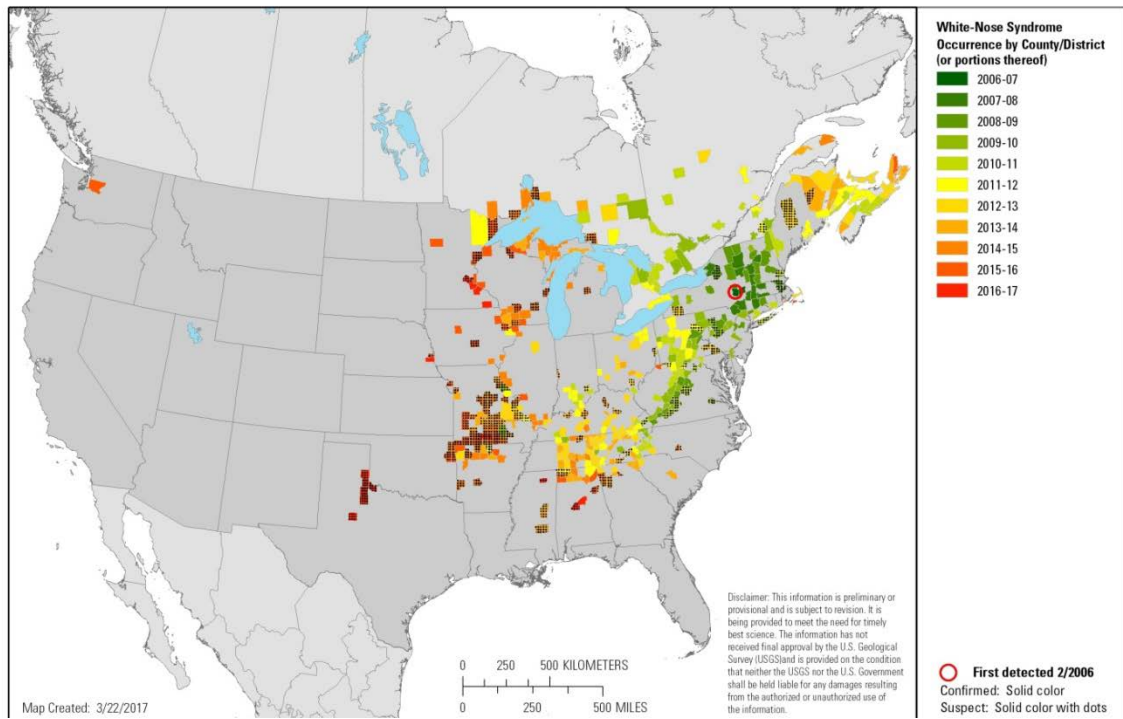


Figure 3.2. Occurrence of white-nose syndrome by county/district throughout U.S. and Canada. Credit: Lindsey Heffernan, PA Game Commission.

Chapter 4: Foraging Behavior, Roosting Ecology, and Torpor

Section One: Foraging Behavior

Little brown myotis are classified as generalist foragers that feed primarily on small aerial insects (Feldhamer et al. 2009; Kunz and Reichard 2010). However, a meta-analysis study found a relationship between climate and diet of little brown myotis that corresponded with longitude, with increased foraging preference for Coleopterans from western to eastern North America (Moosman et al. 2014). More surprisingly, little brown myotis in eastern Alaska consumed mostly spiders, averaging 47 % volume of the diet per bat (Boyles et al. 2016). Bats were also observed covered in webs upon capture. Another study from central Alaska found little brown myotis consumed large quantities of both spiders and moths (largest quantity being moths), with few other insects identified in fecal remains even though mosquitos and other flying insects were abundant in the area (Whitaker and Lawhead 1992). Fecal analyses of little brown myotis in YNP have not been conducted; however, unpublished observations suggest western spruce budworm moths (*Choristoneura occidentalis*) are a potential food source (L. Dodd, EKU, unpubl. data).

Most feeding by little brown myotis occurs over open water, or where water sources connect with adjacent forests (Belwood and Fenton 1976; Anthony and Kunz 1977; Fenton and Bell 1979; Barclay 1991; Saunders and Barclay 1992; Kunz and Reichard 2010). Traditionally, feeding occurs during two or more bouts per night, with little brown myotis occupying night roosts between feeding bouts for rest and digestion (Anthony and Kunz 1977; Kunz 1980; Anthony et al. 1981; Kunz and Reichard 2010). Feeding bouts can vary, however, depending on reproductive condition and location.

Bats at higher latitudes have less foraging time per night, and have been observed participating in only a single feeding bout each night (Whitaker and Lawhead 1992; Boyles et al. 2016). Related directly to foraging success and reproductive activity, night roosting by little brown myotis at lower latitudes has also been shown to be a flexible behavior rather than a predictable one (Anthony and Kunz 1981; personal observation in YNP). Tagged bats throughout YNP were often not gone from roosts during the entire night, but returned to day roosts after foraging for only a few hours. Only non-reproductive females were ever absent from day roosts for the entire night in my study. Lactating bats did not appear to venture far on any given night, as they typically returned to day roosts multiple times each night (See Chapter 9, Section 4). Pregnant bats were occasionally absent from the day roost the entire night, but on other nights were recorded returning to the roost after only a couple of hours of foraging. During peak energy demands, lactating females can consume the equivalent of their body mass in insects each night (Kunz 1980; Kurta et al. 1989). Because high concentrations of arthropods are required by adult females to sustain themselves and their young, lactating females are known to roost in locations with high concentrations of insects nearby (Fenton and Barclay 1980).

Section Two: Roosting Ecology

Foraging requirements among reproductive classes play a role in the roosting ecology of little brown myotis. These bats, as well as most north, temperate zone species, occupy three different roost types during different times of the day and year: night roosts, day roosts, and hibernacula (Fenton and Barclay 1980; Kunz and Reichard 2010). Day and

night roosts are used by bats in spring, summer and fall, whereas hibernacula are used for overwintering (Fenton and Barclay 1980; Kunz and Reichard 2010). Night roosts are generally used after the initial evening feeding period, and may serve multiple purposes (Kunz 1982; Knight and Jones 2009). Little brown myotis in YNP appeared to use night roosts on a limited basis, and only by non-reproductive females and males.

Night roosting is thought to be a tactic for keeping day roosts less conspicuous to predators, as well as providing energy savings from reduced commuting and flight costs (Fenton and Barclay 1980; Wilkinson 1992; Agosta et al. 2005). Because active bats produce more feces than torpid bats, nightly accumulation of feces is higher than daily accumulation of feces; thus, night roosts also prevent day roosts from rapid fecal accumulation which can be recognizable to predators (Fenton and Barclay 1980). Roost switching during the night may also reflect the selection of optimal microclimate conditions, minimizing travel distances to feeding sites, or the ability to enter torpor during sub-optimal foraging conditions (Kunz and Lumsden 2003; Lausen and Barclay 2003; Knight and Jones 2009). Night roosting in some bats may be optional depending on foraging success rates and insect abundance, or the reproductive condition of the bat.

Day roosts of bats can be located in a variety of structures including boulders, cliff crevices, hollow trees, caves, and buildings. Structures used as day roosts are vital for survival and successful reproduction (Kunz and Lumsden 2003). The structure must provide protection from predators and adverse weather conditions, a favorable microclimate that allows for energy savings through both use of torpor and the maintenance of a core body temperature, and space for social interactions among adults and juveniles. Reproductive females of several species, including big brown bats, eastern

red bats, little brown myotis, western long-eared myotis (*Myotis evotis*), and pallid bats (*Antrozous pallidus*), have already been found to select day roosts based on roost microclimate (Chruszcz and Barclay 2002; Hutchinson and Lacki 2001; Kerth et al. 2001; Lausen and Barclay 2003; Willis and Brigham 2005).

Evidence from historic literature sources suggests that buildings have allowed some species of bats to expand their geographic range (Davis et al. 1962; Fenton 1970; and Kunz 1982); however, recent findings indicate that bats simply prefer buildings because they provide better roosting sites (Lausen and Barclay 2006), are used extensively because natural roosts have been destroyed (Kunz 1982; Brigham 1991; Lausen and Barclay 2006), or both.

Hibernacula are the third type of roost and are inhabited during winter months. Hibernacula of *Myotis* species are typically located in caves and mines (Kunz and Reichard 2010). Hibernacula appear to be selected for their high-humidity and relatively stable, cool temperatures that remain above freezing (Hitchcock 1949; Fenton 1970; Griffin 1970; Cope and Humphrey 1976; Thomas et al. 1990; Brack 2007; Kunz and Reichard 2010). Little brown myotis are known to travel as far as 1000 km from summer roosts to hibernacula (Wilson and Ruff 1999), but more typically travel ≤ 300 km to reach winter hibernacula (Davis and Hitchcock 1965; Fenton 1970; Griffin 1970; Cope and Humphrey 1976; Kunz and Reichard 2010). Currently, no record exists of little brown myotis hibernating in buildings. Bats that generally do not feed during winter, including the little brown myotis (Whitaker and Rissler 1993; Kunz et al. 1998), should predictably hibernate in caves where winter energy expenditures are minimized (Boyles

et al. 2007). Interestingly, winter activity of bats has been recorded in YNP, including that of little brown myotis (Johnson et al. 2016).

Because bats spend most of their time in roosts, availability and quality of roosts directly affect bat population numbers and health (Humphrey 1975; Lunney et al. 1988, Evelyn et al. 2004; Barclay and Kurta 2007). Roosts must provide protection from predators and environmental conditions, as well as provide a space for social interactions (O'Shea et al. 2003; Barclay and Kurta 2007); these conditions are especially important for maternity colonies. Preferred roosting habitats can differ among males; non-reproductive females; and pregnant, lactating and post-lactating females. Males and non-reproductive females often roost solitarily or in small groups, whereas pregnant, lactating and post-lactating females typically roost in communal maternity colonies (Kunz and Lumsden 2003; Barclay and Kurta 2007). Each reproductive condition class has different energy requirements, which in turn affects the type of roosts selected.

Pregnant and lactating females roost in large, day colonies to help reduce predation risk (Fenton et al. 1994; Kalcounis and Brigham 1994; Barclay and Kurta 2007), to influence roost microclimate (Burnett and August 1981), and to maintain high body temperatures while minimizing evaporative water-loss, typically through clustering behaviors (Kurta et al. 1989; Webb 1995; Barclay and Kurta 2007). Lactating females are limited in travel distance during foraging because they must return to nurse their young (Henry et al. 2002; Barclay and Kurta 2007) and, therefore, do not use night roosts until after the young have been weaned (Fenton and Barclay 1980).

Roost switching can be influenced not only by environmental conditions and microclimates, but also by social interactions with other roost members (Barclay and

Kurta 2007). Recurrent roost switching and fluctuating composition of group size suggests the existence of a fission-fusion society (Kurta et al. 2002), especially since both random and non-random roosting associations have been observed in many insectivorous bat species (Altringham 2013). Reproductive condition and roost microclimate availability has been shown to affect who roosts with whom among female Bechstein's bats (*Myotis bechsteinii*; Kerth et al. 2001).

Because day roosts are important for both sociality and protection from the environment, the destruction or human interference of roosts, such as exclusion from buildings, can be a factor in the decline of bat populations (Pierson 1998; Barclay and Kurta 2007). Loss of building roosts has been linked to lower reproductive success of big brown bats in Ontario (Brigham and Fenton 1986). Buildings can provide excellent roosts for pregnant and lactating females, permitting use of daily torpor more frequently to facilitate energy savings (Kunz and Reichard 2010).

Section Three: Torpor

Energetic demands interacting with strategies for saving energy are important to survival in wild populations of animals, especially those living at high elevations and latitudes where the reproductive season is short before quickly returning to winter. Heterothermic endotherms, such as bats, are notable for their ability to employ facultative heterothermy, i.e., torpor (Geiser 2004; Storey et al. 2010; Geiser and Brigham 2012; Johnson and Lacki 2013; Boyles et al. 2016). Endotherms maintain high body temperatures by metabolizing food to generate internal heat regardless of the external environment (Altringham 2013). Conversely, ectotherms maintain body temperatures through

behavioral adjustments, i.e., poikilothermy. Heterothermy refers to endothermic organisms, such as bats, that are capable of exhibiting homeothermy at multiple set points when active but exhibiting poikilothermy when not active (Angilletta 2009).

Some heterothermic organisms, including bats, are capable of thermoconforming to their environment (Geiser 2000; Angilletta 2009; Dunbar and Brigham 2010). Warming out of a torpid state is energetically expensive, which is partly why choosing a suitable microclimate is important for animals which use torpor to reduce energy expenditures. For bats, a suitable microclimate allows individuals to thermoconform or passively rewarm from torpor as daily temperatures increase (Geiser 2000; Dunbar and Brigham 2010). Bats can enter and leave torpor without thermoconforming, but this behavior is energetically expensive as it requires an increased production of internal body heat to achieve normothermic body temperatures. Torpor itself is characterized by greatly reduced activity levels and an improved ability to cope with food shortages or adverse climates (Geiser 2004). While in torpor, body temperatures drop below an individual's thermal neutral zone or lower critical temperature. The thermal neutral zone is the range of temperatures within which an organism can maintain a comfortable body temperature without expending appreciable amounts of energy. The thermal neutral zone of little brown myotis and other mammals of similar body size, usually ranges between 30 to 36°C (Studier 1981; Altringham 2013).

An increasing amount of literature suggests that reproductive female bats use torpor for reasons other than food shortages, especially in areas higher in elevation and latitude (Grinevitch et al. 1995; Geiser 2004; Willis et al. 2006; Dzal and Brigham 2014; Boyles et al. 2016). Most bats surviving in colder climates seem to track temperatures inside

roosts with their own body temperatures. This pattern supports the supposition that some bats are capable of thermoconforming to their environments and, therefore, select roosts that permit them to save energy by using this behavioral strategy.

Torpor is most often viewed in the context of hibernation as a winter survival strategy; however, research from the past two decades has revealed that torpor is used throughout the year by numerous species of bats for a wide range of physiological purposes (Geiser and Brigham 2012; Dzal and Brigham 2013; Johnson and Lacki 2013). Bats may enter torpor in response to internal stressors, such as energetic demands, or outside stressors, such as weather (McLean and Speakman 1999; Willis et al. 2006; Schmid and Speakman 2009; Dzal and Brigham 2013; Johnson and Lacki 2013). Torpor is also used to offset energy expenditures during the reproductive months for bats at higher latitudes (Boyles et al. 2016). Although torpor can provide significant energetic savings, the tradeoffs and physiological costs of torpor for small mammals during pregnancy and lactation, when caloric demands are greatest, are not fully understood (Speakman 2008; Johnson and Lacki 2013). Presumably, to speed fetal and neonatal development, pregnant and lactating females at higher elevation sites should not take advantage of torpor as deep or often as females at lower elevation sites (Dzal and Brigham 2012; Alberdi et al. 2014). However, because of unfavorable environmental conditions at higher elevations, pregnant and lactating females may be forced to use torpor more than expected in comparison to patterns for pregnant and lactating females inhabiting sites subject to milder weather extremes. Presumably, given the opportunity to roost in stable, warm microclimates, reproductively active female bats may use torpor to speed accumulation of or maintain existing levels of fat stores; both of which can be

beneficial for developing and raising young. Pallid bats, for example, select roosts that are more sensitive to ambient temperatures when insect abundance is low, permitting the use of torpor and passive rewarming from torpor by these bats (Vaughan and O'Shea 1976). When insect abundance is high, however, pallid bats choose roosts with more stable microclimates (Vaughan and O'Shea 1976), further suggesting that some bats are capable of thermoconforming to their environment.

Potential costs or fitness trade-offs from use of torpor include: reduced vigilance and increased vulnerability to predation (French 1988; Lesinski et al. 2009), accumulation of damaging metabolic by-products (more common during hibernation) (Galster and Morrison 1972), and immunosuppression (Prendergast et al. 2002; Carey et al. 2003; Bouma et al. 2011), which may increase susceptibility to pathogens (Zukal et al. 2014).

Chapter 5: Objectives and Hypotheses

Objective #1: To compare thermoregulation and behavior patterns among non-reproductive, pregnant, and lactating females at differing elevations.

Hypothesis #1: Thermoregulation patterns will differ among reproductive classes given the different energy constraints and requirements of each group. Non-reproductive and post-lactating females will use roosts and thermoregulation patterns similar to solitary males. All females, regardless of reproductive class, will use torpor more frequently and enter deeper torpor at higher elevation sites compared with lower elevation sites.

Objective #2: To evaluate thermoregulation and behavior patterns of bats among different types of roosting structures.

Hypothesis #2: Nightly activity patterns will not differ among roost types for reproductive females, but thermoregulation patterns will vary among roosts across reproductive condition classes. Pregnant and lactating females will use the same roost types but exhibit different activity and thermoregulation patterns. Reproductive females at the higher elevation sites will give birth later in the year than females at lower elevation sites.

Objective #3: To tag and observe males when females are not able to be captured.

Hypothesis #3: Males will exhibit longer foraging bouts than adult females and will use torpor frequently when occupying diurnal roosts. Male activity patterns and thermoregulation behaviors will be similar to that of non-reproductive females, but different from pregnant, lactating, and post-lactating females.

Chapter 6: Study Area, Capture Sites, and Roost Descriptions

Section One: Historical and Present Review of Study Area

My study was in Yellowstone National Park in Park County, Wyoming, USA (Fig. 6.1).

The earliest known inhabitants in the Yellowstone area were the Folsom people, who arrived at some point between the end of the last ice age (13,000-14,000 years ago) and before 11,000 years ago. Little physical evidence has been found except for distinctive obsidian stone tools and similar artifacts found concentrated mostly in what is now the Yellowstone Lake area. As the large Ice Age mammals became extinct, the native people adapted to hunting and eating the small to medium sized mammals, as well as berries, seeds, and roots. An established site at Yellowstone Lake was dated to 9,350 years ago. Artifacts from the site contain trace amounts of blood from rabbits, dogs, deer, and bighorn sheep (*Ovis canadensis*). In-depth investigations on earlier occupancy in the Yellowstone area did not begin until the late 1800s when Park Superintendent Philetus W. Norris sent artifacts to the Smithsonian Institute in Washington, D.C. Before this time, archeologists believed the area would have been inhospitable to humans. More than 1,800 archeological sites dating to the Archaic Period (1,500-7,000 years ago) have since been discovered.

In more recent history, a group from the Shoshone Native Americans were the first known modern humans to establish campsites in the Yellowstone area beginning roughly 700 years ago. They were known as the Tukudika, or the Sheep Eaters. Many different Native American tribes used the Yellowstone area for hunting, fishing, gathering plants, obtaining obsidian, and for spiritual and medicinal purposes for thousands of years before the Park was established. European Americans did not arrive

until the 1700s, when they came in search of furs, and then gold. While the Lewis and Clark Expedition bypassed Yellowstone, a member of the crew left on the return trip to remain and trap in the Yellowstone area. The 1871 Hayden Expedition was the first formal, scientific expedition to survey the Yellowstone area. After sending in a continuous stream of scientific reports, photographs, paintings, and sketches by artists to gain attention, Congress and President Ulysses S. Grant created the world's first official national park in 1872. Park boundaries were changed twice with support from President Hoover since establishment in order to expand winter range protection for elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and moose (*Alces alces*). The U.S. Army arrived in 1886 to guard the major park attractions, evict troublemakers, and patrol the park for poachers after a decade of failed attempts by supervisors and assistants. The Army erected buildings and towns throughout the park that remain and are still in use today. Details on buildings in areas pertaining to this study can be found in the individual roost descriptions later in this chapter. In 1916, President Woodrow Wilson and Congress approved the National Park Service Organic Act, which was the beginning of the National Park Service. The National Park Service gained full control in 1918 after the Army left. Various programs, including the Civilian Conservation Corps, worked in the area from 1932-1941. With the onset of World War II, most national parks quickly became neglected. Mission 66 was launched in 1955 after the National Park Service convinced Congress to allocate more funds to national park maintenance, in preparation for the 50th anniversary. Older buildings were restored and more outposts were erected. All new buildings and towns were built with the modern 1950's rather than keeping the Mediterranean Colonial style.

Management in the national parks during the late 19th and early-mid 20th century was mostly to preserve rather than to conserve. As a result, most park areas were managed to remain static and unchanging as the 1916 Organic Act stated the need to “conserve the scenery.” During the 1960s and ‘70s, ecologists began to realize that ecosystems are not static, and natural processes need to occur. Fire suppression for 100 years, however, had already changed the landscape in unimaginable ways.

Fire suppression practice began in Yellowstone National Park in 1886, and was then written and enforced as policy for all national park lands by the Organic Act in 1916. The policy operated under the idea that: “1) fire damages mature trees and kills seedlings; 2) destroys the best forage plants and perpetuates undesirable grasses; 3) robs the soil of nature’s fertilizer and promotes erosion; and, 4) destroys natural breeding places for birds and animals.” In 1955, a section of Giant Sequoia National Park was threatened by a wildfire, and soon after scientists began to realize that fire suppression had detrimentally altered the landscape. In 1968, NPS altered its policy on fire suppression and began supervising controlled fires on the landscape. Yellowstone did not begin implementing controlled fires until 1972. Only small, controlled burns were allowed because 1) scientists did not quite understand all of the effects of fire suppression, and 2) the public thought all wildland fires were bad. The summer of 1988 in Yellowstone changed everything. A total of 1.1 million acres of land in the Greater Yellowstone Ecosystem (GYE) burned out of control in 1988 (793,880 acres, or 36% in Yellowstone National Park); and cost more than \$120 million to fight the fires. The fires of 1988 in Yellowstone have been attributed to being “instrumental in the public’s understanding of the role of fire in ecosystems” (NPS Fire Management). New fire

management plans were developed from 1989 to 1992 for all national parks.

Yellowstone National Park's most recent fire management plan was revised in 2014.

Today, the National Park System still operate under the 1916 mission statement: "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." The mission statement, however, can and has caused confusion on the fundamental goals of national parks, and so was split into two policies to provide direction: the natural resource policy and the cultural resource policy. The most recent policy manual was published in 2006. In chapter 4: the natural resource management policy states that while it recognizes that natural processes cause natural changes in the landscape, flora, and fauna, the National Park Service will "strive to understand, maintain, restore, and protect the inherent integrity of the natural resources within the park" especially when threatened by external activities (NPS Management Policies 2006).

While the Park does not include the entire GYE, it does form the core. The GYE is a unique, intricate balance among volcanic, hydrothermal, and glacial processes. Vegetation resembling what exists in the GYE today, began to appear roughly 7,000 years ago. Flora and fauna distribution is dependent on rock and sediment distribution. Whitebark pines (*Pinus albicaulis*) need andesitic, volcanic soils (such as Mt. Washburn) to thrive, and grizzly bears (*Ursus arctos*) depend on whitebark pine during the winter months. Elk and bison (*Bison bison*) need grasslands to graze, especially in the winter, and grasslands thrive only in hydrothermal valleys formed by glaciers (such as the Hayden and Lamar Valley areas). Roughly 1,300 native plants, 67 mammals, 322 birds,

16 fish, 10 herpetofauna, and >12,000 insect species exist in the park, with many more within the GYE. Now, the park contains mostly lodgepole pine (*Pinus contorta*) forests (more than 80% of the park) on top of rhyolite soils. Douglas-fir forests (*Pseudotsuga menziesii*) dominate the Lamar, Yellowstone, and Madison River drainages below 2,300 m. Spruce-fir forests dominate older, climax forests found in moist and fertile areas such as andesitic soils. Whitebark pine forests are the primary overstory tree species above 2,560 m. Whitebark pine seeds are the most ecologically important species for wildlife in the park. Few areas contain aspen (*Populus tremuloides*) forests, and few areas are grassland-steppe dominated.

YNP is one of the most geologically dynamic areas on Earth, and contains half of all the world's active geysers. The visible, surface hydrothermal system exists because of the underlying magma body below. Areas with higher concentrations of geysers, hot springs, mudpots, and fumaroles are known as basins, and are located in low places closer to lava flows. Water temperatures exceed 400°F but remain in a liquid state due to the convection current of colder, less dense water near the top and heavy, hotter water near the bottom and next to lava flows. The first Yellowstone eruption occurred approximately 2.1 million years ago, and probably ejected 600 cubic miles of material (Smith and Siegel 2000). The second largest eruption was the third eruption which ejected 240 cubic miles of material roughly 640,000 years ago. For comparison: Mt. St. Helens erupted in 1980 and ejected only 0.1 cubic miles of material which killed 57 people and caused \$969.8 million dollars in losses and damages (volcano.oregonstate.edu).

In 2004, D.A. Keinath led a survey to identify bat species and habitats throughout the GYE. He identified the following species as being present in the Park: little brown myotis, big brown bat, long-eared myotis (*Myotis evotis*), long-legged myotis (*Myotis volans*), Townsend's big-eared bat (*Corynorhinus townsendii*), fringe-tailed myotis (*Myotis thysanodes*), hoary bat (*Lasiurus cinereus*), silver-haired bat, Yuma myotis (*Myotis yumanensis*), and the Pallid bat (*Antrozous pallidus*).

Section Two: Capture Sites

Mist-net trapping sites were located at Joffee Lake (south of Mammoth Hot Springs; 12 T 523559 E; 4977140 N) and at Lava Creek (along Grand Loop Road heading east from Mammoth Hot Springs; 12 T 529021 E; 4976404 N). Attic attainment captures occurred multiple times at Buffalo Ranch in Lamar Valley (western side of Lamar Valley; 12 T 0560404 E; 4971647 N), Roosevelt Lodge (Tower; 12 T 5406032 E; 4973392 N), and Fishing Bridge Service Station (Fishing Bridge; 12 T 549550 E; 4934818 N). All netting and building sites were at high elevations; defined here as elevations above 1,500 m (Young et al. 2002). At 1,500 m, human physiology begins to change due to less oxygen and reduced atmospheric pressure (Young et al. 2002). Plant and animal ecosystems also begin to change above 1,500 m. Detectable metabolic changes in endotherms, as well as changes in plant communities occur approximately every 300 m within high-elevation mountain ranges. Average temperatures drop by 3 °C every 300 m, precipitation increases (especially snow), and wind speeds increase (Whiteman 2000). The highest elevation site I sampled was at Fishing Bridge, roughly 600 m higher in elevation than Mammoth Hot Springs.

Joffee Lake and Lava Creek are primarily forested areas with abundant water sources. The Roosevelt Lodge area is also primarily forested with a river 0.6 km away. Buffalo Ranch, in Lamar Valley, is a sagebrush-steppe plant community dominated by mountain big sagebrush (*Aremisia tridentata* var. *vaseyana*) and Idaho fescue (*Festuca idahoensis*). Drainages and lower sites within the Lamar Valley area are dominated by Douglas-fir.

Fishing Bridge, located on the north side of Yellowstone Lake, is in a mostly forested landscape with alpine meadows nearby. Lodgepole pine is the most common tree throughout the northern half of the Park (Joffee Lake, Lava Creek, Roosevelt Lodge), followed by Douglas-fir at lower, high elevations. Lodgepole pine is replaced by whitebark pine, subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and limber pine (*Pinus flexilis*) at the higher elevations surrounding Fishing Bridge and the Lake area, and at the highest elevations of mountain ranges in the Park.

Joffee Lake, Lava Creek, Lamar Buffalo Ranch, and Roosevelt Lodge represented lower, high elevation sites, whereas the Fishing Bridge Service Station represented a higher, high elevation site. The difference between the lower, high elevation and higher, high elevation sites varied from 457 to 610 m. Elevational differences and site characteristics account for temperature differences across all four locations. Data for precipitation and ambient temperatures at all locations were obtained from the Climate Analyzer website (climateanalyzer.org), which is sourced through the National Weather Service, the Natural Resources Conservation Service, the United States Geological Survey, Remote Automated Weather Stations, and the Hydrological Automated Data System. Data from all locations are automatically delivered every 24 hrs to the Climate

Analyzer. The website is maintained by Walking Shadow Ecology located in Gardiner, Montana, at the North Gate of the Park.

During the 2012 to 2015 study years, Joffee Lake and the Mammoth Hot Springs area received an average of 376 mm of precipitation annually, with a mean minimum temperature of -0.87 °C and mean maximum temperature of 12.4 °C. The Roosevelt Lodge area received an average of 451 mm of precipitation annually, with a mean minimum temperature of -4.8°C and a mean maximum temperature of 11.8°C. The Buffalo Ranch at Lamar Valley received an average of 405 mm of precipitation annually, with a mean minimum temperature of -6.1 °C and a mean maximum temperature of 9.9°C. The fourth study site, Fishing Bridge and the Lake area, received the highest average of 563 mm of precipitation annually, with a mean minimum temperature of -5.2°C and a mean maximum temperature of 8.1°C (Table 8.1).

Mist-Net Capture Sites

Capture Site 1: Joffee Lake (Fig. 6.2)

Location: 12 T 523559 E 4977140 N

Joffee Lake is a small pond, 0.1 km in diameter, located 1.6 km south of Mammoth Hot Springs, WY. A lodgepole pine and Douglas-fir forest surrounds the lake. Western long-eared bat was the most common species captured in the nets set in the forest, whereas little brown myotis was the most common species captured in nets set over Joffee Lake (Appendix III: Breakdown of all bats captured in nets and attic attainment).

Capture Site 2: Lava Creek

Location: 12 T 529021.29 E 4976404.77 N

Lava Creek is a stream that runs across the northern half of the Park. The capture site I used is located near the Lava Creek Picnic Area, directly off the Grand Loop Road heading east towards Roosevelt/Tower Fall/Lamar from Mammoth Hot Springs. Big brown bat was the most common species captured at this site. Female little brown myotis were never captured at this site, however, males were occasionally netted. A handful of other locations in the vicinity were netted in an attempt to capture female little brown myotis but were unsuccessful.

Attic Attainment Capture Sites

Attic Attainment Site and Roost #1: The Bunkhouse of Buffalo Ranch in Lamar Valley (Fig. 6.3)

Location: 12 T 0560404E 4971647N

Roost Type: B

Located in the heart of Lamar Valley, Buffalo Ranch is surrounded by vast, open meadows filled with pockets of ephemeral ponds and water holes. The Lamar River flows across the length of the valley. The Bunkhouse is the most frequently used building in the valley by Park visitors, and serves as the main hub for educational activities, cooking, and eating for the people working and visiting the ranch. Built in 1929, the bunkhouse is a 7.8 x 23m rectangular log structure with a poorly insulated, wooden attic and cobblestone foundation. Maneuvering throughout the attic is restricted

to the few main wooden support beams lying across the insulation. The ceiling of the attic (beneath the roof shingles) is a doubled structure of wooden boards, with spaces small enough between each layer to accommodate roosting bats. Most of the bats in this attic could be heard but were neither visible nor accessible. The few bats tagged from this roost were taken from the cracks between the wooden structures and the brick fireplace that extended vertically from the floor through the roof.

Three HOBO loggers were placed, during summers 2014 and 2015, at various locations in the attic to collect temperature data. Two of the HOBOs from the summer of 2014 were corrupted and data were unable to be recovered. Temperatures inside the Bunkhouse, as well as the Fishing Bridge Service Station, exhibited the lowest average daily temperature among the different types of building roosts compared. The lack of insulation and restoration of the outside wooden beams created an environment that was more exposed to the outside elements such as temperature and wind. Ambient conditions in Lamar Valley, as well as Fishing Bridge, were very similar in mean monthly maximum and minimum temperatures, with both locations having the lowest overall ambient temperatures of any roosting structures (Table 6.1 and Chapter 8).

The Bunkhouse was the second-smallest bat roost monitored throughout the summer seasons. Bats exited the Bunkhouse at one of two locations. The main exit was a 0.6 x 0.6m metal louver located above the front door, with the smaller, back exits being holes on the other end of the building. Bats in this colony did not return to the roost as frequently during the first hour of emergence as did females roosting in other buildings, except for the poorly-insulated wooden buildings. During the first week of June (2015) only four bats were recorded emerging from the building (Fig. 6.1). During this same

week, 60 bats were recorded at Fishing Bridge and 29 at the Power House. By mid-July (2015) the Bunkhouse colony peaked at 284 inhabitants, dropped to 168 on 21 July, and then decreased to only 7 bats exiting on 3 August (Fig. 6.10).

Throughout the summer, many employees and guests were observed sitting out front, walking around, and even playing music and singing songs with no noticeable detrimental effects on the exit and return of bats. The surrounding buildings also contained roosting bats, but these individuals were more solitary, with only a handful of bats roosting at a time in each building. A small number of bats were also found roosting in the boiler building, which possessed a humid and warm climate regardless of the ambient temperature. Mummified, dead bats could usually be found in the boiler building, raising the question of why bats would roost there if it was too warm for them to survive.

Attic Attainment Site and Roost #2: Roosevelt Lodge at Tower (Fig. 6.4)

Location: 12 T 0546032 E 4973392 N

Roost Type: C

Roosevelt Lodge is a well-structured and well-insulated log cabin that serves as the kitchen, restaurant, and gift shop for employees and tourists occupying the surrounding single-room cabins. Originally built in 1919, the lodge has been enlarged, updated, and modified as needed. The structure is made from thick, mature lodgepole pine logs, with additional wooden beam supports throughout the cabin. The most recent modification occurred in late spring 2015, resulting in an even more stable and insulated attic; inadvertently securing the safety and microclimate of the maternity colony inside. The

climate inside the attic exhibited limited daily temperature fluctuations compared with the two poorly-insulated attics of the Buffalo Ranch Bunkhouse and Fishing Bridge Service Station.

Three HOBO loggers were placed during the summers of 2014 and 2015 at various locations in the attic; however, not all data were recovered as result of the attic remodeling. At least a few bats were always accessible within the attic, making Roosevelt Lodge a reliable choice for successful attic attainment. Most of the bats, though, were able to hide within the doubled wooden beams on the ceiling of the attic, as they did at the Bunkhouse, but did so only after observing me entering the attic. I entered during the morning hours and stayed for no more than 45 min. Roosevelt Lodge closes to tourists during the hour between breakfast and lunch and, because the attic entrance is above the dining area, I was only allowed to enter and remain during the allotted time period. Often during this time, bats were observed flying around the attic, grooming each other and themselves, and caring for their young. It is also in this building roost that I found a pregnant female visibly lactating, suggesting these bats may care for pups other than their own.

On the east side of the building, a large, stone fireplace and chimney extends from the ground level to above the attic. Cracks and holes located between the logs and the stone serve as primary exits from the attic for resident bats. No bat was recorded exiting during the first and second week of June, when all other building roosts studied, excluding the Chapel (the only other well-insulated and protected building), had colonies growing in size. The peak size of the Roosevelt Lodge maternity colony is unknown, but 393 bats did emerge on 24 July. Colony size dropped precipitously in mid-August, with

the final exit count on 12 August being only 87 bats (Fig. 6.10). Little brown myotis did not begin occupying Roosevelt Lodge until all of the other sites were occupied, with the Roosevelt Lodge colony vacating the attic more quickly than did bats at any other building site surveyed. The Roosevelt Lodge maternity roost was a site where young pups could be observed learning to fly. Once adult females began emerging in the evening, pups could be seen climbing and falling all around the side of the building near the vicinity of the primary exit.

Attic Attainment Site and Roost #3: Fishing Bridge Service Station, Fishing Bridge, WY (Fig. 6.5)

Location: 12 T 0549550 E 4934818 N

Roost Type B

The Service Station is approximately 8 x 15 m, and is an open attic. An open attic is defined as one without a small entrance opening, but instead has the entire back end of the building providing full access to the attic. No barrier exists between the first floor and the attic. There are two large, glass windows in the attic which allow generous amounts of sunlight and warmth to influence the microclimate within the building. Many portions of the sides of the attic contained broken pieces of wood, as well as gaps between the wooden boards. The service station was classified as a poorly-insulated attic because of the large attic windows, gaps between the wooden boards, broken-off pieces of wood, and the absence of insulation in the attic.

Bats were generally accessible from this attic, but could easily squeeze between the attic ceiling beams beyond reach of human hands. On average, this was the smallest

known maternity colony in the Park with a maximum of 60 bats emerging on 28 June (Fig. 6.10). The following week, construction occurred on the building with windows and sides of the attic all removed. Fishing Bridge was subsequently unable to be sampled for the remainder of the study due to liability issues and the destruction of roosting conditions for the resident maternity colony. Current attic conditions and the possible return of a maternity colony to the site remain unknown.

The Fishing Bridge Service Station was located next to the General Store at Fishing Bridge. The General Store also contained a colony of little brown myotis, however, I was not granted access to this site. Exit counts taken outside the General Store likely were not accurate due to the amount of non-visible exits available to the bats, as well as the high rate of circling and returns to the building. My estimates of the colony size ranged anywhere from 300 to 900 bats. Due to the environmental constraints present at such a high elevation, the General Store probably served as a significant maternity site for little brown myotis in the Fishing Bridge area.

Section Three: Remaining Building Roosts

Roost #4: Power House, Mammoth Hot Springs, WY (Fig. 6.6)

Location: 12 T 524051 E 4979689 N

Roost Type: A

The Power House is an abandoned hydroelectric power plant located in the lower Mammoth area of Mammoth Hot Springs. Completed in 1911, the Power House provided the area with electricity until 1966 when commercial power became abundant and cheap. The Power House, like the Chapel, differs from the standard design of what used to be Fort Yellowstone. Even though it was built around the same time as most of

the other buildings throughout the Fort, the Power House was constructed as a permanent fixture in a Mediterranean Style, not the Colonial Revival Style. The building is a two-story 23.4 x 13m rectangular concrete structure with a hipped red clay, unglazed tile clad roof, and widely overhanging eaves with exposed rafters. The foundation and walls are made of concrete with a wooden framing and steel trusses. This is the only building from the Fort Yellowstone era containing steel trusses and concrete in the fixture. Consistent with a Mediterranean style, the exposed concrete walls are protected with stucco (i.e., a very dense, thick, and protective coating applied to the outside of buildings). The original stucco still exists, covering much of the building, but time and weather have caused some portions to deteriorate, crack, and splinter. The interior concrete walls are covered with plaster, similar to stucco, but not as protective and not meant to withstand harsh climate. Given the time period, designers, and appearance of the Power House, it is likely that clay with some lime added is the base of both the stucco and the plaster.

The Power House remains abandoned and locked to keep humans out of the building due to safety concerns from an unstable structure and asbestos. Because of safety concerns, attic attainment was not possible at this site. One HOBO logger was able to be placed outside the building in a climate-controlled box. Inside temperatures were analyzed indirectly from temperature-sensitive transmitters that had fallen off the bats but were still actively recording the temperatures to which they were exposed.

Most of the females captured at Joffe Lake roosted at the Power House. The maternity colony at this site was the most consistent colony during the reproductive season. Bats were found at this site earlier than any other site, by approximately 2.5 weeks, and remained in the colony longer than any other site by 2 to 5 weeks. Several

other buildings in Mammoth Hot Springs were occupied during the same time frame, but only a handful of bats were ever observed exiting these buildings or tracked back from Joffee Lake after being radio-tagged. The Power House is a safe attic with a more natural environment for the bats to complete their reproductive cycle prior to hibernation. Analyses of temperatures from the Power House are very similar to microclimates within natural rock roosts, but offer a safer and larger space for a maternity colony to raise their young (see Chapter 8).

Twenty-nine bats were observed exiting the building the first week of June. To compare, 60 bats had already been observed at Fishing Bridge, none at Roosevelt Lodge and the Chapel, and four at the Bunkhouse. By the second week of June, numbers had quintupled, and by 21 June, colony size peaked with 397 bats exiting during the observational hour. Colony numbers began decreasing at the beginning of July when tagged bats from this roost and Building #3 were observed switching to the Chapel. The Chapel offers a more stable and cooler microclimate for the hottest parts of the summer season. Colony size at the Power House steadily declined until the beginning of August, when exit counts increased slightly. The final emergence was conducted on 9 August, with 237 bats exiting the Power House (Fig. 6.10).

Roost #5: Chapel, Mammoth Hot Springs, WY (Fig.6.7)

Location: 12 T 523827 E 4979967 N

Roost Type: C

The Chapel at Mammoth Hot Springs was built using local sandstone in 1913 just after completion of the Power House. Unlike the rest of the Mammoth Hot Springs area, the

Chapel was built in a Gothic-style with more rustic stonework cut by hand rather than by machine. The roughly-coursed local sandstone with a buttressed front wall and a series of stone buttresses on the long side walls contrasts with the more finished ashlar masonry of the earlier Colonial Revival/Mediterranean building style. The attic and side add-on have some wooden structures on the inside, but the entire outside and exposed walls and portions of the ceilings were built using sandstone. The Chapel is the only building in Mammoth with the foundation, walls, and the main sanctuary room built entirely from stone. The remaining portions of the ceiling located on the added-on side rooms contain wooden rafters with stone laid on top. The trussed arches also have an underlay of wood, with slate shingles overtop.

The side add-on to the sanctuary made of both wood and stone, contains a small, accessible attic with large piles of built-up guano, but I only found two bats present when I entered to replace the HOBO loggers. HOBO data for this roost site was obtained for 2012 and 2015. Most of the bats could be heard from portions of the attic inaccessible to humans, with guano found surrounding the chapel on the outside. Tagged bats roosted in the building creases. Bat exit behavior suggested all bats were roosting in similar locations throughout the building. At this roost, bats were limited to exiting one-by-one through small holes found in the corners between the roof shingles and the stone walls. The females could be seen and heard pushing and scraping against each other while scrambling to get out and forage for the night. A steady stream of single bats from multiple holes continued for almost an entire hour during exit counts. Unlike the other roost structures, only a handful of bats ever returned to the roost during exit counts.

Returns were probably fewer at this site due to the difficulty of re-entering a small hole that adult bats were still trying to exit.

The Chapel remained unoccupied until the first week of July, when three tagged females (roosting in two different Type A roost locations) were observed switching roosts on the same night of 3 July. On 7 July, 330 bats were observed emerging from the Chapel. Once bats began moving from other roosts to the Chapel, the Chapel became the largest maternity colony being studied, peaking at 469 bats on 15 July. After this maximum count, colony size steadily declined and numbered only 153 individuals at the final count on 11 August (Fig. 6.10).

Roost #6: Building #3; Officer's Row; Mammoth Hot Springs; WY

Location: 12 T 0523724 E 4980295 N

Roost Type: A

Roost #6 is located on Officer's Row and is currently serving as the Superintendent's House. The two- and a half-story residence has walls of sandstone with a wooden, finished attic. Hipped, unglazed red clay tile roofing covers the attic and side overhangs. The unglazed clay tiles are laid over 2.54cm wood sheathings. The trims and eaves of the building are wooden. The attic is similar in structure to the Power House attic. Only seven bats were recorded roosting here from 2012 to 2015. Of the seven bats recorded, only two returned each morning of monitoring to this location. Remaining bats switched building roosts every few nights. No exit count was conducted at this roost

.

Roost #7: Residential Buildings in Mammoth

Location: Throughout Upper Mammoth

Roost Type: Undetermined; no maternity colony existed and no internal temperatures were available

The residential buildings in Mammoth have wooden frames and usually tin roofs. The smaller residential buildings, now referred to as apartments, were constructed during the Fort Yellowstone era and were not built with permanence in mind like the Power House, Hotel, and Officer's Row. The insulation throughout the apartments is poor, and most do not have attics. Only five bats over four summers of tagging roosted in one of the residential buildings, and only did so for a few nights. Exit counts were conducted on all of the apartments in Upper Mammoth, with no more than three bats ever emerging from any one of these buildings.

Section Four: Natural Rock Roosts

Rock Roost #1: Rock in Little America (just outside of Lamar Valley) (Fig. 6.9)

Location: 12 T 0554812 E 4974708 N

Roost Type: A

This roost was a 1.5 x 1.2 m boulder located in the area known as Little America, just to the west of Lamar Valley and roughly 400 m north of the Northeastern Entrance Road.

The boulder had a 2.54cm wide crevice splitting across half of the 101° facing aspect. A pregnant female from the Bunkhouse at Buffalo Ranch was tracked to this location a few days after vacating the Bunkhouse. Multiple bats could be heard from within the crevice, although none was seen. The boulder was located next to a live lodgepole pine that

provided shade for a portion of the day. A HOBO was placed within the crevice to record the temperatures beneath the surface of the rock. No exit count was conducted at this roost.

Rock Roost #2: Cliff in Little America (just outside of Lamar Valley)

Location: 12 T 0554362 E 4974455 N

Roost Type: A

This roost was located directly west of rock roost #1, between Lamar Valley and Slough Creek, and was 400m north of the Northeast Entrance Road. The cliff was 11 m tall, with the tagged bat roosting where three crevices met at 5 m from the base. The major crevice runs vertically with the cliff, with the two smaller crevices meeting perpendicular to form a 5 x 2.5cm triangular hole of an unknown depth. The cliff faces 61° to the northeast. A few trees are in the area, but the crevice was mostly shaded by grasses and lichens growing on the rocks. Two bats could be heard from inside the crevice, but none could be seen. Only one bat was tracked to this roost and she was originally tagged at the Bunkhouse. No emergence count was conducted. A HOBO was placed within the crevice to record the microclimate of the roost.

Rock Roost #3: Sheepeater Canyon

Location: 2.8 km southeast of Mammoth Hot Springs

Roost Type: A

Three bats were tracked to various locations throughout Sheepeater Canyon. Because of the terrain and an inability to access portions of the canyon, specific roosts were triangulated but none was able to be physically accessed. The entire canyon is comprised

of limestone cliffs and scree slopes with lodgepole pine and Douglas-fir occupying sites wherever they could take root. The only tagged female recorded in the canyon was in a roost facing southwest, whereas two males tracked to this site roosted in a northwest-facing cliff. A HOBO was placed in a north-facing crevice and out of direct sunlight on the west side of the canyon.

Sheepeater location #1: A male bat in 2014 roosted for fourteen days on a northwest-facing talus slope located just below a hiker-made lookout point, 0.8km north of the Osprey Falls Trailhead on the Bunsen Loop Trail.

Sheepeater location #2: A male bat in 2015 roosted for eleven days on a northwest-facing cliff located directly across and farther down the canyon from the Osprey Falls Lookout along Osprey Falls Trail.

Sheepeater location #3: A female bat in 2015 roosted for three days on a southwest-facing talus slope.

Rock Roost #4: Cathedral Rock on Mt. Bunsen (4.4km directly south of Mammoth Hot Springs; Fig. 6.9)

Location: 12 T 0522784 E 4975838 N

Roost Type: A

Cathedral Rock is a roosting site used by male little brown myotis. While males do not roost in colonies as large as do females, they can congregate in the same area and occupy separate crevices/holes. A male bat in 2014 and another in 2015 both roosted at Cathedral Rock. One tagged male also roosted here in 2012. Exit counts were not conducted due to poor visibility, but I did observe the area at dusk when a tagged bat was

present. Multiple bats could be seen leaving Cathedral Rock and surrounding scree slopes after the sun went down on four different evenings. An attempt was made to find the roosts on Cathedral Rock, however, the almost vertical scree slopes below prevented ascent. I was able to confirm tagged males roosting in Cathedral Rock though, and not in the scree slope below.

Study Sites in Yellowstone National Park

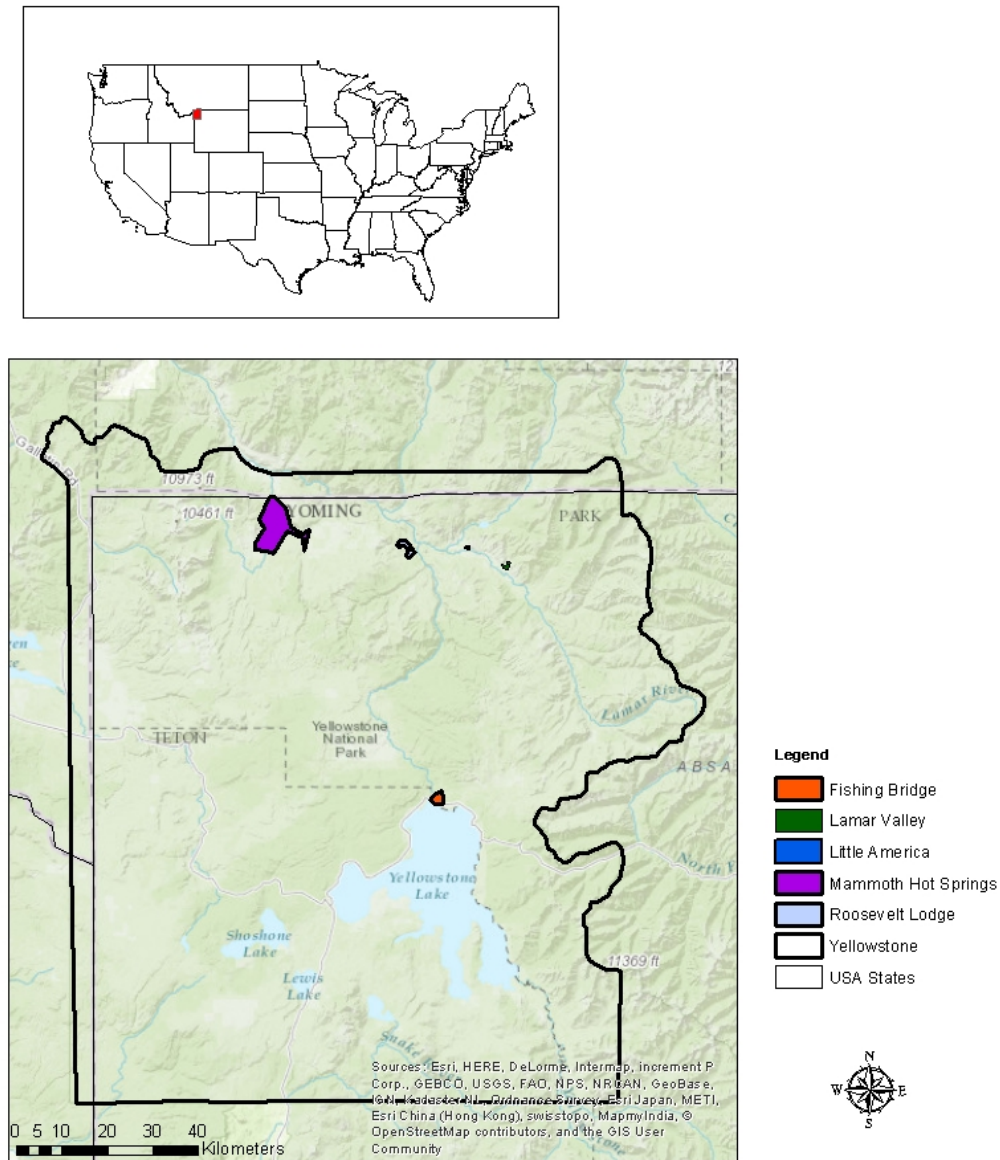


Figure 6.1. Map of Yellowstone National Park and Study Areas.

Table 6.1. Annual mean minimum and maximum temperature, and annual precipitation amounts across four sampling sites in YNP.

Location	Mean minimum °C	Mean maximum °C	Annual precip (mm)
Mammoth Hot Springs	-0.87	12.4	376
Roosevelt Lodge/Tower	-4.8	11.8	450
Buffalo Ranch/Lamar Valley	-6.1	9.9	405
Fishing Bridge/Lake	-5.2	8.1	563



Figure 6.2. Mist-net Capture Site 1: Joffee Lake. Picture taken from the parking area.

The immediate view where open land meets water is where the triple-high mist net was placed when used.



Figure 6.3. Attic attainment site and roost #1: The Bunkhouse at Buffalo Ranch in Lamar Valley. Bats exit primarily through the visible vent above the door. Roost Type B: microclimates with the most daily temperature variance. Picture courtesy of U.S. Government, National Park Service.



Figure 6.4. Attic attainment site and roost #2: Roosevelt Lodge at Tower. Bats exit mostly between the visible stone chimney and the wooden attic. Roost Type C: stable and steady microclimate.



Figure 6.5. Attic attainment site and roost #3: Fishing Bridge Service Station (in the picture still referred to as Hamilton's Store). The highest elevation site. Bats exit through multiple areas on each side of the building. The upstairs window opens to the inside of the attic. Roost Type B: microclimate experiencing the greatest daily temperature variation and lowest daily temperature drops. Picture courtesy of U.S. Government, National Park Service.



Figure 6.6. Roost #4: Power House, Mammoth Hot Springs, WY. Building is now condemned due to asbestos and other dangers. Bats exit primarily through the outcropping on the roof referred to as the “bat cannons.” Roost Type A: the warmest microclimates.



Figure 6.7. Roost #5: Chapel, Mammoth Hot Springs, WY. Bats exit primarily via non-visible cracks throughout the side of the chapel shown in the picture. Roost Type C: the most stable and steady microclimate.



Figure 6.8. Natural Rock Roost #1; Little America (just outside Lamar Valley). One pregnant female tagged in the Bunkhouse at Buffalo Ranch relocated to this roost before returning to Roosevelt Lodge. Roost Type A.



Figure 6.9. Rock Roost #2 Sheepwater Canyon. Males were tracked to cliffs and talus slopes throughout all years. Roost Type A.



Figure 6.10. Rock Roost #4; Cathedral Rock on Mt. Bunsen. Males were usually tracked to this location, roosting solitarily in the rocks. Roost Type A.

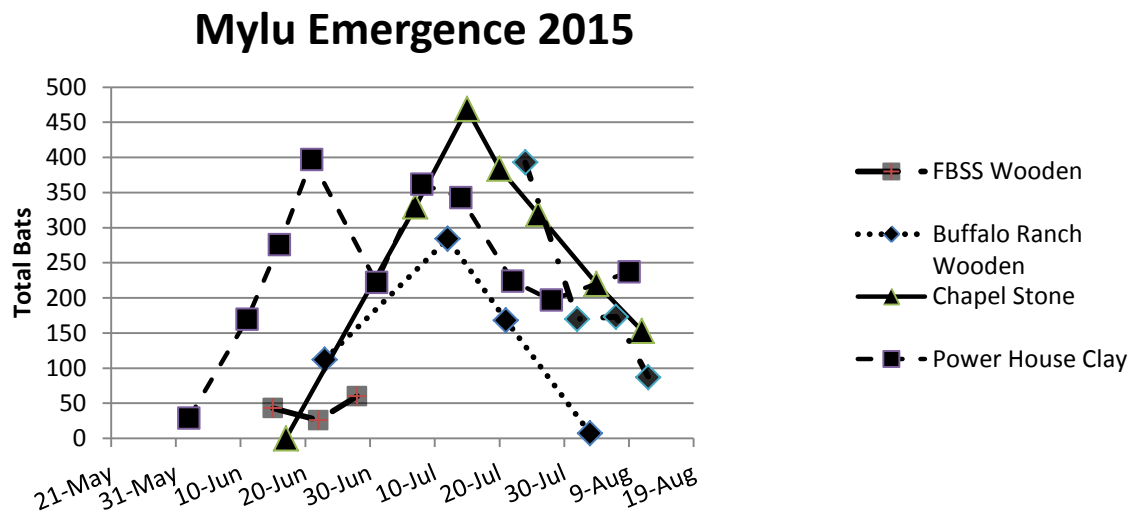


Figure 6.11. 2015 Exit counts of bats from anthropogenic roosts used by little brown myotis in YNP.

Chapter 7: Methodology and Analyses

Section One: Safety Concerns

Observing safety protocols, as determined by the National Park Service staff at YNP, required all personnel working on the project to be up-to-date on their rabies vaccinations, and to be trained in the proper way of handling both the bats being studied and the equipment used to obtain information from the bats. Prior to field work, all personnel also attended a Bear Safety training session required of all researchers working in YNP.

Section Two: Capture and Tagging Methods

Bats were captured using one of two methods: attic attainment and mist netting. Attic attainment refers to bats obtained by hand from building attics rather than during night captures with mist nets. I entered attics during the day, and would then proceed to gather as many bats as possible before they moved to areas where they could not be reached. Bats were processed and fitted with radio-transmitters as described below. Because roosting bats can be easily disturbed by the light of headlamps and the noise of investigators, I spent as little time as possible in attics, and waited a minimum of two weeks before re-entering. Due to different layouts of the attics and internal visibility, I did not attempt to estimate maternity colony size while in the attics, but instead relied on evening exit counts for estimates of population size. I implemented attic attainment captures during summer months 16 times from July 2013 through August 2015.

Following YNP's safety protocol, I conducted mist-netting within sight of a road but not obviously visible to passing tourists. I set up mist-nets before and during sundown (approximately 2030-2100 hrs), with netting beginning approximately 30 min after sundown. Polyester cross-hatched, 38mm nets were used at each capture session (Avinet, Inc., NY, USA). At Joffee Lake, one 2.6 x 18m net was set on the north side of the lake, with a triple-high 2.6 x 18m net set along the south side. One 2.6 x 9m and one 2.6 x 12m net were set just behind the lake and over an ephemeral water hole in the forest next to an old, dirt road. At Lava Creek, three nets were usually set up: one 2.6 x 9m net running across the creek on the north side of the road, and two 2.6 x 12m nets set up farther into the forest on the south side of the road. The net sites were surrounded by lodgepole pines, however, clearings and meadows were visible from the forested capture sites. Capture sessions at both sites occurred on average once every two weeks during summer months of June 2012 to August 2015, for a total of 36 nights. To prevent disturbance at net sites, personnel were positioned slightly away from the nets and remained quiet. Nets were checked every 10 to 15 min.

Captured bats were placed in small, washable cloth bags, and then hung on a clothesline until processing commenced. Forearm measurements (calipers; mm), body mass (Ohaus TAJ501 Gold Balance 500g x 0.1g), sex, reproductive status (females: non-reproductive, pregnant, lactating, or post-lactating; males: non-reproductive or reproductive), and overall health was recorded for all captured bats. Bats not considered for tagging were released immediately after processing. Female little brown myotis weighing more than 7g were considered for radio-tagging. I processed pregnant female ($n = 53$), non-reproductive female ($n = 87$), lactating female ($n = 22$) and post-lactating

female ($n = 6$) little brown myotis. Male little brown myotis ($n = 164$ captured) weighing more than 6.4g were considered for tagging if females were not able to be captured and/or tagged on netting nights.

I used temperature-sensitive transmitters (LB-2XT; 0.29g for 14 days at 40°C; Holohil Systems Ltd. Radio Transmitters, Ontario, Canada) to track bats and to collect body temperatures. I attached transmitters between the shoulder blades with Perma Type Surgical Cement (Perma Type; Plainville, CT, USA), after cutting and removing hair close to the skin. I placed the clipped hair back over the transmitter with glue to facilitate more accurate body temperature readings from the transmitter. Radio-tagged bats were rolled up in the holding bag to limit movement, and allow glue to dry and the transmitter to set, for 15 min before release. Frequencies were re-checked and sometimes modified based on signal strength and pulse rate before release.

Section Three: Tracking and Telemetry

I tracked tagged bats by vehicle and by foot to their day roosts using an R-1000 telemetry receiver (Communications Specialists, INC, CA, USA), a 3-pronged yagi antenna (Advanced Telemetry Systems, MN, USA), and magnetic roof-mount dipole with omnidirection (Advanced Telemetry Systems, MN, USA). The individual transmitter frequencies were input into the R-1000 during the tagging session. Tracking was first accomplished via the dipole and R-1000 by car until a signal was heard from the road. For signals not obviously coming from a building roost, multiple signal points were taken from the side of the road using the 3-pronged yagi and R-1000 before tracking off-road. For bats tagged at Joffe Lake, I would first turn the R-1000 on in Gardiner, MT, and

listen as I drove up to Mammoth Hot Springs, WY. Usually females tagged at Joffee Lake were day roosting in building roosts throughout Mammoth Hot Springs and the males were day roosting in either Sheepeater Canyon or on Bunson Peak, both visibly east of Mammoth. Occasionally I heard no beeps from tagged bats in the Mammoth area, and would proceed on the road towards Norris, first stopping at the terraces, and then continuing until reaching the Sheepeater Cliffs (a separate location from Sheepeater Canyon). One male was found via this route, with signals coming from Quadrant Mountain. After driving the route to Sheepeater Cliffs, I would then return to Mammoth Hot Springs, re-check the 1.6km route through the terraces, and then take the Northeast Entrance road towards Roosevelt Lodge/Tower and Lamar Valley. If no beeps were heard along either of these routes, then that night I would drive around the same area and listen for a signal to determine if the tagged bat was foraging in the area.

Bats tagged at Roosevelt Lodge occasionally stayed at Roosevelt Lodge. One female in 2014 was found roosting in a Douglas-fir 4.8 km west of Roosevelt Lodge. Her transmitter signal was heard at Lone Tree Lake/pullout. One female in 2014 was also heard from within the canyon at Tower Fall at night, but was never located during the day. Bats tagged in the Bunkhouse at Buffalo Ranch usually stayed in the Buffalo Ranch area for at least a portion of the transmitter duration. The females that did not remain at Buffalo Ranch could usually be read on the R-1000 at night while foraging in Lamar Valley or Little America Valley.

Bats tagged at the Fishing Bridge Service Station remained at either the Service Station or the General Store next door. The only exception were four bats tagged at the same time in 2015. A handful of faint signals were heard while driving the road from

Lake to West Thumb, but nothing was heard while driving through the Bridge Bay area. Bats were continually monitored at day roosts until transmitters failed to send signals or fell off of the bat.

Section Four: Data Recording and Processing

Once bats were located, I placed an ATS data logging receiver (Advanced Telemetry Systems R4500S, MN, USA) in the vicinity of roosts to record skin temperatures every five min. R4500S data loggers record pre-set frequencies through frequency selection. The receivers reject any signals and noise outside of the pre-set frequency range. My data logging receivers were set to record 150.000 – 152.999Hz. The transmitters I used on the bats ranged from 150.000-151.999 Hz and emitted fixed pulse rates. To analyze pulse rates, I first had to individually enter each transmitter's calibration chart as provided by the manufacturer. The pulse rates were then run through a third-order polynomial equation to match the calibration. Results are then presented in °C. Bats were analyzed individually to understand their physiological behavior while inside roosts, and their foraging behavior was based on departure and return times from and to roosts. I compared temperature data to field notes to ensure I was correctly analyzing bats based on location, reproductive condition, and ambient weather conditions.

I placed HOBO pendent temperature/daylight data loggers (Onset Corporation, Bourne, MA, USA) in, or as near as possible, to roosts and set them to record roost temperature every 15 min. HOBOs were also placed outside of three roosts housing different maternity colonies to compare immediate external ambient temperatures with internal roost temperatures. I downloaded temperature data after each transmitter went

off air and before another bat was tagged. HOBOS were recovered at the end of the summer season. Five HOBOS were lost during construction on the attics (Roosevelt Lodge and the Fishing Bridge Service Station) and were not recovered. Two HOBOS were deployed inside the Mammoth Chapel on 14 July 2012 and remained until the end of May 2013. One HOBOS was deployed at the Fishing Bridge Service Station on 31 July 2012 and remained until the end of May 2013. In 2014, three HOBOS were deployed at the Fishing Bridge Service Station from 25 June to 25 September, two HOBOS were deployed in the rock roosts just outside of Lamar Valley from 10 July to 25 September, one HOBOS was deployed at Roosevelt Lodge from 16 July to 29 September, and three HOBOS were deployed at Buffalo Ranch from 28 May 2014 to 26 March 2015. In 2015, two HOBOS were deployed at Buffalo Ranch from 2 June to 13 August 2015; two were deployed in the Mammoth Chapel from 3 June to 25 September; three were deployed at Fishing Bridge Service Station on 2 June 2015 but were not recovered, and two were replaced in the rock roosts outside of Lamar Valley from 8 June to 13 August 2015.

Section Five: Exit Counts

I conducted exit counts once per week at four maternity colonies during the summer of 2015 from 1 June through 12 August: the Power House and the Chapel at Mammoth Hot Springs, the Bunkhouse at Buffalo Ranch in Lamar Valley, and Roosevelt Lodge at Tower. These four sites housed the largest known colonies of little brown myotis in the Park throughout the summer, and each one always had bats present. Three counts were also conducted at the Fishing Bridge Service Station (the highest elevation site; 2,370m) before construction rendered the maternity colony uninhabitable during the first week of

July. Occasionally, counts were missed due to inclement weather or allocation of personnel to mist-netting activities. My observations and evidence from counts suggests that little brown myotis still emerged to feed on misty, cold nights in the Park. Two observers were always present during counts in an attempt to cover all exits from the roost and to comply with YNP safety protocols. We would arrive 15 min prior to sunset, and then remain at locations for one hour after the first bat emerged. To count bats, we used GOGO handheld 4-digit tally counters (Amazon.com). For most of the summer and across all locations, bats completed emergence approximately 15 min before the hour ended. By mid-August, bats finished emerging about 30 min before the hour ended at the Bunkhouse and the Chapel. The Power House and Roosevelt Lodge had bats continuously existing up to the 45 min time frame throughout the entire summer season. Regardless of these temporal variations, we remained at emergence sites for one hour after the first bat exited to standardize the data collection procedure and ensure that no bat was missed.

Section Six: Data Analysis

I used nine HOBOs for microclimate analysis of the attic and rock roosts that had temperature-sensitive transmitter tagged bats also roosting in them. Microclimate analysis was conducted on attics of the Bunkhouse at Buffalo Ranch, Mammoth Chapel, Fishing Bridge Service Station, the two natural rock roosts in Little America, the Power House, Roosevelt Lodge, and a cliff in Sheepeater Canyon. Two HOBOs were used from both Mammoth Chapel and the Fishing Bridge Service Station. The two rock roosts in Little America were merged together for temperatures analyses. All analyses were

conducted in SAS (Software 9.2; SAS Institute Inc., Cary, NC, USA) and Microsoft Excel 2010. Mean daily maximum, minimum, average, and variance in roost temperatures were analyzed using ANOVA, coupled with a LSD means separation procedure and a Duncan's Multiple Range Test when ANOVAs were significant. I used differences for mean daily maximum, minimum, and variance in temperature to assign roosts into groupings based on commonality of test outcomes.

Fifty-nine females were tagged during the summers 2012, 2013, 2014, and 2015. Of the 59 females radio-tagged, only 38 were used in the analyses (a 66% success rate of data collected vs. data attempted including a post-lactating female not used in the analyses). Remaining females were not relocated and, therefore, did not provide any temperature data. Analyses were based on data from 21 pregnant, 12 lactating, and 4 non-reproductive females. I used 2-factor mixed model, nested ANOVAs for analysis (Software 9.2; SAS Institute Inc., Cary, NC, USA), with effect size evaluated using Type III Sums of Squares as the error term. I tested effects of reproductive condition (non-reproductive, pregnant or lactating), roost type (A, B or C) and their interaction, with bat day (each day a bat provided data) as the nested effect. I compared number of torpor bouts, average torpor bout depth, average torpor bout duration, maximum torpor bout duration, and minimum, maximum and variance in skin temperatures.

Number and proportion of torpor bouts were compared across all reproductive classes and roost types, with time of day divided into four, six hour categories: morning hours included all torpor bouts within 04:00 – 09:59, afternoon hours were 10:00 – 15:59, evening hours were 16:00 – 21:59, and night hours were 22:00 – 03:59. For temporal comparisons, torpor bouts extending across time categories were counted as one torpor

bout for each time of day in which they occurred. Each torpor bout was analyzed as a single event for all other analyses.

Thermoregulation data were collected from six adult males across the 2012 to 2015 study seasons, with one from 2013, three from 2014, and two from 2015. All males were captured at either Joffee Lake or Lava Creek. Males with temperature-sensitive transmitters were tracked to four different locations: Sheepeater Canyon located at the base of Bunsen Peak on the north side; Cathedral Rock and surrounding cliffs, located on Bunsen Peak on the south side; Quadrant Mountain; and, inside a Douglas fir just 255 m from of Lava Creek. Microclimate data were not collected from inside male roosts due to insufficient access. Statistical analyses were not used to determine differences between males in rocks and trees because only a single male was recorded roosting in a tree. Qualitatively, however, the tree-roosting male exhibited thermoregulation patterns similar to that for adult females than the other five males in rock-roosts (see Chapter 11).

Chapter 8: Roosting Classifications Based on Microclimate Patterns

Section One: Introduction

The means procedures demonstrated five different roost groupings based on mean maximum and minimum temperatures per day, and six different roost groupings based on mean variance in temperature per day. Mean daily maximum roost temperature among all eight roosts was significant ($F_{8,840} = 92.1$; $P = <0.0001$). Mean daily minimum roost temperature among all eight roosts was also significant ($F_{8,840} = 62.8$; $P = <0.0001$). Mean daily variance in roost temperature among the eight roosts was significant per roost ($F_{8,840} = 146.54$; $P = <0.0001$). From these outputs, I classified roosts into three categories—A, B and C—for analyzing bat torpor bouts (Table 8.1).

Mean daily average roost temperature among the eight roosts was also significant per ($F_{8,840} = 32.33$; $P = <0.0001$); however, average temperatures did not accurately reflect roost microclimates. The Mammoth Chapel, for example, shares a similar daily average with the Fishing Bridge Service Station (21.6°C and 20°C, respectively) yet the Mammoth Chapel has a stable microclimate with little daily variance and a high daily minimum (see section 4: Type C Roosts) compared with extremely low daily minimums and medium daily variance in temperatures for the Service Station (see section 3: Type B Roosts).

Section Two: Type A Roosts

Roost Type A represented roosts that experience the widest mean daily temperature variance and the highest mean maximum temperature compared to other roosts. These included all natural rock roosts, the Power House, and Building #3. The Power House and Building #3 both had attics constructed using the same building style and were composed of the same materials, although they differed in foundation and wall design. Because bats roosted in the attics and not throughout portions of the rest of the buildings, roost microclimates and bat roosting behaviors at both buildings were not remarkably different. Mean daily maximum was 38.5°C (± 1 SE) in the Power House and 39.5°C (± 1) in Building #3. Mean daily minimum was slightly higher in Building #3 ($20.1^{\circ}\text{C} \pm 1$) compared with the Power House ($18.2^{\circ}\text{C} \pm 0.4$), but both attics had the highest mean minimum and mean maximum temperatures compared with all other roosts of little brown myotis. Bats relocated from these two buildings to cooler buildings (the Chapel; Roost Type C) once ambient temperatures began to rise in the middle of July. All Type A roosts had mean maximum daily temperatures within 33 to 38°C and a mean daily variance in temperature of 20 to 25°C . Type A roost daily maximums ranged from 10 to 15°C above ambient maximums depending on the roost and, with the exception of the Sheepeater Canyon rock roost, roost daily minimums ranged from 7 to 11°C above ambient minimum (Fig. 8.1). The roosts in Sheepeater Canyon only averaged 0.2°C above daily ambient minimums, despite averaging 10°C above daily ambient maximums. Thus, rock roosts at Sheepeater Canyon were the most variable of all known roosts of little brown myotis in YNP.

Section Three: Type B Roosts

Roost Type B consisted of the Buffalo Ranch Bunkhouse and the Fishing Bridge Service Station. Type B roosts possessed temperatures that did not vary as greatly as Type A roosts, but were more variable than Type C roosts. Both Type B buildings also exhibited the mean lowest minimum temperatures, dropping on average to 10 °C every night. The one exception was a Type A rock roost (#3) which averaged 9°C each night, however, this roost also averaged 33°C (± 0.87) for mean maximum temperature compared with 29°C (± 0.5) at the Bunkhouse and 29°C (± 0.7) at the Service Station. Rock roost #3 also exhibited the greatest daily temperature variation (average 25°C each day) of any roost. Both Type B buildings were poorly-insulated attics that were well-exposed to the environment, but also benefited from human occupancy beneath which resulted in the rooms below the attic being heated. The mean daily maximum temperatures at each location were well above the ambient daily maximums ($\bar{x} = 9.57^{\circ}\text{C} \pm 0.38$ at FBSS; $\bar{x} = 7.06^{\circ}\text{C} \pm 0.55$ at the Bunkhouse), and well above ambient daily minimum temperatures allowing for warmer microclimates suitable for conserving energy and raising young (Fig. 8.2). Mean daily roost minimum temperatures were also well above the ambient daily minimums ($\bar{x} = 7.61^{\circ}\text{C} \pm 0.17$ at FBSS; $\bar{x} = 7.29^{\circ}\text{C} \pm 0.22$ at the Bunkhouse), facilitating use of torpor and passive rewarming as the building steadily warmed during the afternoon each day. Thus, despite both Type B buildings having the lowest overall daily minimums, these roosts were still warmer than the ambient temperatures that bats would have otherwise been exposed to (Fig. 8.2).

Section Four: Type C Roosts

Roost Type C included roosts with the most stable microclimates and the least amount of daily temperature variance (Fig. 8.3): the Chapel and Roosevelt Lodge. While both buildings were made of different materials, both were structurally more sound than any other buildings used as roosts and provided the most insulation between the outside environment and the inside attic. I recovered one HOBO from Roosevelt Lodge from the summer of 2014; all other HOBOs were inaccessible due to construction in early 2015. Two HOBOs were recovered from the Chapel in 2014, along with thirteen days of roost recordings from a transmitter that had fallen-off an adult female little brown myotis. One of the HOBOs in the Chapel was placed closer to the exterior of the building where the bats were not roosting, and the other placed closer to the interior where bats did roost. The shed transmitter was also located, using radio-telemetry from the outside of the building, in the vicinity of where other radio-tagged bats were roosting.

Both buildings had the lowest mean daily maximum temperatures with $19.8^{\circ}\text{C} \pm 0.36$ for the more internal readings inside the Chapel close to where bats roosted; $26^{\circ}\text{C} \pm 0.42$ for the more external temperatures inside the Chapel where bats did not roost; and, $24.5^{\circ}\text{C} \pm 0.55$ inside Roosevelt Lodge. The HOBO readings inside the Chapel at the more external location were more similar to Roosevelt Lodge, likely due to the two structures being similar in design and configuration. The more internal areas of the Chapel where the bats roosted, experienced the least amount of daily temperature variance and the lowest daily maximum temperatures, even compared with Roosevelt Lodge. The internal readings at the Chapel were also the only roost temperatures recorded that remained consistently cooler than the ambient maximum ($\bar{x} = 2.30^{\circ}\text{C} \pm$

0.32 below daily ambient maximum). Patterns at Roosevelt Lodge were comparable, however, exhibiting daily roost maximum temperatures ($\bar{x} = 24.5^{\circ}\text{C} \pm 0.55$) only 1.64°C ($\pm .048$) above ambient maximums on average. Both buildings were well above mean ambient minimum temperatures, with $\bar{x} = 8.71^{\circ}\text{C} \pm 0.2$ above ambient minimum inside the Chapel and $\bar{x} = 12.3^{\circ}\text{C} \pm 0.31$ above ambient minimum inside Roosevelt Lodge. The two buildings were classified as the same type because of daily variance in temperature, with $4.7^{\circ}\text{C} \pm 0.19$ for the Chapel and $8.3^{\circ}\text{C} \pm 0.43$ for Roosevelt Lodge. Daily variance in Type B roosts was 16 to 18°C .

Mean average daily temperatures were not considered when separating roost categories because the average temperatures in a roost that only experienced 4°C daily temperature variance, were similar to roosts that experienced 24°C daily temperature variances (e.g., the Chapel compared with rock roosts in Sheepeater Canyon). Thus, a bat experiencing a comparably stable microclimate when roosting in the Chapel, likely expended much less energy maintaining a core body temperature than a bat experiencing extreme temperature fluctuations each day in a rock roost. The thermal neutral zone varies in little brown myotis from around 30 to 36°C (Altringham 2011). Any temperature outside of that zone is affecting a bats' physiological and behavioral condition. A bat roosting in a Type A roost, for example, experienced a microclimate varying from 13.4 to 37.1°C for the respective mean daily minimum and maximum temperatures resulting in an average daily exposure of temperatures ranging 21.7°C . Conversely, a bat in a Type B roost experienced the same average daily temperature range of 21.6°C , but was less exposed to extreme temperatures because the respective minimum and maximum temperatures within the roost were 17.6 to 26°C . Based on these

patterns, therefore, mean average daily temperature was not considered when categorizing roosts.

Mean minimum daily temperature was considered in grouping roosts. Roosts in the Type A grouping, however, exhibited variable mean temperature minimums across roosts with roosts possessing both the highest and lowest mean minimum temperatures being included within this grouping. Thus, roosts categorized as Type A included those with the greatest variance in daily temperatures and the highest daily temperature maximums. Differences in roost temperatures from ambient conditions were also considered and, with the exception of the mean minimum at Sheepeater Canyon, all roosts versus ambient temperature differences support the Roost Type A, B, and C groupings (Figs. 8.1, 8.2 and 8.3).

Table 8.1. Microclimate comparisons of mean daily maximum, minimum, and variance in temperatures of anthropogenic roosts used by little brown myotis in YNP.

Mean Daily Temperature Celsius								
Roost		Roost						
Roost	Type	N	Maximum	SE	Minimum	SE	Variance	SE
PH	A	62	38.51	1	18.28	0.48	20.22	1.3
LA	A	138	37.11	0.64	13.36	0.24	23.75	0.61
SR	A	66	33.3	0.87	8.9	0.34	24.44	0.79
FB1	B	93	29.14	0.74	12.99	0.45	16.14	0.57
BH	B	122	29.01	0.55	10.8	0.3	18.11	0.52
FB2	B	93	28.12	0.62	11.13	0.43	16.98	0.55
CH2	C	78	26	0.42	17.62	0.37	8.3	0.25
RL	C	76	24.53	0.55	16.13	0.35	8.4	0.43
CH1	C	121	19.87	0.36	15.14	0.34	4.7	0.19

PH = Power House at Mammoth Hot Springs

LA = Little America rock roosts

SR = Sheepeater Canyon rock roost

FB1 and FB2 = Fishing Bridge Service Station

BH = Bunkhouse at Buffalo Ranch in Lamar Valley

CH1 and CH2 = Chapel at Mammoth Hot Springs

RL = Roosevelt Lodge

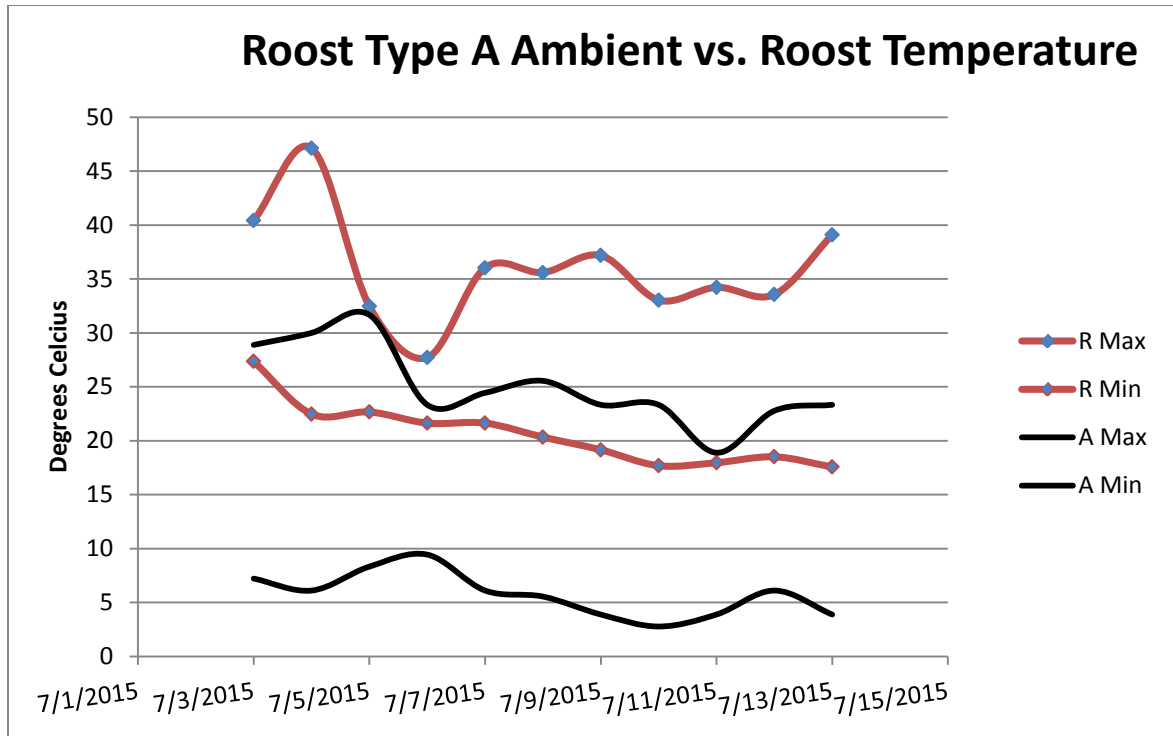


Figure 8.1. Roost Type A temperature comparisons. Graph illustrates roost vs. ambient temperatures for an average week in Type A roosts. R Max and R Min are the roost temperatures. A Max and A Min are the ambient temperatures.

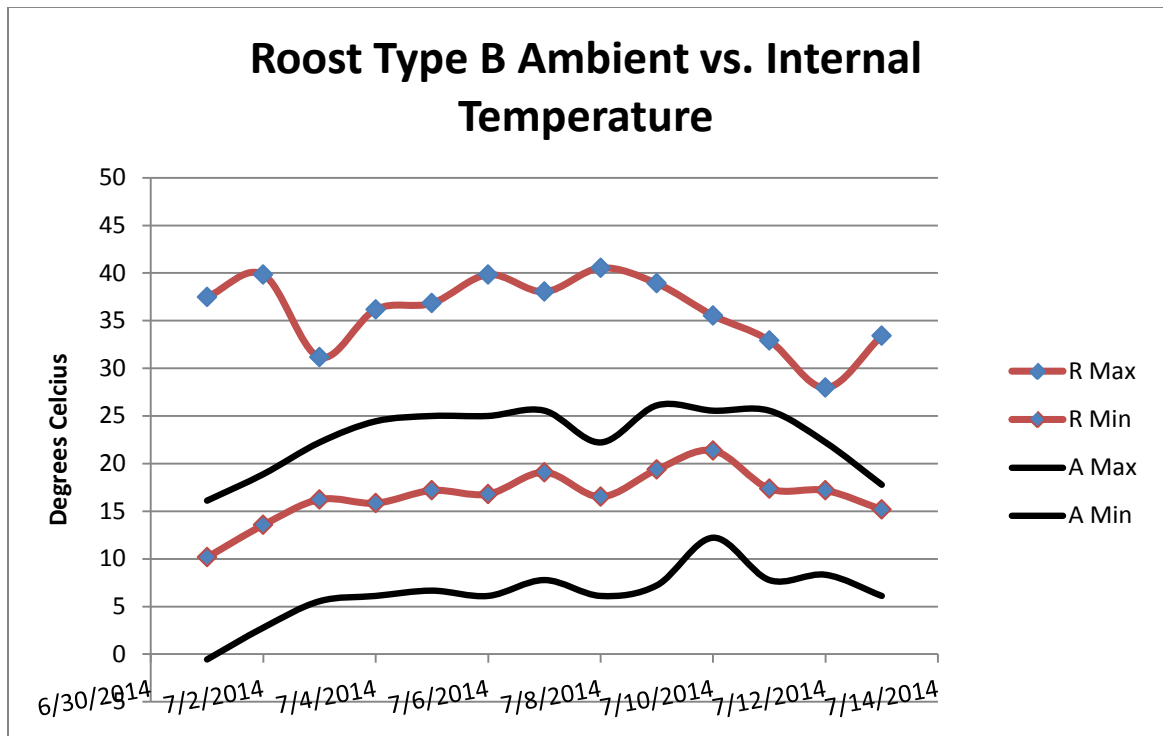


Figure 8.2. Roost Type B temperature comparisons. Graph illustrates roost vs. ambient temperature differences on an average week in a Type B roost. R Max and R Min are the roost temperatures. A Max and A Min are the ambient temperatures.

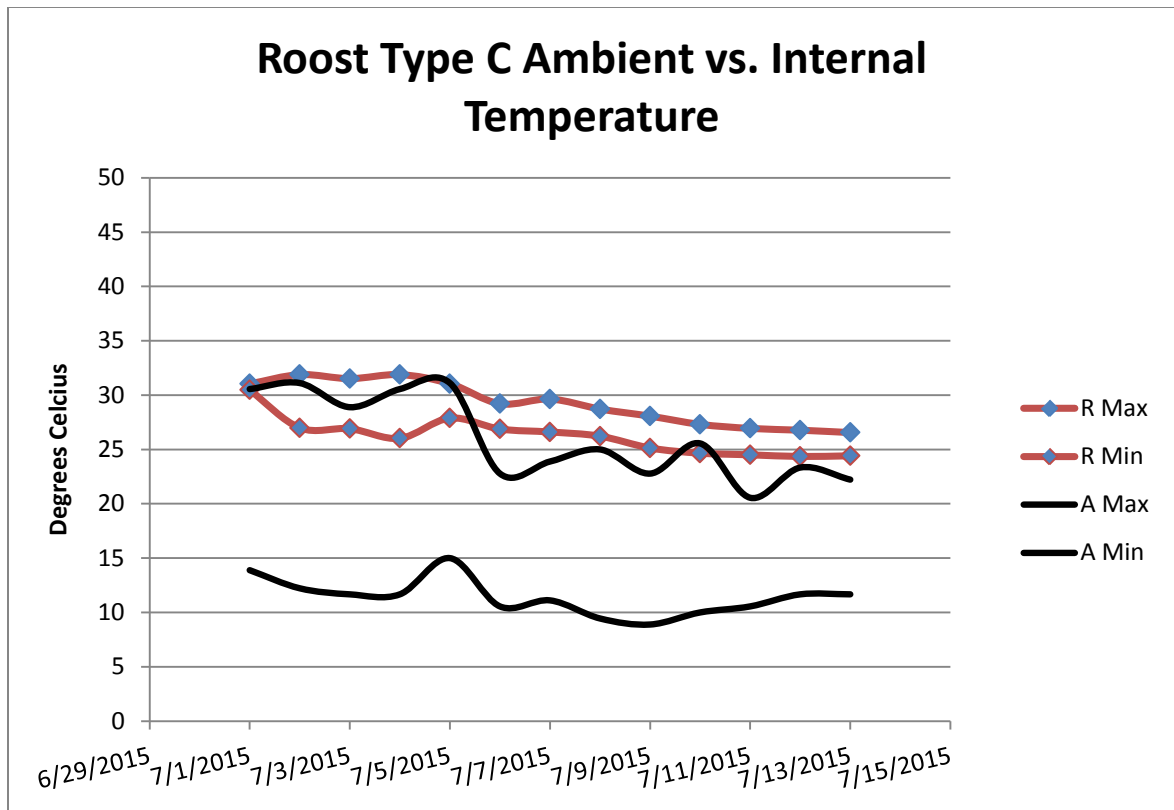


Figure 8.3. Roost Type C temperature comparisons. Graph illustrates roost vs. ambient temperature differences for an average week in a Type C roost. R Max and R Min are the roost temperatures. A Max and A Min are the ambient temperatures.

Chapter 9: Female Torpor by Reproductive Class and Roost

Classification

Section One: Daily Maximum Skin Temperatures across Class and Roost

The grand model for maximum skin temperature was significant ($F_{98,154} = 1.55$, $P = 0.007$). Using Type III Sums of Squares as the error term, the reproductive condition of female bats ($F_{2,154} = 5.87$, $P = 0.003$), roost type ($F_{2,154} = 6.84$, $P = 0.001$), and the interaction between the two ($F_{4,154} = 5.01$, $P = 0.0008$) were different across groupings. Pregnant ($\bar{x} = 32.4^{\circ}\text{C} \pm 0.96$ SE) and lactating ($\bar{x} = 34.9^{\circ}\text{C} \pm 1.12$) females in Type C roosts exhibited the lowest daily average maximum skin temperatures. Pregnant females across all roost types exhibited higher overall maximum temperatures than lactating females, but were slightly cooler on daily average (Tables 9.1 and 9.2). The daily average maximum skin temperature from 15 pregnant females across 91 bat days in Type A roosts was $37.6^{\circ}\text{C} \pm 0.41$, with a maximum of 46.7°C . The daily average maximum skin temperature for 5 pregnant females across 44 bat days in Type B roosts was $38^{\circ}\text{C} \pm 0.61$, with a maximum of 45.6°C . The daily average maximum skin temperature for 4 pregnant females across 25 bat days in Type C roosts was $32.4^{\circ}\text{C} \pm 0.96$, with a maximum of 41°C .

In Type A roosts, 11 lactating females across 56 bat days exhibited a daily average maximum skin temperatures of $38.4^{\circ}\text{C} \pm 0.28$, and a maximum of 43.8°C . The daily average maximum for two lactating females across 14 bat days in Type B roosts was $38.1^{\circ}\text{C} \pm 0.61$, with a maximum of 40.6°C . The daily average maximum temperature for lactating females was much lower in Type C roosts ($\bar{x} = 34.9^{\circ}\text{C} \pm 1.12$),

but the overall maximum was the highest recorded for all lactating females at 44.3°C. Non-reproductive females in Type A roosts ($n = 2$) had a daily average maximum skin temperature of $40.9^{\circ}\text{C} \pm 0.88$, and an overall maximum of 46.1°C across 14 bat days. In Type B roosts, non-reproductive females ($n = 2$) had a daily average maximum skin temperature of $36.6^{\circ}\text{C} \pm 1.72$, and an overall maximum of 39.9°C across 8 bat days. Based on one bat day from one non-reproductive female in a Type C roost, the maximum temperature was 41.3°C (Table 9.3).

Section Two: Daily Minimum Skin Temperatures across Class and Roost

The grand model for daily minimum skin temperature was significant ($F_{98,154} = 1.33$, $P = 0.05$). Effect of reproductive class on minimum skin temperature was significant ($F_{2,154} = 5.38$, $P = 0.005$), as was effect of roost type ($F_{2,154} = 11.28$, $P < 0.0001$) and the interaction between the two ($F_{4,154} = 2.86$, $P = 0.02$). Females in Type B roosts exhibited the lowest minimum skin temperatures and the lowest daily average skin temperatures (Table 9.1). Based on two bats and 20 torpor bouts, lactating females exhibited the lowest daily average skin temperature of $16.5^{\circ}\text{C} \pm 1.5$, and the overall lowest recorded skin temperature of 6.28°C . With five bats and 59 torpor bouts, pregnant females had a daily average minimum temperature of $22.6^{\circ}\text{C} \pm 1.07$, and a low of 9.96°C . Only two non-reproductive females totaling six bouts of torpor were recorded in Type B roosts, and these bats exhibited an average daily minimum skin temperature of $26.8^{\circ}\text{C} \pm 1.93$, and a low of 16.2°C .

Females occupying Type A roosts had lower skin temperatures than females in Type C roosts, but higher temperatures than females in Type B roosts (Tables 9.1, 9.2, and 9.3). Lactating and pregnant females exhibited similar patterns, except for

individuals occupying Type B roosts. Average daily minimum skin temperatures from 11 lactating females across 77 torpor bouts was $25.7^{\circ}\text{C} \pm 0.9$, whereas the daily average minimum for pregnant females ($n = 15$), based on 111 torpor bouts, was $25.4^{\circ}\text{C} \pm 0.41$. The lowest temperature recorded for lactating females in this roost type was 12.3°C , whereas the lowest skin temperature for pregnant females inside this roost type was 13.9°C . Two non-reproductive females with six torpor bouts recorded, exhibited a daily average minimum of $30.5^{\circ}\text{C} \pm 1$, and a low of 23.8°C . All females in Type C roosts exhibited more stable skin temperatures compared with other roost types (Tables 9.1 and 9.2). The lowest temperature recorded was 19°C from a pregnant female. The daily average minimum skin temperature from four pregnant females across 39 torpor bouts was $27.1^{\circ}\text{C} \pm 0.83$. The daily average minimum skin temperature for four lactating females across 14 torpor bouts was $29.3^{\circ}\text{C} \pm 1$, with a low of 22.9°C . No torpor bout was recorded for a non-reproductive female occupying a Type C roost.

Section Three: Daily Skin Temperature Variations across Class and Roost

The grand model for daily variation in skin temperature was significant ($F_{98,154} = 1.56$, $P = 0.006$). Effect of reproductive condition was marginally important ($F_{2,154} = 2.73$, $P = 0.06$). Roost type ($F_{2,154} = 12.72$, $P < 0.0001$) and the interaction between the two ($F_{4,154} = 2.93$, $P = 0.02$), however, were significant. Lactating and pregnant females exhibited similar daily averages in temperature variance (12.2 and 12.4°C , respectively), but when partitioned by roost type and reproductive class, I found extreme differences between lactating and pregnant females inhabiting Type B roosts (Tables 9.1 and 9.2). Lactating females ($n = 2$), based on 20 torpor bouts in Type B roosts (FBSS was the only Type B roost with recordings from lactating females), exhibited the widest daily average variance

($21.6^{\circ}\text{C} \pm 2$) and maximum variance (34°C) in skin temperature. Pregnant females ($n = 5$), based on 59 torpor bouts in Type B roosts (collected from both Type B roosts), exhibited the second widest daily average variance ($15.8^{\circ}\text{C} \pm 1$) and maximum variance (28.7°C) in skin temperature.

Variation in skin temperatures for pregnant and lactating females in Type A and C roosts were similar, with females in Type C roosts being different from those in Type B roosts (Table 9.1). Daily maximum variance in skin temperatures for bats in Type A roosts was 29.5°C for pregnant females and 31.1°C for lactating females. Daily variance in average skin temperature for bats in Type A roosts was $12.6^{\circ}\text{C} \pm 0.75$ for pregnant females ($n = 15$ bats, 111 torpor bouts) and $12.8^{\circ}\text{C} \pm 0.9$ for lactating females ($n = 11$ bats, 77 torpor bouts). The maximum daily variance in skin temperature for pregnant females ($n = 4$ bats, 39 torpor bouts) in Type C roosts dropped to 14.6°C , with an average daily variance in skin temperature of only $5.5^{\circ}\text{C} \pm 0.8$. Similarly, the maximum daily variance in skin temperature for lactating females ($n = 4$ bats, 14 torpor bouts) dropped to 16.1°C , with an average daily variance in skin temperature of only $5.65^{\circ}\text{C} \pm 1.21$. Daily variations in skin temperature for non-reproductive females differed from lactating and pregnant females (Table 9.1). The average daily variation in skin temperature for two non-reproductive females in Type A roosts (6 torpor bouts) was $10.4^{\circ}\text{C} \pm 1.8$, with a maximum of 22.2°C . Results were similar for two non-reproductive females in Type B roosts (6 torpor bouts), with a daily average variation in skin temperature of $11.2^{\circ}\text{C} \pm 2.3$, and a maximum of 23.7°C . Only one, non-reproductive female was recorded in a Type C roost and she did not exhibit any torpor bouts.

Section Four: Torpor Use across Reproductive Class and Roost Type

A total of 347 torpor bouts were recorded from 38 females across the 2012 to 2015 summer seasons. However, to analyze torpor across time of day, I used data for 403 definable torpor bouts because many bats used torpor across the night-morning, morning-day, and the day-evening time frames. Few torpor bouts ($n = 62$) were recorded across the evening-night intervals. The grand models for average depth of torpor ($F_{80,98} = 0.77$, $P = 0.88$), average torpor duration ($F_{80,97} = 0.71$, $P = 0.94$), and maximum torpor bout duration ($F_{80,95} = 0.67$, $P = 0.96$) were not different.

Bats across reproductive classes and roost types used torpor at different hours of the day. Only 12 torpor bouts were recorded for four non-reproductive females. Non-reproductive females only used torpor during the morning (83%) and evening (17%) hours (Fig. 9.1). With such a small sample size, however, these results may not be reflective of population-level patterns and comparisons to those of pregnant and lactating females should be made with caution. Never-the-less, even with such a small sample size, non-reproductive females exhibiting torpor only in the morning and evening hours suggests less of a need for energy savings than for pregnant and lactating females.

I recorded 247 torpor bouts for pregnant females (Fig. 9.2). Torpor use by pregnant females was distributed throughout the 24-hour daily cycle, with most bats using torpor during the morning hours (42%), followed by the evening hours (25%), daytime hours (18%) and nighttime hours (15%). Lactating females exhibited comparable patterns in torpor use (Fig. 9.3), with slightly more equitable use of torpor throughout the 24-hour daily cycle. I recorded 144 torpor bouts for lactating females,

with torpor occurring most often during the morning hours (37%), followed by daytime use (22%), evening hours (24%), and 17% during nighttime hours.

When looking at differences across roost type, lactating females in Type A and B roosts exhibited a pattern similar to that described above (Fig. 9.3), with torpor spread relatively evenly throughout the day. Lactating females in Type B roosts used torpor slightly more during the afternoon than did lactating females in Type A roosts (30% to 22%, respectively, Figs. 9.4 and 9.5). Lactating bats roosting in Type C roosts, however, demonstrated different patterns (Fig. 9.6), with these four lactating bats using torpor primarily at night (40%), followed by the morning hours (35%). Use of daytime torpor remained about the same (22%), with use of torpor in the evening hours dropping to only 0.04%, compared with the 18% use for lactating females in Type C roosts. Pregnant females roosting in Type A and B roosts were not remarkably different from each other (Figs. 9.7 and 9.8). Pregnant bats occupying Type C roosts, however, were different with use of torpor at night increasing to 30%. Use of torpor during the morning and evening hours dropped to 34% and 11%, respectively, for pregnant females (Fig. 9.9).

Female bats in Type A natural rock roosts used torpor most often in the evening (45%), followed by the morning hours (36%), and daytime hours (18%, Fig. 9.10). Pregnant females in Type A natural rock roosts were not recorded using torpor at night, despite their use of nighttime torpor when occupying building roosts.

Although I was unable to detect statistically significant patterns ($P > 0.05$), in my view average and maximum torpor depths showed variation among reproductive classes and roost types (Tables 9.1, 9.2, and 9.3). Based on 91 bat days and 111 torpor bouts,

pregnant females ($n = 15$) showed an average daily torpor depth of $-4.37^{\circ}\text{C} \pm 0.6$ (i.e., below the 31°C temperature threshold calculated for torpor in little brown myotis), with a maximum depth achieved of -12.4°C . Lactating females in Type A roosts had an average daily torpor depth of $-4.24^{\circ}\text{C} \pm 0.6$, with a maximum of -16.4°C , based on 77 torpor bouts and 11 individuals. Non-reproductive females in Type A roosts used torpor the least, exhibiting shallow depths compared with pregnant and lactating females, but this reproductive class is poorly represented in the data with only two bats and six torpor bouts in this roost type. Non-reproductive females had an average torpor depth in Type A roosts of $-3.83^{\circ}\text{C} \pm 0.7$, with a maximum depth of torpor of -7.1°C .

Most females, excluding non-reproductive, appeared to use deeper torpor while in Type B roosts when compared with other roost types, presumably because both Type B roosts experienced the coldest overall nightly temperatures, with one location (Fishing Bridge) being the highest elevation study site in the area. Based on 59 recorded torpor bouts from 5 pregnant females, average daily torpor depth for these bats in Type B roosts was $-5.49^{\circ}\text{C} \pm 0.8$, with a maximum of -14.7°C . Lactating females exhibited a daily average depth of $-9.33^{\circ}\text{C} \pm 1.6$ and a maximum depth of -20.2°C across 20 torpor bouts from two individuals. Non-reproductive females exhibited shallow depths compared with pregnant and lactating females, with a daily average depth of $-4.82^{\circ}\text{C} \pm 0.9$ and a maximum depth of only -7.35°C .

Females in Type C roosts exhibited the most shallow torpor depths, regardless of reproductive condition. From four pregnant females across 25 days and 39 torpor bouts, average daily torpor depth was $-2.36^{\circ}\text{C} \pm 0.4$, with a maximum depth of only -5.8°C . Four lactating females across 21 bat days and 14 torpor bouts had an average daily depth

of torpor of $-4.62^{\circ}\text{C} \pm 0.4$, with a maximum depth of -6.74°C . No torpor bout was recorded in a Type C roost for a non-reproductive female.

Table 9.1. Means (SE) for variables describing skin temperatures and torpor bouts of pregnant little brown myotis by roost type in YNP. Number of bats monitored and number of torpor bouts are also presented.

	Pregnant					
Roost Type	A	SE	B	SE	C	SE
Bats	15		5		4	
Tbouts	111		59		39	
Days	91		44		25	
Tsk Max Avg	37.64	0.4	37.57	0.5	32.43	1
Tsk Max	46.7		45.63		40.96	
Tsk Min Avg	25.38	0.4	22.57	1	27.12	0.8
Tsk Min	13.87		9.96		19.04	
Tsk Var Avg	12.57	0.75	15.83	1	5.5	0.8
Tsk Var Max	29.53		28.71		14.61	
Avg Bout Depth	-4.37	0.57	-5.33	0.67	-2.36	0.38
Bout Depth Max	-12.35		-14.71		-5.8	
Avg Bout Duration (minutes)	172.98	22	354.37	48	311.28	61.57
Max Bout Duration (minutes)	1250		1105		980	

Tbouts = total bouts in specified roost

Days = total bat days in specified roost

Table 9.2. Means (SE) for variables describing skin temperatures and torpor bouts of lactating little brown myotis by roost type in YNP. Number of bats monitored and number of torpor bouts are also presented.

	Lactating					
Roost Type	A	SE	B	SE	C	SE
Bats	11		2		4	
Tbouts	77		20		14	
Days	56		14		21	
Tsk Max Avg	38.45	0.28	38.08	0.62	34.91	1.12
Tsk Max	43.76		40.58		44.26	
Tsk Min Avg	25.68	0.9	16.53	1.51	29.26	1
Tsk Min	12.31		6.28		22.86	
Tsk Var Avg	12.76	0.97	21.55	2	5.96	1.21
Tsk Var Max	31.07		33.96		16.12	
Avg Bout Depth	-4.24	0.57	-9.33	1.57	-4.62	0.45
Bout Depth Max	-16.44		-20.2		-6.74	
Avg Bout Duration (minutes)	171	28	282.7	46	254.13	49.52
Max Bout Duration (minutes)	1135		865		303	

Tbouts = total bouts in specified roost

Days = total bat days in specified roost

Table 9.3. Means (SE) for variables describing skin temperatures and torpor bouts of non-reproductive female little brown myotis by roost type in YNP. Number of bats monitored and number of torpor bouts are also presented.

Non-reproductive females				
Roost Type	A	SE	B	SE
Bats	2		2	
Tbouts	6		6	
Days	14		8	
Tsk Max Avg	40.93	0.88	36.61	1.72
Tsk Max	46.06		39.88	
Tsk Min Avg	30.5	1	26.81	1.93
Tsk Min	23.81		16.22	
Tsk Var Avg	10.43	1.78	11.19	2.35
Tsk Var Max	22.25		23.66	
Avg Bout Depth	-3.83	0.71	-4.82	0.89
Bout Depth Max	-7.1		-7.35	
Avg Bout Duration (minutes)	185	31	150.38	37.25
Max Bout Duration (minutes)	380		354	

Tbouts = total bouts in specified roost

Days = total bat days in specified roost

Non-reproductive (n = 12 torpor bouts)

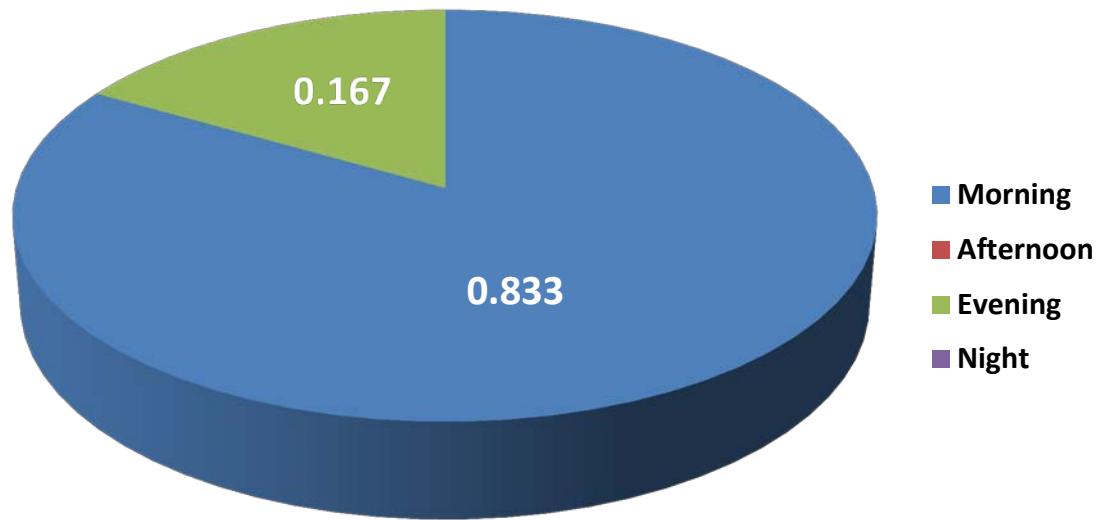


Figure 9.1. Timing of non-reproductive female torpor bouts across all roosts in YNP.

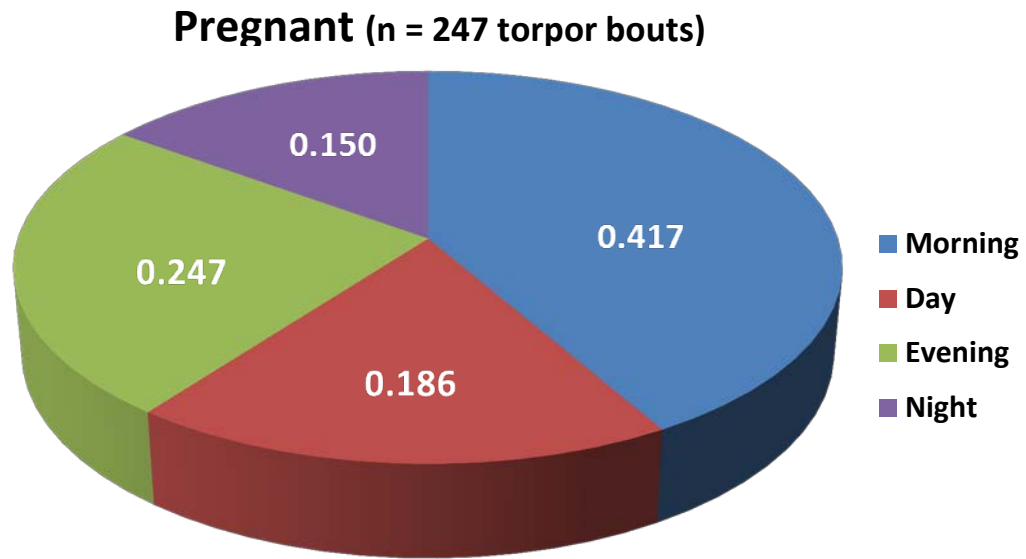


Figure 9.2. Timing of pregnant female torpor bouts across all roosts in YNP.

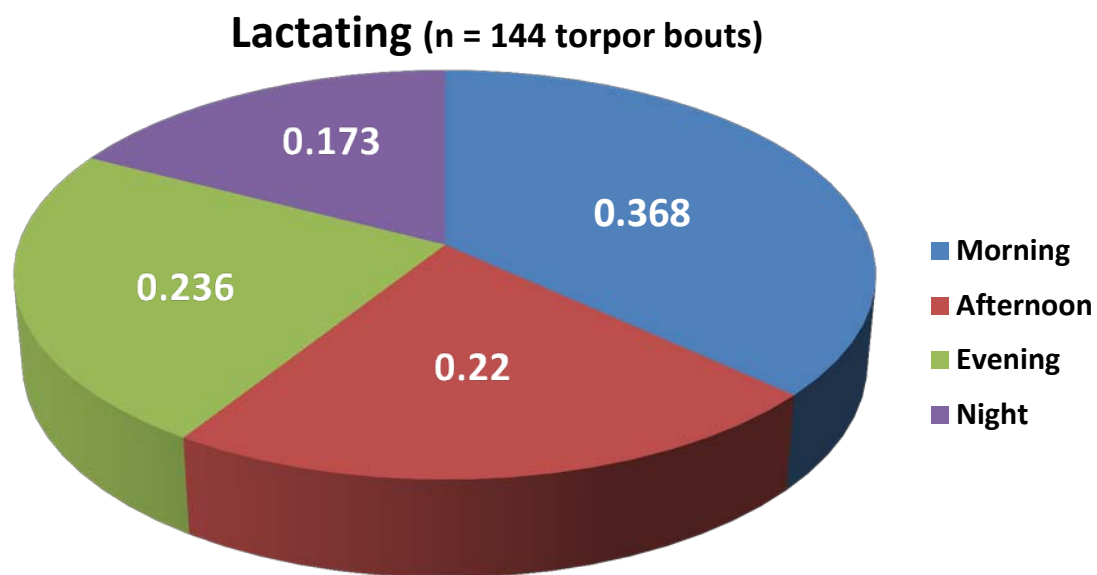


Figure 9.3. Timing of lactating female torpor bouts across all roosts in YNP.

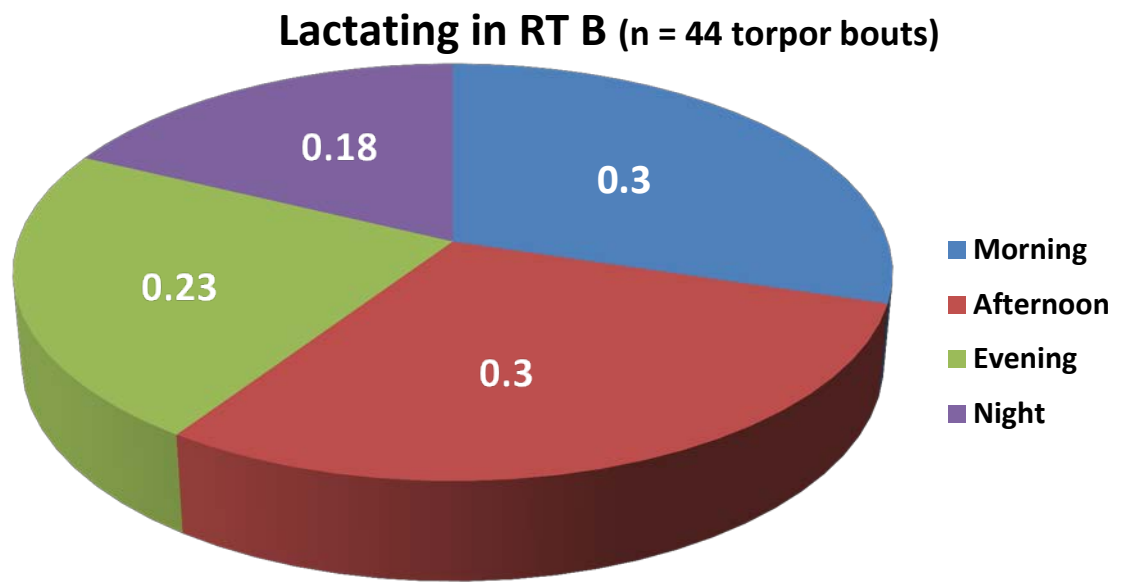


Figure 9.4. Daily patterns in use of torpor by lactating females in Type B roosts in YNP.

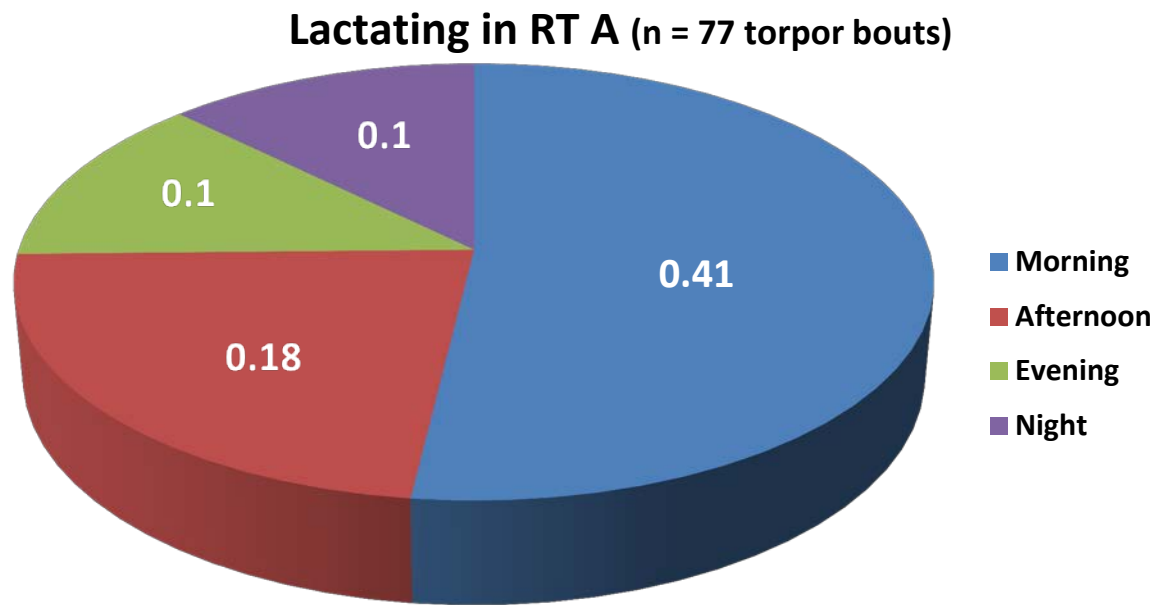


Figure 9.5. Daily patterns in use of torpor by lactating females in Type A roosts in YNP.

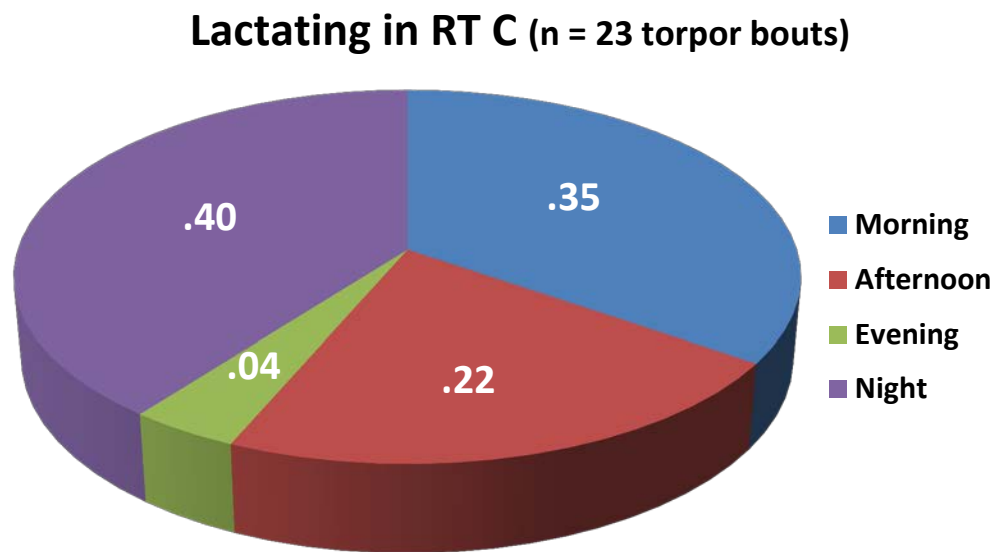


Figure 9.6. Daily patterns in use of torpor by lactating females in Type C roosts in YNP.

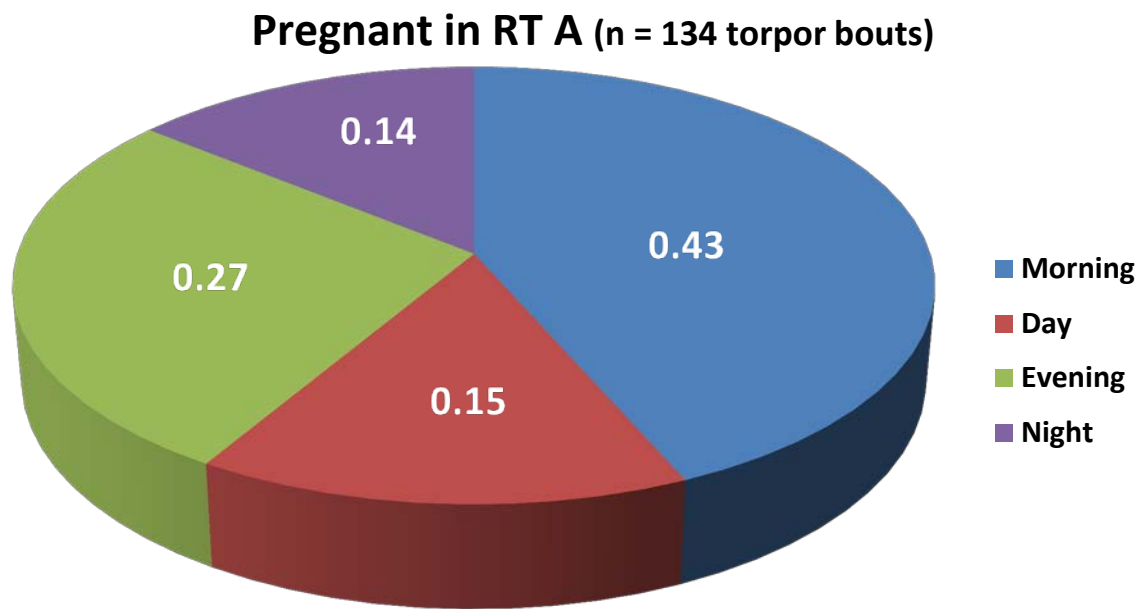


Figure 9.7. Daily patterns in use of torpor by pregnant females in Type A roosts in YNP.

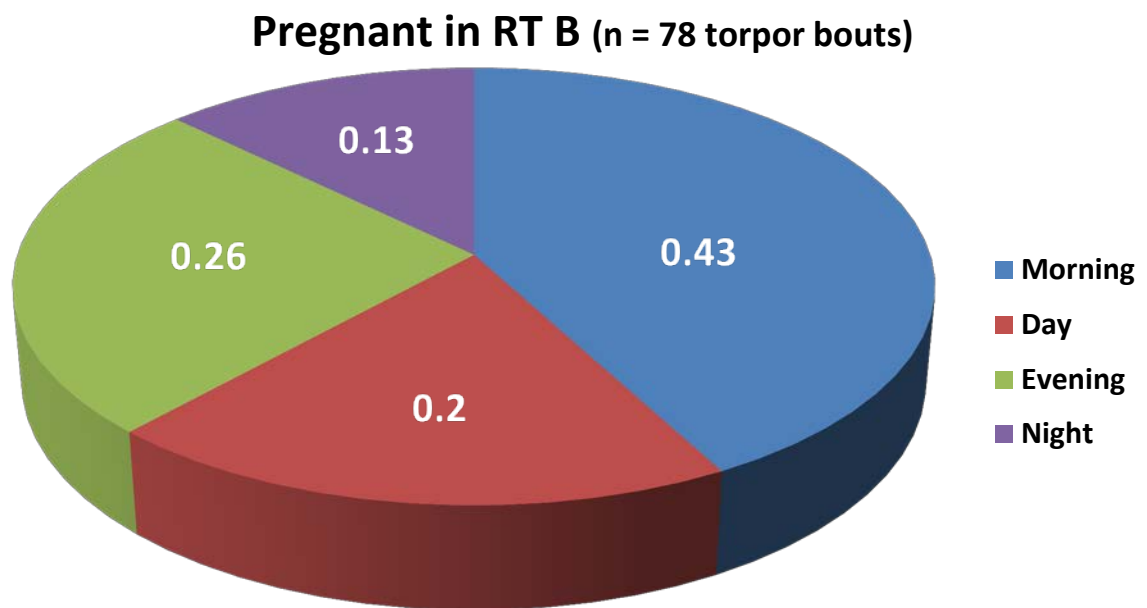


Figure 9.8. Daily patterns in use of torpor by pregnant females in Type B roosts in YNP.

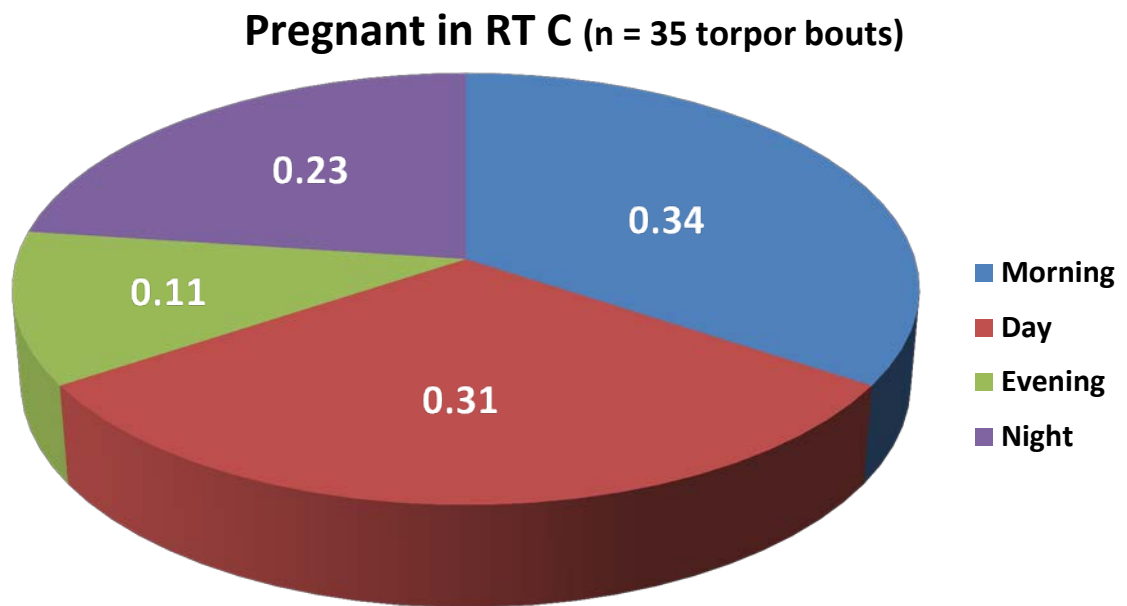


Figure 9.9. Daily patterns in use of torpor by pregnant females in Type C roosts in YNP.

Natural Rock Structures (n = 11 torpor bouts)

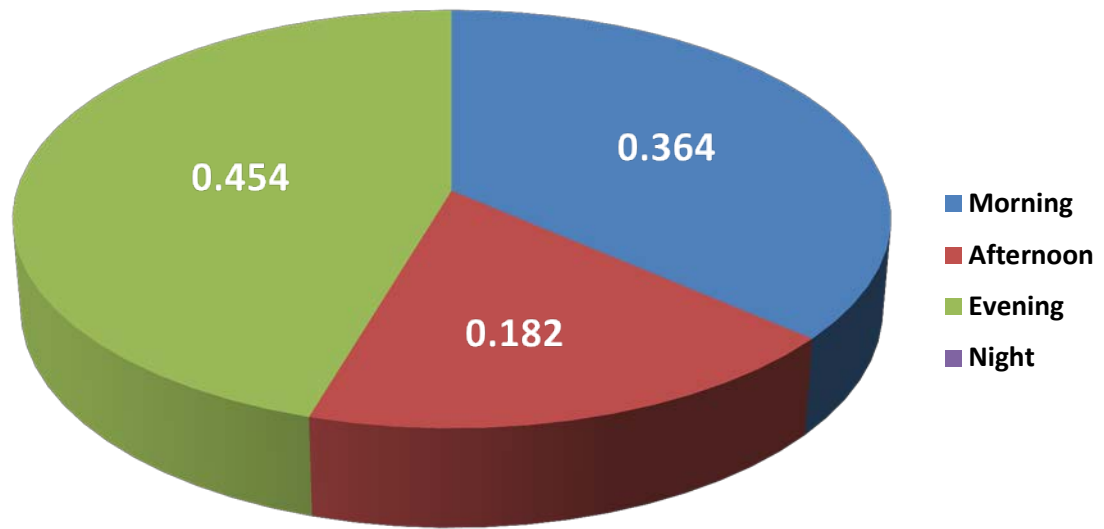


Figure 9.10. Daily patterns in use of torpor by adult females in natural rock roosts (Roost Type A) in YNP.

Chapter 10: Roost Switching Behavior

Most radio-tagged females did not switch roosts during the duration that transmitters were attached, however, exit counts and the few number of tagged females that did switch roosts ($n = 11$) suggests that some roost switching likely occurred for energetic benefit rather than social interactions. A significant drop in emergence from the unstable Type A roosts (the Power House and Building #3), which experienced the highest internal temperatures in relation to ambient conditions, occurred while I also recorded a large increase in exit counts from a stable, relatively cool Type C roost (the Chapel, Fig. 10.1). This took place during a period of the summer when ambient temperatures sharply increased. This mass switching of roosts in the Mammoth area occurred at the beginning of July. No bat was observed exiting from the Mammoth Chapel on 17 June compared with 276 bats exiting the Power House on 16 June. Emergence at the Power House peaked on 21 June, with 397 bats emerging. On 24 June, I tagged one non-reproductive female captured at Joffee Lake, and on 25 June I tagged three pregnant females captured at the Power House. Two of these four bats eventually relocated the next day to Building #3 in the Mammoth area, one remained at the Power House, and the other went undetected. An exit count on 1 July at the Power House indicated that population numbers in that particular roost had dropped from a maximum of 397 to 222 individuals. On 2 July, three of the tagged bats (two from Building #3 and the one that had disappeared) all relocated on the same night to the Mammoth Chapel. Many bats could be heard while standing next to the outside of the Chapel on that evening. I conducted an exit count on 7 July at the Chapel, and counted 330 emerging individuals. These shifts in bat numbers all occurred following the first day of the summer when daytime highs

reached $> 32^{\circ}\text{C}$ (June 28), and remained at such ambient temperature extremes over the next few days.

Three tagged females from the Bunkhouse at Buffalo Ranch were observed switching roosts in Lamar Valley, but only solitarily and only for a day or two after being radio-tagged. I suspect these females were stressed from disturbance due to my presence inside their roost in the attic of the Bunkhouse, and from having a transmitter attached to them, because all three bats returned to the Bunkhouse one to two days after being radio-tagged. All three used the Bunkhouse attic after returning for the duration of the life of the transmitters.

Three tagged females, one from the Bunkhouse at Buffalo Ranch in 2014, one from Roosevelt Lodge in 2014, and one from the Power House in 2015, left their attic roosts for a few days and switched to natural roosts. The female from the Bunkhouse at Buffalo Ranch moved to a rock roost just outside of Lamar Valley the morning following attic attainment. Multiple bats could be heard inside the rock roost, but none was visible. The next day, this same female switched to another rock roost 400 m west of the first rock roost selected. Again, multiple bats could be heard from inside the roost, but none was observed. Two days later, this same female relocated to the attic of Roosevelt Lodge where she remained for the duration of the transmitter life (i.e., five more days). I hypothesize that this female probably searched for a more preferred roost after being handled in the Bunkhouse. She was pregnant and rock roost microclimates were variable and likely less suitable for reproductively active females than they were for male bats; thus, she chose not to remain in the rock roosts for more than two days. The female from Roosevelt Lodge also switched to a natural roost after being radio-tagged. She relocated

to a 100-cm diameter Douglass fir located approx. 4 km from Roosevelt Lodge. She switched back and forth between the two roosts for a few days before the transmitter failed. The remaining female tagged at the Power House relocated to a rocky, river bank in Gardiner, Montana, the morning after being tagged. I was unable to get permission to access the private land where her rock roost was located. I did confirm that she was likely in rocks by hiking around the other side of the river and monitoring radio signals from her transmitter. She eventually moved to Mammoth Building #3 where she remained until she participated in the mass roost switching to the Mammoth Chapel.

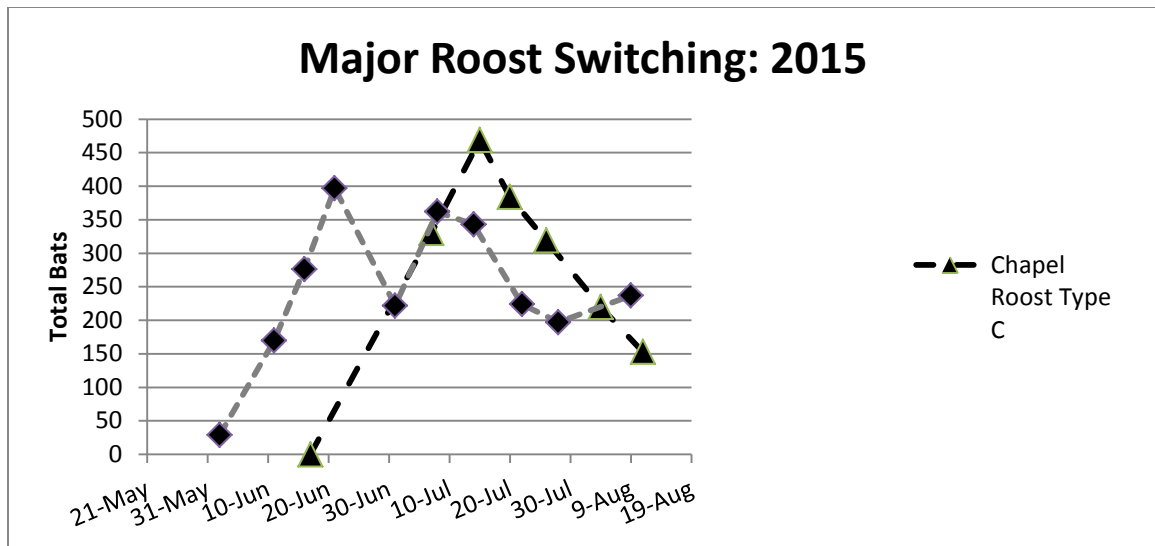


Figure 10.1. Roost switching by large numbers of bats from Roost Type A (Power House) to Roost Type C (the Chapel) in Mammoth Hot Springs, WY, during the third week of July, 2015.

Chapter 11: Use of Torpor by Male Bats

Section One: Introduction

Thermoregulation data were collected from six adult males across the 2012-2015 study seasons, with 1 from 2013, 3 from 2014, and 2 from 2015. All males were captured at either Joffee Lake or Lava Creek. Males with temperature-sensitive transmitters were tracked to four different locations: Sheepeater Canyon located at the base of Bunsen Peak on the north side; Cathedral rock and surrounding cliffs, located on Bunsen Peak on the south side; Quadrant Mountain; and, a Douglas fir just 255 m south of Lava creek.

Microclimate data from inside male roosts were not collected.

Section Two: Results and Discussion

Sixty-one torpor bouts were recorded across 48-bat days from five adult, non-reproductive males roosting in rock formations. The average daily skin temperature variation was $12.5^{\circ}\text{C} \pm 0.7 \text{ SE}$, with an average minimum of $18^{\circ}\text{C} \pm 0.3$ and an average maximum of $30.5^{\circ}\text{C} \pm 0.8$. The average torpor duration for these rock-dwelling males was $715 \text{ min} \pm 87$. Males rarely entered a euthermic state, and remained in torpor during most of their time inside roosts.

Twenty-five torpor bouts were recorded across 13-bat days from one adult, non-reproductive male roosting in a Douglas fir. The average daily skin temperature variation was $22.5^{\circ}\text{C} \pm 1$, with an average minimum of $13.3^{\circ}\text{C} \pm 1$ and an average maximum of $35.8^{\circ}\text{C} \pm 0.5$. The average torpor duration for this tree-dwelling male was $473 \text{ min} \pm 96$. Nightly and early morning temperature drops for this male closely followed the ambient nightly lows, and on some nights values were almost exactly the same. I postulate that

cold temperatures within the tree roost may have forced the male to forage nightly and then return to use torpor, rather than foraging inconsistently as did rock-dwelling males. Rock-dwelling males did not drop their temperatures as low as the ambient temperatures but still used deep torpor, suggesting that the microclimate within the rock roosts retained heat from the day and did not get as cold as the Douglas fir tree roost.

Two males roosted in Sheepeater Canyon. One remained in a steep scree slope for five days and the other male remained in a rock face for 13 days. Both bats sustained similar maximum torpor depths, but varied in average skin temperature, average torpor depth, average duration, and maximum duration (Table 10.1). The male in the scree slope sustained lower daily average skin temperatures and a lower average torpor depth, by 2°C, than did the male in the rock face. The male in the scree slope also exhibited a maximum torpor duration of 1,604 min and an average torpor duration of 915 min $\pm$ 179, compared to a maximum of 1,341 min and average of 657 min $\pm$ 112 for the male in the rock face. The male in the scree slope also sustained lower skin temperatures with a maximum of 31.4°C and an average of 20.1°C $\pm$ 1. The male in the rock face showed a maximum skin temperature of 37.4°C, and an average skin temperature of 23°C $\pm$ 0.7 when roosting.

Another male roosted at Cathedral Rock on Mt. Bunsen for 12 days in 2014, and used 13 torpor bouts with an average duration of 555 min $\pm$ 277. This male sustained the longest torpor bout recorded, compared with all other tagged bats including females. For 4,288 min, this male remained in torpor at an average torpor depth of -14°C $\pm$ 1.8. Storms were in the area during the two nights this male chose to remain in torpor rather than leaving to forage, and also this particular bat did not return to his roost the night

before he entered the three-day long torpor bout. This male achieved the highest skin temperature of 53.1°C. This measure is questionable and I suspect the transmitter was exposed to direct sunlight during this time, because skin temperatures were above 49°C for only one hour while ambient temperatures were at 30°C with sunny conditions.

A fourth male also roosted at Cathedral Rock for 16 days in 2015. This male had a maximum torpor duration of 2,981 min, and an average torpor duration of 787 min $\pm$ 155. Both bats roosting at Cathedral Rock held similar average skin temperatures, average torpor depths, and maximum torpor depths (Table 10.1).

The fifth male was the only bat recorded on Quadrant Mountain, approx. 16 km southeast of Mt. Bunsen and Joffee Lake where the bat was originally tagged. This bat was captured later in the night at 0100 hr, after most other *Myotis* bats had left the capture area to forage elsewhere or enter nightly torpor bouts. He was covered in rock dust more heavily than any other *Myotis* I captured. Based on four bat days and four torpor bouts, this male's average torpor bout duration was 938 min $\pm$ 199. His average daily skin temperature variation was 9.2°C $\pm$ 3.2, with an average minimum of 14.7°C $\pm$ 0.2 and an average maximum of 23.9°C $\pm$ 0.4. This male was euthermic inside the roost only just prior to exiting or re-entering the roost, based on data from the data-logging receiver. I was unable to confirm a specific roost for this bat due to an inaccessible landscape. The signal came strongest from the side of a cliff that spanned almost the entire north side of Quadrant Mountain.

Table 11.1. Means (SE) for variables describing skin temperatures and torpor bouts of male little brown myotis by roost type in YNP. Number of bats monitored and number of torpor bouts are also presented.

	Roost Rock	SE	Roost Tree	SE
Bats	5		1	
Tbouts	61		25	
Days	48		13	
Tsk Max Avg	30.5	0.8	35.78	0.8
Tsk Max	53.1		39.92	
Tsk Min Avg	18	0.3	13.3	1
Tsk Min	14.2		9.27	
Tsk Var Avg	12.5	0.6	22.46	1
Tsk Var Max	33.12		29.62	
Avg Bout Depth	-7.7	0.5	-7.45	1
Bout Depth Max	-16.86		-21.72	
Avg Bout Duration (minutes)	715	87	473.32	96
Max Bout Duration (minutes)	4288		2391	

Chapter 12: Discussion and Recommendations

Section One: Females not used in the Analysis

Of the 59 females radio-tagged, only 38 were used in the analyses (a 64.4% success rate of data collected vs. data attempted including the one post-lactating female not used in the analyses). A total of eight pregnant, nine lactating, one non-reproductive, and three post-lactating females across the four summers were either never relocated or their transmitters malfunctioned. Several explanations can account for these limitations to data collection and are detailed below.

One lactating female completely disappeared following radio-tagging during the 2012 season. In 2013, three pregnant females captured at Joffee Lake roosted in three widely separate locations and were not able to be recorded by data loggers. Two tagged lactating females were also never relocated. In 2014, seven bats were radio-tagged just prior to my departing YNP in an attempt to continue collecting data on lactating and post-lactating females in building roosts near the end of the reproductive season. Data-loggers were placed outside of the buildings with data collected up to two weeks later by Wildlife Health Program technicians. Three females (one post-lactating and two lactating) from Roosevelt Lodge were tagged on 11 August, but never returned to the roost for the remaining days the transmitters were active. Three females (one lactating and two post-lactating) at Fishing Bridge were tagged on 12 August, but only one of the post-lactating females returned to the roost each morning after foraging. This is the only post-lactating female that I have data for including the 2012 and 2013 years. Thus, she was excluded

from the torpor and temperature analyses. Her thermoregulation patterns, however, were different from all other females and can be found in Appendices I and II.

In 2015, four females (one lactating, two pregnant, and one pregnant bat that was also lactating) were tagged on 30 June at Fishing Bridge but were never relocated. Faint, but irregular signals could be heard from road telemetry routes, suggesting these females were in nearby but different locations. Because this section of the Park has a high grizzly bear population and a carcass dump, tracking on foot in this area was too dangerous to be permitted so these females were never relocated. A pregnant bat that was also visibly lactating was captured at this location. She was the largest of all little brown myotis captured across the four years of sampling at 11.9g and a forearm length of 39.4mm.

After applying radio-transmitters to these four bats at the Fishing Bridge Service Station, construction occurred on the attic and I was no longer allowed access to this highest elevation roost site. Three females (two lactating and one pregnant) from the Roosevelt Lodge area were tagged on 27 July and were located inconsistently at night in locations throughout Little America Valley, but due to the inconsistency of signals, and limitations imposed on backcountry radio-tracking due to grizzly bears, confirmation of roosting locations was not possible. One pregnant female from the Bunkhouse in Lamar Valley also disappeared after the second day of being radio-tagged. She was first tracked overtop mountains leading out of the Valley, but was unable to be located the next day upon climbing Bison Peak with a five-pronged yagi antennae to achieve better coverage. A Wildlife Health Program technician listened for the frequency by plane the following week, but no signal was found.

Across all three field seasons of sampling at Fishing Bridge, three females (one each year) were tracked or recorded roosting just east of the Fishing Bridge roost in Pelican Valley. Two ranger outposts and one cabin exist further into the Valley, and additional research on possible roosts of little brown myotis in the area are needed. Unfortunately, Pelican Valley has the highest presence of grizzly bears in the Park, and therefore hiking (including radio-tracking) are restricted.

Section Two: Results Discussion

Similar to patterns observed for western long-eared myotis reproductive females in the Saskatchewan River Valley, AB (Chruszcz and Barclay 2002), little brown myotis in YNP used torpor almost every day. By conforming to roost temperatures, females may be balancing a trade-off between energy needed for maintenance and energy used for reproduction. Because rewarming from torpor can be an energetically costly phase of the daily torpor cycle, choosing roosts that permit passive rewarming as the ambient increases, and concomitantly the internal roost temperatures increase, allows bats to avoid costly heat production to return to a normothermic condition. By conforming to minimum roost temperatures during torpor, and passively rewarming with rising ambient temperatures, lactating females in YNP probably spend less energy on thermoregulation when roosting and allocate more energy to milk production. I believe my data indicate that roost temperatures are important in allowing reproductive females in YNP to save energy in thermoregulation, with the potential for allocating that energy towards giving birth and raising their young. Thus, I purport that the presence of building roosts of these bats, which provide suitable temperature conditions, is essential for the long-term survival of this species in the Park, including at both lower and higher elevations.

Roost microclimate temperatures directly affected the ability of little brown myotis to thermoregulate and maintain normothermic body temperatures or use torpor to minimize energy expenditures. Bats often tracked the daily fluctuations in roost temperatures (Fig. 12.1), and took advantage of the low temperatures in the early morning hours to enter torpor before following the rise in daily temperature out of torpor in the late afternoon-early evening hours. Type B roosts exhibited the lowest mean average daily temperatures, with a moderate variance in daily temperature. Females occupying Type B roosts also exhibited the lowest mean average daily skin temperatures, as well as the lowest overall average skin temperatures. The lowest skin temperatures occurred in the early morning hours, when the ambient and roost temperatures were also the coolest (Figure 12.1). Lactating females dropped their skin temperatures close to roost temperature lows, whereas pregnant and non-reproductive females did not achieve temperatures as low as the lowest extremes in internal roost temperatures. Daily mean minimum roost temperatures ranged from 10-12°C for this study, while the daily minimum skin temperature averages across lactating and pregnant females were 16°C and 23°C, respectively. Regardless, all of these females rewarmed from morning torpor, using the passive rewarming strategy as day temperatures began to rise (Figure 12.1).

Mean daily minimum roost temperatures for Type A roosts ranged from 13-18°C depending on location, with the lowest average minimum of 13°C recorded in the Lamar Valley area. The mean daily average minimum skin temperatures for lactating females was $25^{\circ}\text{C} \pm 0.75$ with an average minimum of 18°C, and 25.4°C for pregnant females when averaged across all Type A roosts. Daily mean maximum temperatures inside Type B roosts ranged from 28-29°C, with the daily maximum skin temperatures of females

ranging from 37-38°C. Both Type B roosts had poor insulation and were located in areas that experienced the coldest ambient temperatures: Fishing Bridge and Lamar Valley. Mean daily minimum roost temperatures for Type C roosts ranged between 16-17°C and the mean daily minimum skin temperatures of bats in these roosts were 27.1°C and 29.2°C for pregnant and lactating females, respectively.

Higher roost temperatures can reduce the energetic cost of maintaining a high body temperature for females during the day and for neonates at night when adult females are foraging (Lausen and Barclay 2006). Contrary to this observation, my data indicated that female little brown myotis occupying buildings in YNP used torpor as often as individuals roosting in rock-crevices, with both using passive warming to achieve high body temperatures. Lausen and Barclay (2006) also found that some bats in buildings entered deeper torpor than females in rock crevices. They suggested that increased protection afforded by building roosts allowed these bats to enter deeper torpor and reduce energy expenditures. All tagged little brown myotis in building roosts in YNP entered deeper torpor than females in the rock crevices.

Warm, stable microclimates reduce the energetic demands of thermoregulation during gestation and lactation, and enhance the growth of offspring (Lausen and Barclay 2003; Speakman and Thomas 2003). A cooler microclimate early in the day, however, is beneficial for facilitating entrance into and withdrawal from torpor. Structural habitats, both natural and anthropogenic, that offer a diversity of microclimates could be most beneficial to survival and reproduction of little brown myotis, and may potentially aid this species should WNS reach populations of this bat in the Park. WNS causes increased energy expenditure during hibernation that prematurely reduces fat stores (Warnecke et

al. 2012; Verant et al. 2014). This means that bats which survive the winter following exposure to WNS are likely to emerge in the spring when resources are still scarce, and with the bare minimum body fat stores necessary to survive and carry offspring into the summer maternity season. Data on spring emergence for bats in YNP indicate that individuals are active in April, when snow persists and winter temperature conditions prevail (Johnson et al. 2016).

Wilcox and Willis (2016) concluded from their study that little brown myotis which survive WNS may attempt to compensate for energetic costs from low temperature extremes by selection of roosts possessing warm, stable microclimates. Their study found that infected bats almost always selected heated bat houses over non-heated bat houses, whereas non-infected bats were not as selective. Availability of warm roost microclimates could help bats make it through harsh spring conditions and initiate reproduction earlier in the summer, which in turn improves offspring survival (Wilcox and Willis 2016). My data suggest this thermoregulatory strategy is already the case for some populations of little brown myotis in YNP; however, it is unclear how these bats might alter their patterns should WNS reach and affect populations of little brown myotis inhabiting the Park.

Protection of high-quality habitats at all seasons of the year is important for conservation and recovery of populations of threatened species (Knaepkens et al. 2004; Savard and Robert 2007; Kapust et al. 2012; Wilcox and Willis 2016). Provision of roosts with warm, stable microclimates could help the survivors of WNS make it through harsh spring conditions, including populations of little brown myotis in YNP, by helping bats initiate reproduction earlier in the summer and improving survivorship of their

offspring (Wilcox and Willis 2016). Identifying such structures will be important in future management efforts for these bats in the Park. I hypothesize that Type A and B building roosts may be structures that provide such conditions for little brown myotis, and predict that these summer roosts will be important to WNS survivors should this fungal disease reach the Park. Type A and B building roosts house the greatest number of bats (depending on location and what is available) earlier in the summer when the ambient temperatures are cooler. These roosts have warmer microclimates and experience less temperature variations than natural roosts. Type A natural rock roosts experience wider variations in daily temperatures (see Chapter 8), and lack the space required for large maternity colonies and group thermoregulation. The availability of warm and safe microclimates earlier in the summer when bats are emerging from hibernation should allow for faster build-up of body mass and regeneration of health compared with females that roost in colder microclimates (Lausen and Barclay 2003; Speakman and Thomas 2003). Type C roosts are also important in the reproductive cycle of female little brown myotis, but are more useful later in the summer when the ambient temperatures increase and Type A building microclimates become too warm and variable.

Reproductive females of several species have been found to select roosts based on roost microclimates (Hutchinson and Lacki 2001; Kerth et al. 2001; Chruszcz and Barclay 2002; Lausen and Barclay 2003; Willis and Brigham 2005). I hypothesize that in YNP, female little brown myotis have likely switched from historic natural roosts to buildings structures as result of a combination of preference for preferred building microclimates and because of a history of disturbance to natural roosts, especially trees, due to wildfires and anthropogenic effects. What is unclear is whether these bats are now

more abundant in the Park, as a result of enhanced reproductive success due to preferred building roosts, compared with historic population levels, the latter of which remain unknown. Habitat quality influences survival, reproduction, and fitness of wildlife (Nager and Noordwijk 1992; Bryan and Bryant 1999), and protection of high-quality habitat is important for conservation and recovery of threatened species or populations (Knaepkens et al. 2004; Savard and Robert 2007; Kapust et al. 2012; Wilcox and Willis 2016). Based on the patterns found in my data, I believe the building structures in YNP represent important roosting habitats of little brown myotis during the summer maternity season. Conservation efforts for this species in the Park should sustain these roosting structures for the bats, and also allow for the existence of a diversity of structure types (i.e., Types A, B and C) at a range of altitudes to help these bats meet their seasonal thermoregulatory and reproductive needs.

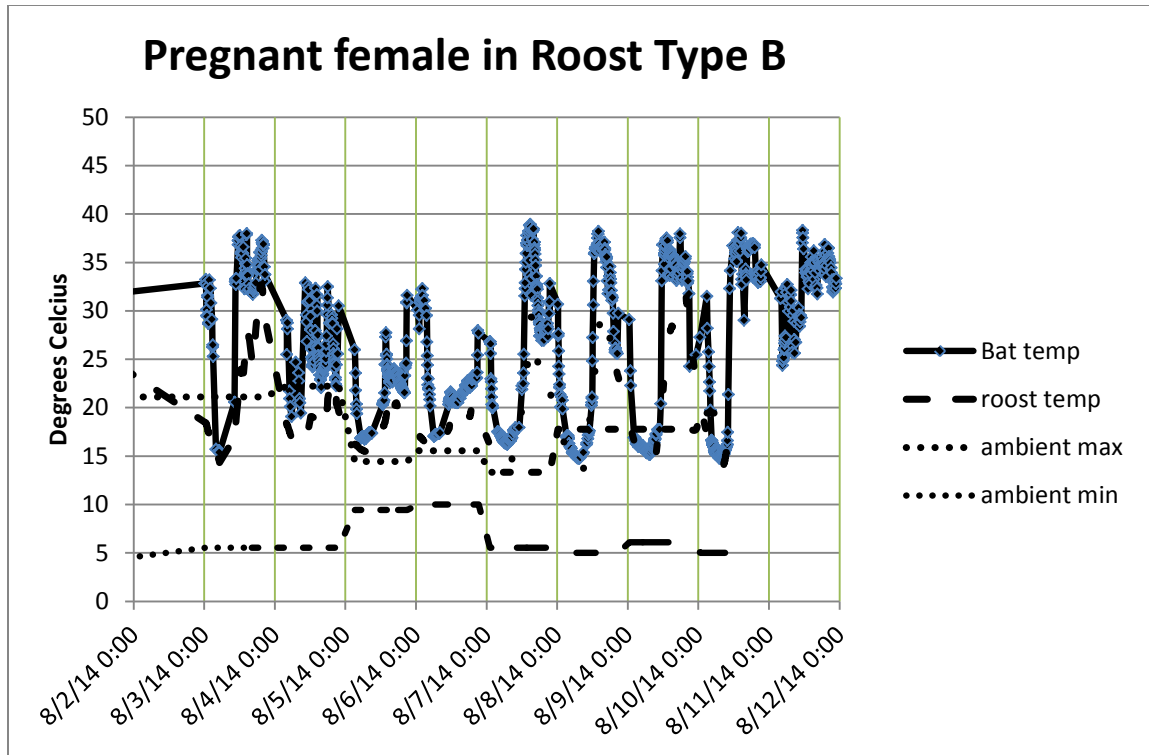
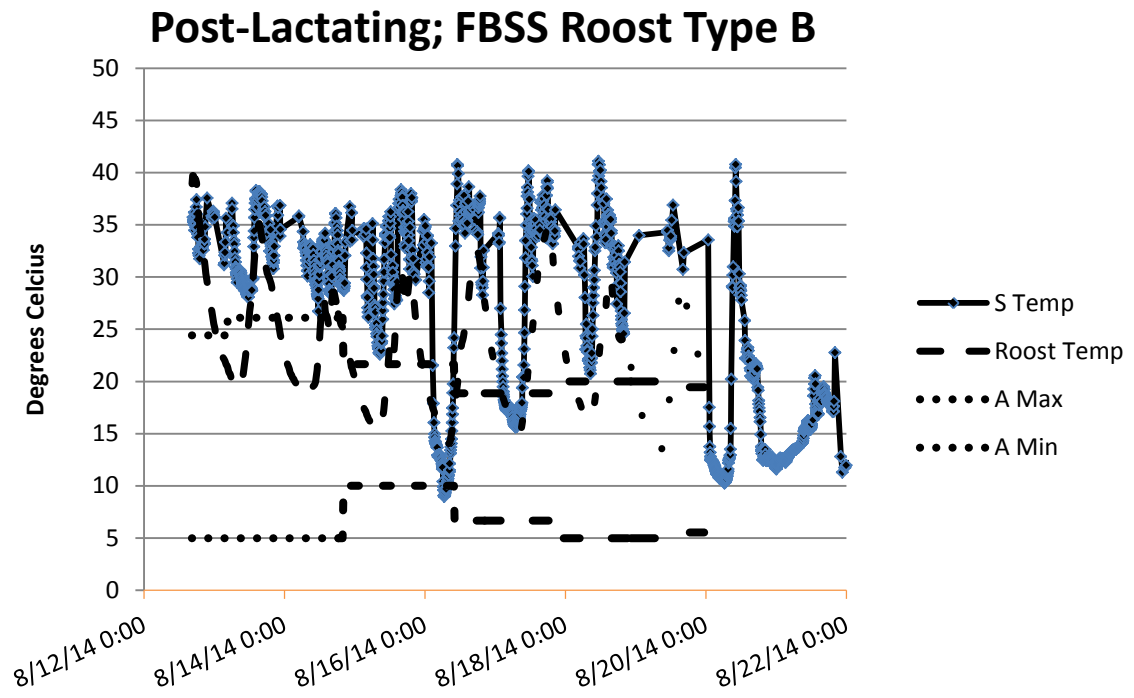


Figure 12.1. Temperature profile of a pregnant female at Fishing Bridge Service Station, YNP, illustrating typical body temperature patterns in comparison with roost temperatures and ambient temperatures.

Appendix I. Means (SE) for variables describing skin temperatures and torpor bouts of the lone post-lactating female little brown myotis radio-tracked in YNP. Number of torpor bouts is also indicated.

Post-Lactating		
Bats	1	
T Bouts	15	
Days	8	
Avg Tsk Max (Daily)	38.72	0.61
Tsk Max (total)	41.08	
Tsk Min	8.95	
Tsk Min Avg	23.14	2.77
Avg Tsk Variance	15.58	3.3
Max Tsk Variance	24.53	
Avg Bout Depth	-5.47	1.65
Bout Depth Max	-22.05	
Avg Bout Duration	242	63
Max Duration	523	

Appendix II. Temperature profile for the lone post-lactating female radio-tracked in YNP.



Appendix III: Capture Data across all Sites and Years

Bat.ID	Date	Location	Capture length (hrs)	Nets	Species	Age	Sex	Repro	Forearm	Wt.Bat	Trans.Freq
1	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYVO	A	F	P	41.2	10.24	
2	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	F	L	38.1	7.15	151.139
3	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYEV	A	M	NR	38.2	7.14	
4	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYEV	A	escaped			0	
5	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.5	7.25	
6	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYTH	A	F	P	40.1	7.42	
7	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYTH	A	M	NR	37.9	6.52	
8	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.9	6.92	
9	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.9	6.7	
10	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	39.2	7.36	
11	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	38.1	7.48	
12	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	38.9	6.97	
13	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	38.3	7.08	
14	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	LANO	A	M	NR	41.4	12.62	
15	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.8	7.21	
16	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	39.4	6.86	
17	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	F	L	38.6	7.66	151.239
18	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	F	L	37.9	7.05	151.179
19	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	38.2	6.97	
20	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.8	7.55	
21	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.5	6.62	
22	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	38.5	6.93	
23	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYTH	A	F	L	39.7	8.75	
24	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	EPFU	A	M	NR	48.9	18.05	
25	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.2	5.83	
26	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	LANO	A	M	NR	42.2	12.23	
27	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	37.3	7.52	
28	7/9/2012	Joffee Lake	2	2*18m, 1*6m, 1*9m, 1*12m	MYLU	A	M	NR	39.7	7.28	
	7/11/2012	Treanor's Pond	2	2*18m, 1*12m	0					0	
1	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.2	7.54	
2	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.6	6.39	
3	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYTH	A	M	NR	35.8	6.56	
4	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU*	A	M	NR	35.6	5.92	
5	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYTH	A	M	NR	39.3	6.56	
6	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.2	6.7	
7	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	39.5	8.03	
8	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.8	6.52	
9	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	F	P	37.6	8.93	151.298
10	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYEV	A	M	NR	38.3	6.77	
11	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.3	6.48	
12	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	LANO	A	M	NR	43	12.59	
13	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYEV*	A	M	NR	39.3	7.22	
14	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38	8.87	
15	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	LANO	A	M	NR	41.9	11.54	
16	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	F	L	39.2	10.4	151.419
17	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.7	6.98	
18	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	F	L	38.2	8.08	151.538
19	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.9	7.78	
20	7/12/2012	Joffee Lake	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.2	8.16	

Bat.ID	Date	Location	Capture length (hrs)	Nets	Species	Age	Sex	Repro	Forearm	Wt.Bat	Trans.Freq
21	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	39.6	8.2	
22	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	F	L	38.1	6.74	151.599
23	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	38.6	8.68	
24	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	39.3	9.17	
25	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.5	6.89	
26	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	36.7	6.79	
27	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.7	7.54	
28	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.1	7.16	
29	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.3	6.99	
30	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.1	6.34	
31	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYEV	A	M	NR	39.9	9.56	
32	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	36.3	8.24	
33	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.5	6.97	
34	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.3	7.9	
35	7/12/2012	Joffee Lak	1:45	1*18m, 1*12m, 1*9m	MYEV	A	M	NR	38.8	7.78	
1	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	38.4	8.75	
2	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	37.4	7.62	
3	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	37	7.34	150.477
4	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	36.6	6.96	
5	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39.7	8.04	
6	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	37.9	7.48	150.619
7	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	38.7	7.48	
8	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	F	L	37.8	7.9	151.657
9	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39.7	8.88	
10	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	36.9	8.74	
11	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39	8.14	
12	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYTH	A	F	NR	39.6	7.76	
13	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39.3	7.51	
14	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39.4	8.12	
15	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39.6	8.33	
16	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	F	L	37.3	8.12	151.698
17	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39.8	8.41	
18	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	38.6	8.23	
19	7/16/2012	Joffee Lak	?	1*18m, 1*12m	MYLU	A	M	NR	39.8	7	
20	7/16/2012	Joffee Lak	?	1*18m, 1*12m	EPFU	A	M	NR	45.7	17.72	
1	7/18/2012	Lava creek	?	2*12, 1*18, 2*9	MYLU	A	F	NR	40.8	8.63	
2	7/18/2012	Lava creek	?	2*12, 1*18, 2*9	LANO	A	M	NR	39.8	10.07	
3	7/18/2012	Lava creek	?	2*12, 1*18, 2*9	MYLU	A	M	NR	38.3	8.4	
4	7/18/2012	Lava creek	?	2*12, 1*18, 2*9	LACI	A	M	NR	53.5	25.83	
5	7/18/2012	Lava creek	?	2*12, 1*18, 2*9	MYLU	A	M	NR	38.8	9.47	
6	7/18/2012	Lava creek	?	2*12, 1*18, 2*9	MYLU	A	M	NR	37.2	8.83	

Bat.ID	Date	Location	Capture length (hrs)	Nets	Species	Age	Sex	Repro	Forearm	Wt.Bat	Trans.Freq
1	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	LAC	38.0	6.69	
2	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	38.4	5.40	
3	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYEV	A	M	NR	38.9	5.61	
4	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	NR	39.2	6.69	
5	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	NR	38.0	5.65	
6	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	EPFU	A	M	NR	46.5	13.94	
7	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	NR	37.9	6.41	
8	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	NR	36.9	6.21	
9	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	34.9	6.56	
10	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	LAC	36.8	7.82	
11	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	34.2	6.12	
12	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	37.3	6.78	
13	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYEV	A	M	NR	36.5	5.41	
14	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	35.9	5.32	
15	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	LAC	36.9	6.54	
16	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	37.0	6.07	
17	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	37.0	6.36	
18	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	39.2	6.36	
19	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	NR	38.1	6.61	
20	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	F	NR	39.9	6.89	
21	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYLU	A	M	NR	--	5.79	
22	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYEV	A	M	NR	38.9	6.17	
23	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYEV	A	M	NR	38.2	4.92	
24	6/17/2013	Joffee Lake	1:06	1*18m, 1*12m, 1*12m	MYEV	A	M	NR	38.7	5.81	
1	6/25/2013	Joffee Lake	2:20	1*18m, 1*12m, 1*12m	MYLU	A	F	NR	36.8	7.07	
2	6/25/2013	Joffee Lake	2:20	1*18m, 1*12m, 1*12m	MYLU	A	F	P	38.6	8.11	151.8355
1	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	A	M	NR	37.7	5.96	
2	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	A	M	NR	38.1	7.46	
3	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	A	M	NR	38.4	7.60	
4	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	J	M	NR	37.6	6.22	
5	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYVO	A	M	NR	39.1	7.39	
6	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	J	M	NR	37.3	7.10	
7	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYEV	A	M	NR	39.6	5.43	
8	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	A	M	NR	37.3	6.50	
9	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	EPFU	A	M	NR	44.3	14.91	
10	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	A	M	NR	33.4	7.34	
11	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	A	F	NR	36.4	5.62	
12	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYLU	A	M	NR	35.7	6.68	
13	6/27/2013	Lava Creek	2:45	1*12m, 1*12m, 1*12m, 1*9m, 1*6m	MYVO	A	M	NR	41.6	7.43	
1	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	38.7	6.99	
2	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	38.0	6.45	
3	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	38.2	6.61	
4	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	38.6	6.67	
5	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	F	NR	37.7	5.81	
6	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	37.8	5.74	
7	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	F	P?	41.2	7.25	151.475
8	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	38.5	6.36	
9	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	LANO	A	M	NR	42.1	10.89	
10	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYVO	A	M	NR	38.0	7.41	

11	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	37.6	6.64	
12	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	36.6	5.35	
13	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A*	F	NR	39.5	4.27	
14	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	F	P?	38.8	7.63	151.919
15	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	F	P?	38.9	7.75	151.879
16	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	F	NR	36.5	6.70	
17	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A*	F	NR	38.6	5.55	
18	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	37.4	5.91	
19	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	F	NR	36.2	5.80	
20	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A*	M	NR	37.4	6.11	
21	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	38.1	5.63	
22	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	36.8	5.70	
23	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYVO	A	M	NR	40.7	7.78	
24	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A*	F	NR	41.0	6.71	
25	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A	M	NR	39.3	8.55	
26	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	MYLU	A*	F	NR	38.5	6.65	
27	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	LANO	A	M	NR	43.4	11.37	
28	6/30/2013	Joffee Lake	2:45	1*18m, 1*12m, 1*12m, 1*12M	LANO	A	M	NR	40.6	11.28	
1	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYEV	A	F	NR	38.9	6.03	
2	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYVO	A*	M	NR	38.4	8.04	
3	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A	M	NR	37.2	6.19	
4	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYEV	A	F	NR	40.1	7.46	
5	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	LACI	A	M	NR	53.3	26.75	
6	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	43.9	18.18	
7	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A	M	NR	37.5	6.02	
8	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	S	47.5	15.27	
9	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	46.4	15.58	
10	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	48.1	13.55	
11	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	43.8	14.61	
12	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	LANO	A	M	NR	41.8	12.24	
13	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYEV	A	M	NR	38.8	5.77	
14	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	45.8	16.36	
15	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	LANO	A	M	NR	40.1	11.15	
16	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	LANO	A*	M	NR	41.9	11.56	
17	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYVO	A	M	NR	39.8	7.71	
18	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	45.4	14.97	
19	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	LANO	A	M	NR	43.2	19.37	
20	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	LANO	A	M	NR	40.6	11.00	
21	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A*	M	NR	38.7	7.11	
22	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A	M	NR	38.8	7.09	
23	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	LANO	A	M	NR	41.1	11.67	
24	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A	M	NR	38.6	7.96	
25	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A	M	NR	37.8	7.62	
26	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	46.2	19.21	
27	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	47.7	18.44	
28	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A	M	NR	39.6	7.71	
29	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	44.6	16.11	
30	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYLU	A	M	NR	37.9	7.94	
31	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	44.7	17.82	
32	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	MYVO	A	M	NR	40.0	9.90	

33	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	M	NR	45.2	18.63	
34	7/15/2013	Lava Creek	2:25	1*9m, 1*9m, 1*12m, 1*12m, 1*12m	EPFU	A	F	NR	47.8	18.28	
1	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	P	37.8	9.73	
2	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	40.2	7.90	
3	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	36.4	7.65	
4	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	P	37.9	6.46	
5	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	P	40.8	9.07	151.071
6	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.8	7.16	
7	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	39.0	6.08	
8	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	39.1	8.29	
9	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	39.7	8.54	
10	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	L	39.7	8.63	151.149
11	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	40.0	8.26	
12	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	37.6	6.53	
13	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	39.8	7.72	
14	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	P	38.8	7.72	151.188
15	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	M	S	38.2	7.77	
16	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYEV	A	M	S	37.4	6.43	
17	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYEV	A	F	NR	38.3	7.05	
18	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	EPFU	A	F	L	51.6	24.66	
19	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	P	38.5	9.31	151.958
20	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	P	40.3	8.15	
21	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYEV	A	M	NR	38.1	7.10	
22	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	F	P	38.6	9.64	
23	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	37.5	8.72	
24	7/22/2013	Joffee Lake	0:27	1*18m, 1*12m, 1*9m	MYEV	A	F	L	39.9	7.06	
1	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	EPFU	A	M	NR	45.5	19.96	
2	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYVO	A	M	NR	36.6	8.09	
3	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	EPFU	A	M	S	46.4	16.22	
4	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	EPFU	A	M	S	48.0	18.06	
5	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	EPFU	A	M	S	46.8	16.74	
6	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	LACI	A	M	S	53.1	25.50	
7	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYLU	A	M	NR	37.9	7.81	151.311
8	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYVO	A	M	NR	37.6	8.23	
9	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	EPFU	A	M	S	45.8	19.19	
10	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYVO	A	M	NR	39.7	8.54	
11	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	LANO	A	M	NR	39.7	13.59	
12	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	LANO	A	M	NR	42.2	13.14	
13	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYEV	A	M	NR	37.9	7.14	
14	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	LANO	A	F	P	41.8	14.07	
15	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYEV	A	M	NR	33.0	7.16	
16	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYEV	A	M	NR	38.0	7.10	
17	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	EPFU	A	M	S	44.0	15.39	
18	7/24/2013	Lava Creek	2:10	3*9m, 1*9m, 1*12m	MYLU	A	M	NR	37.6	8.42	151.427
1	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.0	7.08	151.548
2	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	MYLU	A	M	NR	38.2	7.35	151.667
3	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	38.8	7.16	
4	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	MYLU	A	F	L	38.8	8.04	151.8664
5	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	MYLU	A	F	NR	39.5	8.17	
6	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	MYLU	A	F	L	39.0	8.84	151.788*

7	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	COTO	A	M	S	44.6	10.42	151.907
8	7/25/2013	Joffee Lake	0:30	1*18m, 1*12m, 1*9m	EPFU	A	M	S	45.6	12.89	
1	8/8/2013	Fishing Bridge	0:00	None	MYLU	A	F	P	40.7	9.13	150.231
2	8/8/2013	Fishing Bridge	0:00	None	MYLU	A	F	L	38.8	7.61	150.146
3	8/8/2013	Fishing Bridge	0:00	None	MYLU	A	F	L	39.0	8.09	150.307
1	8/12/2013	Joffee Lake	2:30	1*18m, 1*12m	MYLU	A	F	P	37.7	7.33	150.346
2	8/12/2013	Joffee Lake	2:30	1*18m, 1*12m	MYLU	J	F	NR	35.7	6.22	
3	8/12/2013	Joffee Lake	2:30	1*18m, 1*12m	MYEV	A	M	S	35.8	6.26	
4	8/12/2013	Joffee Lake	2:30	1*18m, 1*12m	MYEV	A	M	S	35.9	8.52	
5	8/12/2013	Joffee Lake	2:30	1*18m, 1*12m	LANO	A	M	S	39.9	10.29	
6	8/12/2013	Joffee Lake	2:30	1*18m, 1*12m	MYLU	J	M	NR	36.8	6.68	
7	8/12/2013	Joffee Lake	2:30	1*18m, 1*12m	MYLU	A	M	S	36.2	7.31	
1	8/14/2013	Lava Creek	2:38	2*9m	LANO	A	M	S	41.9	10.26	
2	8/14/2013	Lava Creek	2:38	2*9m	MYEV	A	M	NR	39.0	6.88	
3	8/14/2013	Lava Creek	2:38	2*9m	MYEV	A	M	NR	38.0	5.95	
4	8/14/2013	Lava Creek	2:38	2*9m	LANO	A	M	NR	41.8	13.66	
5	8/14/2013	Lava Creek	2:38	2*9m	EPFU	J	M	NR	47.4	17.33	
6	8/14/2013	Lava Creek	2:38	2*9m	LANO	A	M	NR	41.8	13.92	
7	8/14/2013	Lava Creek	2:38	2*9m	EPFU	A	M	NR	45.6	17.92	
8	8/14/2013	Lava Creek	2:38	2*9m	EPFU	A	M	NR	43.7	15.37	
9	8/14/2013	Lava Creek	2:38	2*9m	EPFU	A	F	NR	47.5	22.67	
10	8/14/2013	Lava Creek	2:38	2*9m	LANO	A	F	P	41.4	16.08	
1	8/15/2013	Unnamed Cave	1:43	1*9m, 2x12m	COTO	J	M	NR	45.5	9.14	
2	8/15/2013	Unnamed Cave	1:43	1*9m, 2x12m	COTO	A	F	L	45.4	11.15	150.435
3	8/15/2013	Unnamed Cave	1:43	1*9m, 2x12m	COTO	A	F	L	45.0	11.24	150.4945
4	8/15/2013	Unnamed Cave	1:43	1*9m, 2x12m	COTO	J	F	NR	-	-	
5	8/15/2013	Unnamed Cave	1:43	1*9m, 2x12m	COTO	J	M	NR	43.3	8.06	
6	8/15/2013	Unnamed Cave	1:43	1*9m, 2x12m	COTO	J	F	NR	44.6	9.42	
1	8/26/2013	Joffee Lake	1:13	1*18m, 1x12m	MYLU	A	F	NR	38.2	7.57	
2	8/26/2013	Joffee Lake	1:13	1*18m, 1x12m	MYLU	A	F	P	37.7	8.72	150.512
3	8/26/2013	Joffee Lake	1:13	1*18m, 1x12m	MYLU	A	M	NR	37.4	7.71	
4	8/26/2013	Joffee Lake	1:13	1*18m, 1x12m	MYLU	A	F	P	37.4	8.52	150.573
1	8/27/2013	Lava Creek	2:00	1*12m, 1*9m	EPFU	A	M	NR	45.3	16.39	
2	8/27/2013	Lava Creek	2:00	1*12m, 1*9m	EPFU	A	F	P	46.0	18.36	
3	8/27/2013	Lava Creek	2:00	1*12m, 1*9m	MYLU	A	M	NR	39.0	7.58	150.5951
4	8/27/2013	Lava Creek	2:00	1*12m, 1*9m	MYLU	A	M	NR	32.0	6.88	
1	8/28/2013	Fishing Bridge	NA	NA	MYLU	A	F	P	NA	NA	151.0272
1	10/24/2013	Devil's Kitchen	1:15	1*12m	COTO	A	M	NR	44.0	10.59	150.4786
2	10/24/2013	Devil's Kitchen	1:15	1*12m	COTO	A	M	NR	44.2	10.39	150.5376
3	10/24/2013	Devil's Kitchen	1:15	1*12m	COTO	A	M	NR	42.5	10.00	150.5554

Bat.ID	Date	Location	Capture length (hrs)	Nets	Species	Age	Sex	Repro	Forearm	Wt.Bat	Trans.Freq
1	6/9/2014	Joffee Lake	2:24	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	37.4	6.19	
2	6/9/2014	Joffee Lake	2:24	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	38.8	6.84	
3	6/9/2014	Joffee Lake	2:24	(1x18m) (1x12m) (1x9m)	EPFU	A	M	NR	44.5	11.45	
4	6/9/2014	Joffee Lake	2:24	(1x18m) (1x12m) (1x9m)	MYEV	A	M	NR	37.8	8.08	
5	6/9/2014	Joffee Lake	2:24	(1x18m) (1x12m) (1x9m)	EPFU	A	M	NR	44.8	15.25	
6	6/9/2014	Joffee Lake	2:24	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	36.7	7.16	
1	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	37.7	6.6	
2	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	38.6	7.19	
3	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	37.4	6.01	
4	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	38	5.94	
5	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	37.6	6.42	
6	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	38.9	7.08	
7	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	38.1	6.14	
8	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	39.1	6.23	150.715
9	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	38.4	6.84	
10	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	36.4	6.21	
11	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	36.7	7.19	
12	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	39.9	7.24	
13	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	36.3	5.65	
14	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	35.6	5.59	
15	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	39.4	6.47	
16	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	37	6.1	
17	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	36.5	6.92	150.754
18	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	38.7	6.48	
19	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	36.9	6.2	
20	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	38.8	6.04	
21	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	38.4	5.86	
22	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	38.3	5.75	
23	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	36.2	5.71	
24	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	37.4	6.49	
25	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	38.1	6.19	
26	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	36.4	6.36	
27	6/23/2014	Joffee Lake	2:35	(1x18m) (1x12m) (1x9m)	N/A	N/A	N/A	N/A	N/A	6.3	
1	6/24/2014	Lava Creek	2:35	(1x12m) (1x9m)	MYLU	A	M	NR	37	6.17	
2	6/24/2014	Lava Creek	2:35	(1x12m) (1x9m)	MYLU	A	M	NR	36.9	5.37	
3	6/24/2014	Lava Creek	2:35	(1x12m) (1x9m)	MYLU	A	M	NR	38.5	6.34	
4	6/24/2014	Lava Creek	2:35	(1x12m) (1x9m)	MYLU	A	M	NR	37.3	6.01	
1	6/30/2014	Fishing Bridge	0:00	None	MYLU	A	F	NR	38.7	7.78	
2	6/30/2014	Fishing Bridge	0:00	None	MYLU	A	F	NR	34.4	7.55	
3	6/30/2014	Fishing Bridge	0:00	None	MYLU	A	F	NR	38.8	8.42	
1	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	38.6	6.41	
2	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	37.2	6.47	
3	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	36.3	6.21	
4	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	38.1	7.21	
5	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	37.3	5.15	
6	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYEV	A	F	NR	39.7	5.38	
7	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	EPFU	A	M	NR	47	15.16	
8	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	38.7	6.83	
9	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	39.1	6.43	
10	7/1/2014	Joffee Lake	2:30	(1x18m) (1x12m) (1x9m)	MYLU	A	M	NR	37.5	6.12	
1	7/7/2014	Lamar Bunkhouse		None	MYLU	A	F	P	38.6	9.2	
2	7/7/2014	Lamar Bunkhouse		None	MYLU	A	F	P	36.6	9.02	151.311
3	7/7/2014	Lamar Bunkhouse		None	MYLU	A	F	NR	36.5	8.13	
4	7/7/2014	Lamar Bunkhouse		None	MYLU	A	F	P	37.2	9.3	151.188
1	7/10/2014	Joffee Lake	3:08	(1x18m) (1x12m) (1x9m)	MYEV	A	F	NR	39.9	8.02	
2	7/10/2014	Joffee Lake	3:08	(1x18m) (1x12m) (1x9m)	LANO	A	M	NR	41.6	11.91	
3	7/10/2014	Joffee Lake	3:08	(1x18m) (1x12m) (1x9m)	MYEV	A	M	NR	38.6	6.46	
4	7/10/2014	Joffee Lake	3:08	(1x18m) (1x12m) (1x9m)	LANO	A	M	NR	40.8	12.96	
5	7/10/2014	Joffee Lake	3:08	(1x18m) (1x12m) (1x9m)	LANO	A	M	NR	41.1	11.58	
6	7/10/2014	Joffee Lake	3:08	(1x18m) (1x12m) (1x9m)	LACI	A	M	NR	51.4	21.8	
7	7/10/2014	Joffee Lake	3:08	(1x18m) (1x12m) (1x9m)	MYLU	A	F	NR	37.8	6.11	
1	7/16/2014	Roosevelt Lodge	na	na	MYLU	A	F	P	40.4	9.95	151.387
1	7/16/2014	Joffee Lake	1:50	(3x18m) (1x12m)	MYLU	A	F	P	38.9	9.13	150.695
2	7/16/2014	Joffee Lake	1:50	(3x18m) (1x12m)	MULU	A	F	P	37.8	8.56	150.633
3	7/16/2014	Joffee Lake	1:50	(3x18m) (1x12m)	LANO	A	M	NR	40.5	10.8	
4	7/16/2014	Joffee Lake	1:50	(3x18m) (1x12m)	MYLU	A	M	NR	37.3	7.87	
5	7/16/2014	Joffee Lake	1:50	(3x18m) (1x12m)	MYLU	A	M	NR	37.6	7.99	
6	7/16/2014	Joffee Lake	1:50	(3x18m) (1x12m)	MYLU	A	M	NR	38.4	8.12	
7	7/16/2014	Joffee Lake	1:50	(3x18m) (1x12m)	LANO	A	M	NR	40.4	12.79	
1	7/29/2014	Fishing Bridge Service Station			MYLU	A	F	L	39	6.54	
2	7/29/2014	Fishing Bridge Service Station			MYLU	A	F	P	35.6	8.73	

Bat.ID	Date	Location	Capture length (hrs)	Nets	Species	Age	Sex	Repro	Forearm	Wt.Bat	Trans.Freq
1	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	36.5	5.07	
2	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	35.3	7.01	
3	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	38	8.73	151.108
4	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	38.3	8.97	151.149
5	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	37	7.3	
6	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	39.4	8.26	
7	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	36.8	7.85	
8	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	37.9	6.83	
9	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	?	37.7	8.38	
10	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	38.7	7.82	
11	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	40.4	8.87	151.587
12	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	36.7	7.35	
13	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	39.2	7.47	
14	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	39	8.14	
15	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	38.6	8.24	
16	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	39.4	5.97	
17	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	37.1	7.75	
18	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	39.8	8.02	
19	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	39	7.94	
20	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	38.6	5.89	
21	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	36.7	6.05	
22	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	38	6.97	
23	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	37.9	5.22	
24	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	38.1	7.63	
25	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	41.1	8.11	
26	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	36.9	8.01	
27	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	39.6	7.67	
28	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	39.2	6.94	
29	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	36.4	7.25	
30	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	38.6	7.39	
31	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	38	7.25	
32	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	P	37.1	8.53	
33	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	27.1	7.21	
34	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	38.3	7.23	
35	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	40.3	6.56	
36	6/25/2015	Power House	:30	(3x18m) (1x18m) (1x12m)	MYLU	A	F	NR	34.2	5.38	
1	6/24/2015	Joffee Lake		(1x18m) (1x9m) (1x12m)	MYEV	A	F	NR	40.3	5.42	
2	6/24/2015	Joffee Lake		(1x18m) (1x9m) (1x12m)	MYLU	A	F	NR	38.1	7.2	150.992
3	6/24/2015	Joffee Lake		(1x18m) (1x9m) (1x12m)	MYLU	A	M	NR	37.1	6.75	
4	6/24/2015	Joffee Lake		(1x18m) (1x9m) (1x12m)	MYLU	A	M	NR	38.2	6.67	
1	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	M	NR	35.8	6.52	
2	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	M	NR	37	6.94	
3	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	M	NR	37	9.4	
4	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	Myvo	A	M	NR	39	7.31	
5	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	F	L	35	6.73	
6	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	M	NR	37	6.85	
7	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	F	NR	37.5	7.21	
8	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	M	NR	36	6.62	
9	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYLU	A	M	NR	36	7.84	
10	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYEV	A	M	NR	37	6.17	
11	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYLU	A	M	NR	37	5.36	
12	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYLU	A	M	NR	36	4.93	
13	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYLU	A	M	NR	35	5.5	
14	6/30/2015	Osprey Trailhead		(3x6m) (1x12m) (1x18m) (1x18m) (1x18m)	MYLU	A	M	NR	36.4	4.95	
1	7/16/2015	Joffee Lake		(1x18m) (1x12m)	MYEV	A	M	NR	37.4	8.39	
2	7/16/2015	Joffee Lake		(1x18m) (1x12m)	MYLU	A	F	NR	39.6	8.71	151.309
3	7/16/2015	Joffee Lake		(1x18m) (1x12m)	MYLU	A	M	NR	37.2	7.41	
4	7/16/2015	Joffee Lake		(1x18m) (1x12m)	MYLU	A	M	NR	39.7	8.46	
5	7/16/2015	Joffee Lake		(1x18m) (1x12m)	MYLU	A	M	NR	38.2	8.1	

6	7/16/2015	Joffee Lake	(1x18m) (1x12m)	MYLU	A	F	P	39.7	8.82	151.066
7	7/16/2015	Joffee Lake	(1x18m) (1x12m)	MYEV	A	M	NR	40.2	6.13	
8	7/16/2015	Joffee Lake	(1x18m) (1x12m)	LANO	A	M	NR	42.4	14.62	
9	7/16/2015	Joffee Lake	(1x18m) (1x12m)	MYEV	A	M	NR	28	6.86	
10	7/16/2015	Joffee Lake	(1x18m) (1x12m)	MYEV	A	M	NR	41.5	8.25	
11	7/16/2015	Joffee Lake	(1x18m) (1x12m)	MYEV	A	M	NR	38.4	7.14	
12	7/16/2015	Joffee Lake	(1x18m) (1x12m)	MYLU	A	F	P	36.4	11.54	151.468
13	7/16/2015	Joffee Lake	(1x18m) (1x12m)	MYLU	A	M	NR	37.2	8.91	
1	8/6/2015	Joffee Lake	:30 (1x18m) (1x12m)	MYLU	A	M	NR	36.1	7.98	150.935
2	8/6/2015	Joffee Lake	:30 (1x18m) (1x12m)	MYEV	A	F	NR	37.4	6.53	
3	8/6/2015	Joffee Lake	:30 (1x18m) (1x12m)	MYLU	A	M	NR	38.3	6.01	
4	8/6/2015	Joffee Lake	:30 (1x18m) (1x12m)	MYLU	A	M	NR	38.7	8.4	
5	8/6/2015	Joffee Lake	:30 (1x18m) (1x12m)	MYLU	A	M	NR	38.5	7.67	
1	8/10/2015	Joffee Lake	(1x18m) (1x12m) (3x9m)	MYLU	A	F	PL	39	8	150.526
2	8/10/2015	Joffee Lake	(1x18m) (1x12m) (3x9m)	MYEV	A	M	NR	38.4	6.31	
3	8/10/2015	Joffee Lake	(1x18m) (1x12m) (3x9m)	MYLU	J	F	NR	38.4	6.26	
4	8/10/2015	Joffee Lake	(1x18m) (1x12m) (3x9m)	MYLU	A	M	NR	38.9	7.78	
5	8/10/2015	Joffee Lake	(1x18m) (1x12m) (3x9m)	LANO	A	F	NR	42.9	13.83	
1	6/29/2015	Joffee Lake	(1x12m) (1x18m) (3x18m)	MYLU	A	M	NR	36.8	8.07	
2	6/29/2015	Joffee Lake	(1x12m) (1x18m) (3x18m)	MYLU	A	F	P	37.3	11.75	
3	6/29/2015	Joffee Lake	(1x12m) (1x18m) (3x18m)	MYLU	A	F	L	37.7	7.34	
1	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	36.6	6.65	
2	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	38.4	5.81	
3	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	37.8	7	
4	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	NR	38.1	7.13	
5	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	36	6.41	
6	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	P	39.2	8.26	
7	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	38.3	8.08	
8	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	S	36.3	8.32	
9	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	P	39.1	9.8	
10	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	LANO	A	M	NR	40.4	10.25	
11	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYEV	A	M	NR	38		
12	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	37.9		
13	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	P	38		
14	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	38.4		
15	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	26.8	5.87	
16	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	P	37.1		
17	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	P	38.8	8.7	
18	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	P	38.1	9.65	
19	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	23	5.06	
20	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	17.2	6.96	
21	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	F	NR	37.5	7.12	
22	6/27/2015	Joffee Lake	(3x18m) (1x12m) (1x18m)	MYLU	A	M	NR	36.6	5.97	
1	7/6/2015	Joffee Lake	(1x18m) (1x9m) (1x12m)	MYLU	A	M	NR	37.8	6.31	150.229
2	7/6/2015	Joffee Lake	(1x18m) (1x9m) (1x12m)	MYEV	A	M	NR	35.5	5.13	
3	7/6/2015	Joffee Lake	(1x18m) (1x9m) (1x12m)	MYLU	A	F	NR	39	7.01	
1	7/7/2015	Lamar Bunkhouse		MYLU	A	F	P	38.6	9.2	
2	7/7/2015	Lamar Bunkhouse		MYLU	A	F	P	36.6	9.02	151.309
3	7/7/2015	Lamar Bunkhouse		MYLU	A	F	NR	36.5	8.13	
4	7/7/2015	Lamar Bunkhouse		MYLU	A	F	P	37.2	9.3	151.185
1	6/30/2015	FBSS		MYLU	A	F	NR	37.5	7.95	
2	6/30/2015	FBSS		MYLU	A	F	L	39.6	9.97	151.186
3	6/30/2015	FBSS		MYLU	A	F	P	39	8.01	
4	6/30/2015	FBSS		MYLU	A	F	P	39.6	11.18	151.346
5	6/30/2015	FBSS		MYLU	A	F	P	38	12.9	
6	6/30/2015	FBSS		MYLU	A	F	P	39.4	11.9	151.268
7	6/30/2015	FBSS		MYLU	A	F	NR	38	7.76	
8	6/30/2015	FBSS		MYLU	A	F	NR	38.9	7.84	
1	6/4/2015	FBSS		MYLU	A	F	P	38.3	8.51	150.496
2	6/4/2015	FBSS		MYLU	A	F	NR	39	7.05	150.573
3	6/4/2015	FBSS		MYLU	A	F	NR	38.5	7.94	
4	6/4/2015	FBSS		MYLU	A	F	NR	41.4	8.39	
5	6/4/2015	FBSS		MYLU	A	F	NR	40.7	8.64	150.653
6	6/4/2015	FBSS		MYLU	A	F	NR	38	7.62	
7	6/4/2015	FBSS		MYLU	A	F	NR	41	8.01	
8	6/4/2015	FBSS		MYLU	A	F	NR	38.2	8.15	
9	6/4/2015	FBSS		MYLU	A	F	NR	38.5	8.23	150.735
10	6/4/2015	FBSS		MYLU	A	F	NR	38.4	7.33	
11	6/4/2015	FBSS		MYLU	A	F	NR	40.4	7.89	

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Vita

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EDUCATIONAL BACKGROUND

University of Arkansas Monticello May 2013 Monticello, Arkansas	B.S. in Forestry; emphasis on Forest Management: B.A. in English Literature: May 2013
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Fort Zumwalt North High O'Fallon, Missouri	Magna Cum Laude: May 2009
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PROFESSIONAL POSITIONS

Jun. 2014 – Present	Graduate Teaching and Research Assistant—University of Kentucky, KY
Mar. – Jun. 2014	Mexican Spotted Owl Technician—AZ
Oct. – Dec. 2013	Biological Intern—Big Oaks National Wildlife Refuge, Madison, IN
Jan. - May 2013	Forest Soils Lab Assistant—University of Arkansas Monticello, AR
May – Aug. 2012	Wildlife Biology Technician—Bighorn Canyon National Recreation Area, WY and MT.
Sept. 2010 – Mar. 2011	Seasonal Interpreter—Cane Creek State Park, Star City, AR

SCHOLASTIC AND PROFESSIONAL HONORS

University Scholarship – University of Arkansas at Monticello, AR
George H. Clippert Scholarship – University of Arkansas at Monticello, AR
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