

## **THE THERMAL ENVIRONMENT OF A CONCRETE BRIDGE AND ITS INFLUENCE ON ROOST SITE SELECTION BY BATS (*MAMMALIA CHIROPTERA*)**

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### **ABSTRACT**

Globally, bat populations are declining; and roost availability and abundance are limiting factors. As the quantity and quality of natural roost sites dwindle, manmade infrastructures (e.g., bridges, buildings, mines) become increasingly important. Numerous studies document the propensity of bats to exploit manmade bridges. However, few studies examine the thermal properties of those bridge microhabitats functioning as suitable roosts. Identifying the preferences and thermodynamics of bridge roosts broadens the definition of suitable roosting habitat for microchiropteran species; which increases the ability to provide alternate roosts, determine management options, and enable more effective conservation planning.

From 12 May 2012 to 31 March 13 2013, we monitored the temperature and humidity of 259 roost structures (external expansion joints between spans, internal expansion joints above piers, metal drainage pipes) in a cast-in-place concrete bridge in north central New Mexico. We classified each structure type as occupied or unoccupied (usable), or unusable, relative to bat presence or absence. Statistical analyses were used to elucidate differences in temperature and humidity variables between structure types and ambient conditions, and relationships, if any, between roost measurements and use classifications.

External ambient temperature and relative humidity fluctuated throughout the study period; by comparison, bridge roosts exhibited minimal variation. External and internal roosts (expansion joints) had the most and least variation, respectively. Internal roosts are spatially buffered from climatic extremes; whereas, external roosts are directly exposed to ambient temperatures and moisture and therefore, closely mimic trends of ambient conditions. Mean nighttime temperatures (22:00 - 06:00 h) of concrete structures were warmer than ambient conditions; whereas, daytime temperatures (07:00 - 21:00 h) within roosts were approximately 2-3 °C cooler. Across the study, the range of occupied roost temperatures was 5.1 °C in the non-reproductive time of year, to > 40 °C during parturition and lactation.

Our study confirms that concrete bridge roosts proffer thermal characteristics reminiscent of natural roosts (i.e., stable temperatures and humidity, protection from climatic extremes) with the additional benefit of relative permanence, protection from predators, and proximity to optimal foraging areas. Our results support the contention that small heterothermic bats occupy relatively wide temperature ranges, and are opportunistic with reference to roost structures and conditions. Additionally, our findings indicate that, for maternity colonies; thermal stability, rather than high temperatures, operates as the controlling factor influencing roost selection.

## INTRODUCTION

Worldwide, roost availability and abundance are critical elements limiting chiropteran populations. North American bats are secondary cavity nesters; they rely on preexisting crevices and cavities. The processes of cavity creation (e.g., wood decay, fire, insect activity, excavation) and loss (e.g., deterioration, tree fall) determine the availability and abundance of quality roosts (Sedgeley 2001). Within undisturbed forests, these processes attain an approximate equilibrium; within urban environments, these ecosystem dynamics are absent. Consequently, synanthropic species are further limited by roost availability and abundance than rural or forest inhabiting species. Additionally, bats may occupy specific roosts that provide critical microclimates for different aspects (e.g., night roost, maternity roost, transient roost, hibernaculum); no individual roost satisfies the energetic requirements of variable weather conditions or reproductive phases (Kerth et al. 2001). Therefore, a finite number of available structures may be suitable; constraining large segments of regional populations to a few specific roosts during critical periods (O'Shea and Bogan 2003). Temperate zone bats spend over half their lives within their roost environment, and possess life history traits (e.g., low reproductive rates) that dampen their ability to overcome population declines. Thus, roost site selection has considerable consequences relative to the survival and reproduction of the individual, and fundamentally the species.

As the quantity and quality of natural roost sites dwindle, manmade infrastructures (e.g., mines, buildings, culverts, bridges) function as vital habitat for bat communities. Numerous studies document the propensity of bats to exploit concrete bridges, (Davis and Cockrum 1963, Keeley and Tuttle 1999, Zahn 1999, Ferrara and Leberg 2005, Goodman et al. 2008, Geluso and Mink 2009) which function as alternative roosts (i.e., diurnal roosts, nocturnal roosts, maternity roosts) and stepping-stone refugia (i.e., transitory roosts) for migratory populations. Presumably, these anthropogenic structures proffer physical and thermal characteristics reminiscent of natural roosts and therefore, have become amenable substitutes. A multitude of factors influence the roosting ecology of these mammals; including insect availability, predator avoidance, sociality, thermoregulation and roost structure, location, availability and abundance. Microclimatic conditions, particularly temperature and humidity, are principal components influencing behavioral thermoregulation, and consequently, roost choice. However, few studies examine the thermal properties of those concrete bridge microhabitats functioning as suitable roosts. Identifying the preferences and thermodynamics of bridge roosts broadens the definition of suitable roosting habitat for microchiropteran species. Additional and refined information of bat temperature requirements and their impact on roost selection increases the ability to estimate populations, provide alternate roosts, determine management options, and enable more effective conservation planning.

## METHODOLOGY

Our study site was the Route 6 bridge (34° 48.268' N, 106° 43.062' W) in Los Lunas, New Mexico. This cast-in-place, concrete structure is unique in its availability and abundance of roost structures. At least four microchiropteran species (*Myotis lucifugus occultus*, *Myotis velifer*, *Myotis yumanensis*, *Tadarida brasiliensis*) utilize nine distinctive structures as roosts; including concrete spalls, ¼" crevices in the 2 terminal spans (transverse joint between eastbound and

westbound decks), steel drainage pipes, external expansion joints between spans, internal expansion joints above piers, “open” beams between centermost girders (.639 m), typical “open” beams (1.459 m), bolt cavities within pre-insulated pipes, and space between piers and pedestals. Prior to study onset, we surveyed each available roost structure within the bridge. Based on the abundance, feasibility of establishing recorders, and frequency of use; we chose to focus on internal expansion joints, external expansion joints, and pipes. One hundred thirty two metal pipes, 32 external expansion joints (hereafter external roosts), and 208 internal expansion joints (hereafter internal roosts) were categorized as either unusable or usable. Although the presence of bats directly influences roost temperature and humidity, Boyles (2007) argues the importance of measuring microclimates of both occupied and unoccupied roosts to fully characterize roost microclimate and consequently, to determine the ecological and physiological underpinnings of roost site selection. Therefore, each week, prior to recorder placement, every available roost structure was re-surveyed to 1) confirm unusable roosts and 2) to identify which usable roosts were occupied or unoccupied. Once surveyed, ten HAXO-8 recorders with internal sensors (LogTag Recorders Ltd., New Zealand) were placed within roosts that contained  $\geq$  one bat; an equal number of recorders were placed within randomly generated unusable and unoccupied roosts of similar structure. An unoccupied roost refers to any location used by bats at some time during the year, but unoccupied at time of measurement. An unusable roost refers to any location that has attributes similar to occupied roosts but no evidence (e.g., guano, urine staining) exists as to its use at any time during the year. These 30 data loggers recorded hourly temperature and relative humidity values from 12 May 2012 to 31 March 13 2013. Data was not collected from all study roosts simultaneously, but as each successive roost site was sampled, a paired sample from both a randomly generated unoccupied roost and unusable roost was collected concurrently. Data loggers from unusable and unoccupied roosts were repositioned at different roost sites weekly, and recorders from occupied roosts were repositioned only after its associated colony / individual switched roosts and the roost became unoccupied. Because roosts were checked only once per week and because we cannot predict roost fidelity or patterns of roost-switching behavior, we could not assume that each roost was suitable or unsuitable to bats for a time period longer than 24 hours. Therefore, only readings for the 24-hour period from time of placement were used. However, if roosts were occupied at time of placement and were also occupied during the subsequent survey day (approximately 6-7 days later), we assumed that the roost remained suitable throughout this time period and all associated readings were used. Additionally one recorder measured external ambient conditions throughout the study period. The following roost measurements were taken for external roosts; height to deck (A), column cap to roost entrance (B), roost entrance to elastomeric seal (top of roost) (C), channel (expansion joint) width (D); for internal roosts; height to deck (E), column cap to roost entrance (F), column cap to elastomeric seal (G), channel width (H), channel depth (I); and for pipes; height to opening (bottom of roost), and height to deck (top of roost).

Statistical analyses (GraphPad InStat 3.1a for Macintosh; GraphPad Software, San Diego, CA) were used to elucidate differences in temperature and humidity variables between structure types and external ambient conditions, and relationships, if any, between roost measurements and use classifications (i.e., occupied, unoccupied, and unusable). To further identify differences between occupied structures and environmental variables, data were grouped into biological seasons (gestation, 1 May - 2 June; parturition, 3 June - 13 July; lactation, 14 July - 23 August; and post lactation / non-reproduction, 24 August - 4 November) and categorized into hourly

intervals over a 24-hr period. These calculations were then compared to ambient values and between structure types.

Occupancy decreased significantly during October, and no bats remained after 11 November 2012. Therefore, all calculations derive from data collected 12 May 2012 and 4 November 2012 (last survey day with occupancy).

## RESULTS & DISCUSSION

### Bridge Use

On account of re-surveying to confirm classifications and occupancy prior to recorder placement, we have documentation of complete bridge occupancy (presence/absence for every available roost structure) throughout the study season. Of 372 structures (132 pipes, 32 external roosts, and 208 internal roosts), bat exploitation was extensive and widespread. Four different species (*Myotis lucifugus occultus*, *Myotis velifer*, *Myotis yumanensis*, *Tadarida brasiliensis*) used 72.1, 50, and 53% of internal roosts, external roosts, and metal pipes, respectively. Only *Myotis* spp. were documented using pipe roosts.

### Roost Measurements

Although not all available roosts were monitored; we were able to determine, based on occupancy, which structures were usable ( $n = 236$ ) versus unusable ( $n = 136$ ). We used these classifications to compare roost measurements.

In one study by Ferrara and Leberg (2005), bats roosted in narrow channels more frequently than in wide channels. We found significant correlations between several roost measurements, but not for crevice widths. Pipe measurements were extremely significant; both for height to entrance ( $P < 0.0001$ ,  $t = 6.070$ , 130 d.f.) and height to deck ( $P < 0.0001$ ,  $t = 6.059$ , 130 d.f.). Internal roost measurements E, F, and G were also very significant (A,  $P = 0.0022$ ,  $t = 3.098$ , 206 d.f.; B,  $P < 0.0001$ ,  $t = 4.337$ , 206 d.f.; C,  $P = 0.0008$ ,  $t = 3.400$ , 206 d.f.), however measurement H ( $P = 0.6682$ ,  $t = 0.4292$ , 205 d.f.) and I were not ( $P = 0.8487$ ,  $t = 0.1911$ , 206 d.f.). All external roost measurements were not considered significant (A,  $P = 0.1464$ ,  $t = 1.491$ , 30 d.f.; B,  $P = 0.4200$ ,  $t = 0.8176$ , 30 d.f.; C,  $P = 0.8761$ ,  $t = 0.1572$ , 30 d.f.; D,  $P = 0.5119$ ,  $t = 0.6638$ , 30 d.f.).

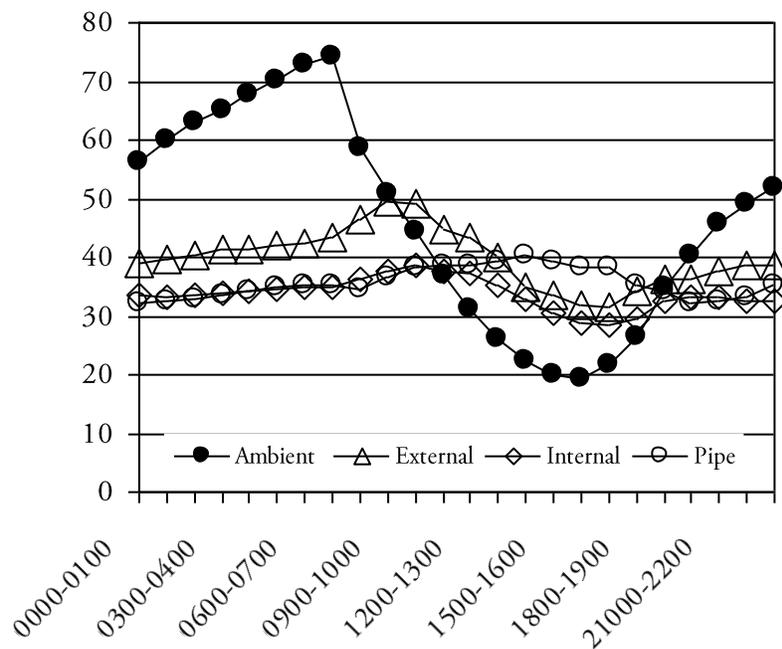
Minimum, maximum, and mean values for height to entrance of used pipes were 1.20 m, 2.58 m, and 1.96 m, respectively; equivalent values for height to deck were 2.15 m, 3.55 m, and 2.92 m. The difference between these measurements was equal to the depth of the roost, which ranged from .913 - .999 m (mean of .958 m). Bats used internal roosts with the following measurements; height to deck (E), range 2.15 - 3.55 m, mean of 2.83 m; column cap to roost entrance (F), range .80 - 1.05 m, mean of .939 m; and column cap to elastomeric seal (G), range .995 - 2.29 m, mean 1.167 m.

## Ambient Temperature and Humidity

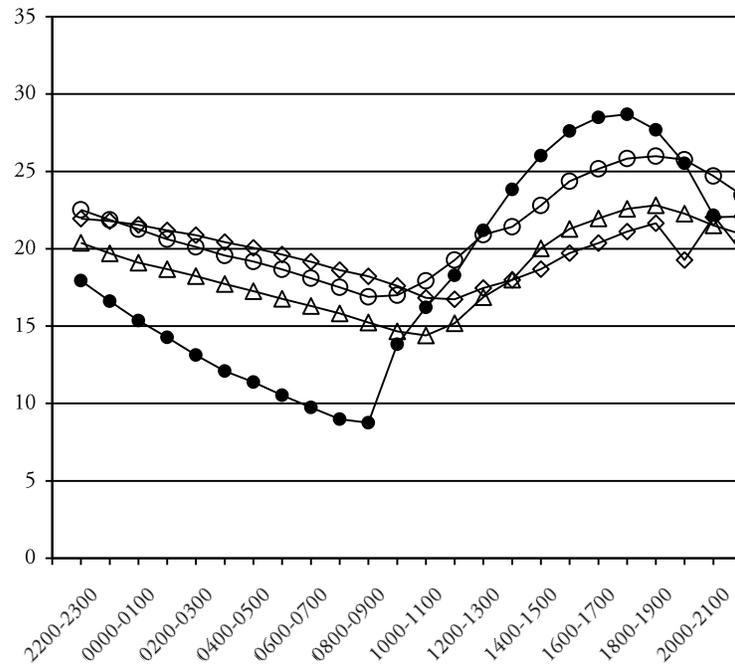
External ambient temperature fluctuated throughout the study period, with values ranging from -4 to 46.17 °C. Similarly, ambient relative humidity ranged from 0 - 100%. Humidity recorder accuracy can be reduced above 90% relative humidity (Sedgeley 2001); therefore, readings of continuous 100% humidity for extended periods may be inaccurate.

## Thermal Characteristics of Roosts

All bridge roost structures exhibited minimal variation compared to ambient values (Figure 1). As anticipated, external and internal roosts had the most and least variation, respectively.



**FIGURE 1A. Relative humidity of ambient versus bridge roosts**



**FIGURE 1B. Temperature of ambient versus bridge roosts**

Internal roosts are spatially buffered from climatic extremes; whereas, external roosts are directly exposed to ambient temperatures and moisture and therefore, closely mimic trends of ambient conditions.

The differences between the three use classifications (occupied, unoccupied, unusable) of external roosts (Kruskal-Wallis nonparametric ANOVA,  $P = .3036$ ) and pipe roosts were not significant ( $P = 0.1352$ ). When combined, the difference between all external roosts and all pipes was extremely significant (Mann-Whitney test,  $P < 0.0001$ ). Temperatures between internal roost classifications differed (Kruskal-Wallis,  $P = 0.0012$ ); specifically, between occupied versus unusable, and unoccupied versus unusable. The comparison between occupied versus unoccupied internal roosts was not significant (Mann-Whitney,  $P = 0.2338$ ). When combined and compared with all pipes, the means differed significantly (unpaired t-test,  $P < 0.0001$ ,  $t = 13.967$ , d.f. = 9808). However, when compared against all external roosts, the results were not significant (Mann-Whitney,  $P = 0.4436$ ). The medians of all external roosts and unusable internal roosts were significantly different (Mann-Whitney,  $P = 0.0019$ ). Similarly, the comparison between all pipe roosts and unusable internal roosts was significant (Mann-Whitney,  $P < 0.0001$ ). Pipe roost temperatures were consistently cooler than external roosts, except for the period of post-lactation, when ambient temperatures, and consequently external roosts, were lowest. Comparably, pipe roost temperatures were cooler than those of unusable roosts, except during the post-lactation months. Usable internal roosts maintained warmer temperatures than pipes; however, temperature oscillations followed similar patterns.

Mean temperatures between roost types were extremely significant for all reproductive seasons (gestation,  $P = 0.0005$ ,  $t = 3.474$ , 3679 d.f.; parturition,  $P < 0.0001$ ,  $t = 23.747$ , 7218 d.f.; lactation,  $P < 0.0001$ ,  $t = 51.352$ , 5389 d.f.; post lactation,  $P < 0.0001$ ,  $t = 11.449$ , 5982 d.f.

Mean relative humidity between roost types were also extremely significant for all reproductive seasons; gestation,  $P < 0.0001$ ,  $t = 4.690$ , 3679 d.f.; parturition,  $P < 0.0001$ ,  $t = 15.552$ , 7218 d.f.; lactation,  $P < 0.0001$ ,  $t = 13.457$ , 5389 d.f.; post lactation ( $P < 0.0001$ ,  $t = 9.195$ , 5982 d.f. Mean external roost temperature differences varied between 7.67 °C and 15.97 °C (range = 8.3), whereas internal roost and pipe differences varied from 5.35 °C and 6.55 °C (range = 1.2) and 7.23 °C and 9.14 °C (range = 1.91), respectively.

Maximum and minimum temperatures for external roosts, internal roosts, and pipes were as follows; external, 38.07 °C, 14.39 °C; internal, 35.36 °C, 16.73 °C; pipes, 31.20 °C, 16.89 °C. Mean external roost relative humidity differences varied between 17.88% and 56.0% (range = 38.12), whereas internal roosts and pipe differences varied from 10.18% to 11.65% (range = 1.47) and 7.14% and 16.28 % (range = 9.14). Maximum and minimum humidity values for external roosts, internal roosts, and pipes were as follows; external roosts, 88.30%, 9.50%; internal roosts, 60.00%, 23.02%; and pipes; 56.34%, 32.20%.

Maternity roosts are typically insulated against temperature extremes and have significantly smaller temperature and humidity ranges relative to external, ambient conditions (Sedgeley 2001). Low temperatures may delay gestation, reduce birth size, or slow postnatal growth (Tuttle 1976, Lourenço and Palmeirim 2004). Additionally, warm temperatures allow females to minimize daily torpor, which can negatively impact reproductive success and mother/offspring fitness (Sedgeley 2001, Kerth et al. 2001, Willis and Brigham 2007). Thus, *Myotis sodalis* chooses roosts with more solar exposure because elevated temperatures accelerate embryonic and juvenile development (Carter and Feldhamer 2005), and *Chalinolobus tuberculatus* selects for large roost-tree diameters and thicker cavity walls that precipitate warmer, and more stable microclimatic conditions (Sedgeley 2001). Contrastingly, we found that maternity colonies of *Myotis* spp. and *Tadarida brasiliensis* preferentially selected internal roosts relative to other available structure types. If warmth functions as the predominant factor, reproductive females should have chosen external roosts, which provide not only the highest diurnal temperatures, but the opportunity to maintain body temperature passively. One explanation may correlate to thermal extremes and consequently, heat stress. Approximately 40-42 °C represents the upper critical temperature (temperature above which thermoregulation is energetically expensive) for most temperate species (Licht and Leitner 1967, O'Farrell and Studier 1970, Avila-Flores and Medellín 2004, Lourenço and Palmeirim 2004, Willis et al. 2005). Above this limit, bats exhibit heat stress responses (e.g., panting, salivating), restlessness and movements distal to extreme temperatures. O'Farrell and Studier (1970) report a critical thermal maximum ambient (roost) temperature of 44.5 °C (temperature at which short-term exposure was lethal) for *Myotis yumanensis*, *M. thysanodes*, and *M. lucifugus occultus*. *Antrozous pallidus* abandons crevices with temperatures  $\geq 38$  °C, and movements of *Tadarida brasiliensis* commence once temperatures exceed 41-42 °C (Licht and Leitner 1967). From 1 May - 13 July (pregnancy and parturition periods), 4.80 % and .023 % of temperature readings were  $> 40$  °C in external roosts and internal roosts, respectively. Thus, relative to upper critical temperatures, internal structures may simply provide more moderate, and therefore less stressful, conditions more often than external structures. However, both structure types are conducive to thermoregulatory movements; bats can move within (latitudinally) or between (longitudinally) roosts to escape extreme temperatures. Our results indicate that thermal stability, rather than high temperatures, operates as the controlling factor. Presumably, bats selected internal structures because external

roost temperatures declined precipitously after 0100 h from May - July and remained colder than internal roosts until approximately 1100-1200 h. Similarly, Betts' (1997) results do not substantiate the contention that reproductive females select the warmest available roosts. Used roosts of all structure types demonstrated the least variability across biological seasons; temperatures exhibited more diminutive oscillations and maintained warmer temperatures more often than ambient. Mean, minimum, and maximum nocturnal roost temperatures, and minimum diurnal temperatures of used structures were consistently higher than corresponding unused and ambient values; whereas, maximum diurnal temperatures were cooler than ambient. Across seasons, mean diurnal temperatures for used and unused were similar; 27.43 °C and 26.34 °C, respectively. Ambient temperature differences (maximum minus minimum) varied from 7.20 - 19.94 °C (range of 12.74) whereas used roosts varied from 5.91 - 7.68 °C (range of 1.77). However, mean diurnal temperatures between roosts and ambient were similar (ambient, 27.95 °C; used roosts 27.43 °C). Mean diurnal humidity values were also similar (ambient, 40.06%; used roosts 38.76%). Mean nocturnal humidity values were 38.47% and 51.82% for used roosts and ambient, respectively. Mean nocturnal temperatures were 28.23 °C and 23.21 °C for used roosts and ambient. The fluctuation between minimum and maximum mean nocturnal relative humidity was considerably more stable, with average differences from .17 - 3.84 °C, whereas ambient humidity values were 2.44 - 23.98 %.

Temperatures of occupied roosts ranged from 5.111 °C, in the non-reproductive time of year, to > 40 °C during parturition and lactation. As noted above, 97.4 % (37 of 38 readings) of temperatures above 40 °C were within external roosts. During the same time period, unused roosts had 61 readings with temperatures above 40 °C. The parturition season exhibited the least variability relative to environmental conditions. Temperature and relative humidity ranges were 7.20 °C and 5.34%, respectively. Comparatively, temperature range varied during the other seasons by 13.26 - 19.94 °C. Similarly, the ranges of relative humidity varied by 30 - 55%. The medians of day and night did not differ significantly between usable (Mann Whitney test,  $P = 0.9977$ ) and unusable roosts ( $P = 0.0910$ ). The lowest amplitude between temperature and relative humidity values occurred between 10:00 and 11:00 h, and between 20:00 and 21:00. Mean nighttime temperatures (22:00 - 06:00 h) of both concrete structures (internal roosts, and external roosts) were significantly warmer than ambient conditions; whereas, daytime temperatures (07:00 - 21:00 h) within roosts were approximately 2-3 °C cooler. After birth, structures that maintain warmth benefit pre-volant juveniles with poor thermoregulatory abilities. In Louisiana, *C. rafinesquii* roost temperatures were consistently about 5 °C cooler than the ambient temperatures (Ferrara and Leberg 2005). Sedgeley (2001) documents maximum roost temperature occurring 5 h after ambient maximum. Our data shows that maximum temperatures of internal roosts (preferred roosts) occurred approximately 4 h after ambient maximum. Across all structures, the same effect ranged from one to five hours after ambient maximum.

## CONCLUSION

It is evident that manmade bridges function as important components of the roosting ecology and habitat of North American bats. A considerable proportion of the 45 extant bat species exploit either timber, concrete, or masonry structures as alternative roosts (Geluso and Mink 2009, Hendricks et al. 2004, Keeley and Tuttle 1999, Kunz and Reynolds 2003, MacGregor and Kiser 1998). This study, and numerous others, clearly illustrate the advantages that concrete,

specifically, provides. Structural precast concrete, although not an especially excellent heat conductor or insulator, exhibits thermal stability; the ability to maintain internal temperature within a certain interval, given normal external temperature oscillations. A large thermal mass provides “inertia” against temperature fluctuations; thereby, producing “chamber” temperatures beneath the bridge that are higher (often by 10 C or more) and more stable than external ambient conditions (Lacki et al. 2007, Erickson et al. 2002). Occupancy of roosts with appropriate microclimates can minimize energetic costs relative to thermoregulation, gestation, embryonic development, parental care, lactation, and spermatogenesis (Avila-Flores and Medellín 2004, Hamilton and Barclay 1994, Humphrey 1975, Lausen and Barclay 2003, Tuttle 1976). Intraspecific and interspecific roost requirements may vary relative to season, sex, reproductive status, and age. For example, pregnant females select warm, thermally stable environments to maintain homeothermy and accelerate embryonic development; whereas solitary males choose colder temperatures to optimize behavioral thermoregulation.

Our study results confirm those of other authors who conclude that although structural characteristics may be important because they influence microclimatic parameters, temperature functions as the foremost physical factor determining roost selection (Avila-Flores and Medellín 2004, Betts 1997, Hamilton and Barclay 1994, Kalcounis and Brigham 1998, Kerth et al. 2001). The majority of North American bats are opportunistic with reference to roosting habits, and exploit a variety of roost structures and conditions. Typically, small heterothermic (employ daily torpor) species occupy the widest temperature range (Avila-Flores and Medellín 2004); whereas torpid and reproductive bats exhibit a relatively narrow microclimatic specificity. However, we did not identify the reproductive status or physiological state of roosting individuals. Nonetheless, maternity colonies were easily identifiable and conform to this premise. Of 208 internal roost structures, both *Myotis* spp. and *Tadarida brasiliensis* showed fidelity to several maternity roosts. After comparing the microclimatic values of these roosts, it was evident that humidity (*Myotis* spp., range 9.4 - 87.3%; *T. brasiliensis*, range 5.6 - 42.10%) was less important than temperature (*Myotis* spp., range < 10 °C; *T. brasiliensis*, 22.22 - 35 °C).

Across the study, the range of usable roost temperatures was 5.1 °C to 43.17 °C. Although there was variation between classifications (external versus internal), all bridge roost structures exhibited minimal variation compared to ambient conditions. Similar to natural unused trunk hollows (Sedgeley 2001), temperatures within unused structures were much less stable, often fluctuating similarly to ambient temperature. Mean nighttime temperatures of concrete structures were warmer than ambient conditions; whereas, daytime temperatures within roosts were approximately 2-3 °C cooler.

Our study site was exceptional in its availability, abundance and type of roost structures; and may therefore, provide different microclimatic regimes not available in most bridges. Nonetheless, several publications document occupancy rates of 90 - 92% (Ferrara and Leberg 2005, Wolf and Shaw 2002). Proximity to water, foraging sites, permanency, and predator avoidance may further contribute to why bats choose concrete bridges as both diurnal and nocturnal roosts.

Keeley and Tuttle (1999) estimate 4,250,000 bats currently inhabit 211 highway structures. Adams (2003) surmises that 93 percent of California’s rare bat species benefit from these

structures. Within the southern United States, estimates approach 33 million bats per 3,600 highway structures (Keeley and Tuttle 1999). However, an increasing proportion of national infrastructure (e.g., bridges, culverts) currently exceeds or approaches its terminal service life (Doyle et al. 2008), and bridges without “bat-friendly” roosts are continually replacing those that function as important roost sites. In the Kisatchie National Forest, the United States Forest Service currently replaces approximately three older bridges per year with “bat unfriendly” slab concrete structures; and this trend occurs throughout North America (Lance et al. 2001, Feldhamer et al. 2003). Construction of deficient or new structures offers an exceptional opportunity to incorporate design modifications that reestablish or improve roosting opportunities for local bat communities.

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## **BIOGRAPHICAL SKETCHES**

Holly Smith is a wildlife biologist and co-owner of RD Wildlife Management. She is also the founder of FIGHTWNS, a non-profit initiative to raise critical funds for white-nose syndrome research, a disease that is devastating North American bat populations.

Justin Stevenson is a wildlife biologist and co-owner of RD Wildlife Management. His 10 year career started with USDA National Wildlife Research Center and prior to the launch of his own management and consulting company in 2011, was a wildlife disease biologist for USDA Wildlife Services. His expertise lies in mesocarnivore research and invasive species management.

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