

EASTERN PIPISTRELLE (*PERIMYOTIS SUBFLAVUS*) INTERNAL TEMPERATURE  
DIFFERENCES AND SEX RATIO IN GORMAN CAVE HIBERNACULUM

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## ABSTRACT

### EASTERN PIPISTRELLE (*PERIMYOTIS SUBFLAVUS*) INTERNAL TEMPERATURE DIFFERENCES AND SEX RATIO IN GORMAN CAVE HIBERNACULUM

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Gorman Cave in Colorado Bend State Park, Texas is a hibernaculum for a population of nearly 500 eastern pipistrelles (*Perimyotis subflavus*). This study conducted from 1995-98 addressed different stages of torpor during winter hibernation by eastern pipistrelles. The effects of gender and environmental variables on the internal temperature and sex ratio were assessed. Bats in hibernation are known for leaving and returning to stages of torpor. Gender had no apparent effect on the internal temperature of eastern pipistrelles and any variation in internal temperature was more of a synergistic effect of environmental variables of which the strongest effects were distance from

entrance of the cave, ambient temperature of roost site, and sampling time. The sex ratio of eastern pipistrelles in the hibernaculum was determined to be 1:1 and occasionally was disproportionately skewed toward females.

## CHAPTER I

### INTRODUCTION

Chiroptera means “hand-wing” (Schmidly 1991). Almost 1,100 species of bats worldwide comprise this mammalian order. Seventy percent of bat species are insectivores. In the insectivorous Family Vespertilionidae, one of the smallest and most common temperate bat species in North and Central America is the eastern pipistrelle, *Perimyotis subflavus* (Barbour and Davis 1969; Fujita and Kuntz 1984; Harvey et al. 1999; Sandel et al. 2001). Eastern pipistrelles are year-round residents in Texas and are most common in the eastern half of the state (Schmidly 1991). Eastern pipistrelles vary in pelage color from pale yellow-orange to dark-reddish dorsally and light- to dark-brown ventrally (Davis 1959a). These bats have tricolor hairs with a dark base, a lighter yellowish-brown middle, and a dark tip (Barbour and Davis 1969; Schmidly 1991). They are about 7.7-8.9 cm in total length (Davis 1959a) with a 22-25 cm wingspan. They are a slightly dimorphic species in mass (Myers 1978) with males weighing about 7.5 g and females slightly larger at about 7.9 g (Fitch 1966).

Eastern pipistrelles are sensitive to environmental changes. When ambient temperatures decline and food availability is reduced (Johnson et al. 1998), pipistrelles are forced to either migrate (Krzanowski 1964; Strelkov 1969) or hibernate (Hock 1951; Kunz 1982; Speakman and Rowland 1999) to conserve energy. Eastern pipistrelles

migrate short distances, about 136 km (Griffin 1940), between summer and winter roosts (Fujita and Kunz 1984; Schwartz and Schwartz 2001; Whitaker and Hamilton 1998). Therefore, hibernation is a physiological adaptation that allows most insectivorous bat species to survive extreme climatic conditions (Yalden and Morris 1975).

The selection of a roost site is a very important behavior with a major influence on survival and fitness for bats (Vanhof and Barclay 1996). Pipistrelles tend to forage over waterways near forest edges (Barley 1923; Broders et al. 2001; Davis and Mumford 1962; Fujita and Kunz 1984; Sandel et al. 2001; Schmidly 2004). Therefore, summer roosts tend to occur in foliage of deciduous trees (Barbour and Davis 1969; Carter et al. 1999; Findley 1954; Kurta et al. 1999; Leput 2004; Perry and Thill 2007; Veilleux et al. 2003), tree or rock cavities (Humphrey 1975; Menzel et al. 1999; Veilleux et al. 2003; Whitaker 1998), occasionally in buildings or other man-made structures (Fujita and Kunz 1984; Kunz and Lumsden 2003; Schwartz and Schwartz 2001; Whitaker 1998) and in caves for both small maternal colonies and solitary males (Barbour and Davis 1969; Kunz and Lumsden 2003). Winter hibernacula and summer maternity sites generally are at separate locations (Griffin 1934, 1936; Guthrie 1933a). As for winter hibernacula, eastern pipistrelles inhabit buildings, bridges (Ferrara and Leberg 2005), culverts (Sandel et al. 2001), ammunition-storage bunkers (Jones and Pagels 1968; Jones and Suttkus 1973) or other anthropogenic structures but favor underground caves or mines (Barbour and Davis 1969; Davis 1964; LaVal and LaVal 1980; Mumford and Whitaker 1975). Eastern pipistrelles have high site fidelity and return to the same place on a cave wall year after year (Hahn 1908; Humphrey 1975; Tuttle 1991). Unfortunately, little

information is available on site selection and natural history of eastern pipistrelles (Fujita and Kunz 1984; Guthrie 1933a; Sandel et al. 2001; Sealander and Young 1955).

Temperate bats, such as eastern pipistrelles, cannot tolerate temperatures below freezing (Tuttle 2000) and tend to occupy colder caves with a wide range of ambient temperatures, 1.6-29.8°C (Avila-Flores and Medellín 2004). Consequently, hibernation extends from mid-September to early-May depending on the seasonal timing of freezing temperatures. Females tend to enter hibernacula first, and males stay the longest (Jones and Suttkus 1973). Males and females do not segregate and often hibernate in the same hibernaculum (Griffin 1940) usually solitary or in small clusters of two to three (Brigger and Prather 2003; Griffin 1940; Hall 1962; Hitchcock 1949; McNab 1974; Sandel et al.). Roost selection may be vital to bats roosting solitary versus those roosting in large clusters, where the accumulation of collective metabolic heat can be beneficial. When selecting a location within the hibernaculum, eastern pipistrelles tend to locate away from the entrance, deep in the cave in the most stable and warmest environment with a temperature range of 0-11°C (Brack 2007; Brack and Twente 1985; Brigger and Prather 2003; Fitch 1966; Hitchcock 1949; Kurta et al. 2007; McNab 1974; Ploskey and Sealander 1979; Rabinowitz 1981; Tuttle 2000; Unger and Kurta 1998; Yalden and Morris 1975) and humidity > 80%. The high humidity of a cave allows for minimization of evaporative water loss and dehydration, one of the most common causes of death in hibernating bats (Ploskey and Sealander 1979). This type of environment is metabolically advantageous and minimizes weight loss, (Clawson et al. 1980); thereby, decreasing the amount of body fat lost during hibernation and increasing the overall chance of survival (Tuttle 2000).

Bats become torpid and decrease several physiological parameters, such as oxygen-consumption rate, heart-beat rate and internal temperature, during hibernation (Geiser and Ruf 1995; Wang and Wolowyk 1988). When entering torpor, heart-beat rate decreases from a normal 400 beats per min for a small bat to about 25 beats per min (Tuttle 1991; Yalden and Morris 1975). Oxygen intake decreases from 3.0 ml (active) to about 0.03 ml per g of body weight per h (Yalden and Morris 1975). Internal body temperature decreases to within a few tenths of 1° of ambient temperature (Tuttle 1991). Bats are considered “true hibernators” because body temperature is cold to human touch and breathing is barely noticeable (Tuttle 1991). Torpor may slow growth of juveniles during hibernation (Chruszcz and Barclay 2002), meaning subadults show no apparent growth during hibernation (Thompson 2006). The amount of evaporative weight loss also decreases during torpor (Webb et al. 1995).

Hibernation is not a constant static physiological state (French 1985), and individuals may arouse for physical or biochemical events to occur during external environment warming periods (Park et al. 2000); however, the exact trigger of arousal is unclear (Avery 1985; Speakman and Racey 1989; Whitaker and Rissler 1993). There are several theories as to the cause of naturally occurring arousals. Throughout hibernation bats slowly lose water due to evaporative loss until a critical water-blood threshold is reached, which forces bats to arouse possibly to drink (Fisher and Mannery 1967; Thomas and Cloutier 1992). Torpor is cyclically interrupted by periods of spontaneous arousal (Avery 1985; Brack and Twente 1985; Hardin and Hassell 1970; Lyman et al. 1982; Ransome 1971; Thompson 2006), when aroused bats passively warm themselves (Hamilton and Barclay 1994; Vaughan and O’Shea 1976). Re-warming requires

metabolic heat production making it the most costly phase of torpor (Yalden and Morris 1975). In a stable environment, any fluctuations in the cave environment can cause moisture to condense on fur (Brack 2007; Davis 1970; Hitchcock 1949; Ploskey and Sealander 1979; Tuttle 2000; Vernon 1933; Yalden and Morris 1975), and bats lick this condensation when aroused (Davis 1970) possibly to rehydrate. Various species of bats seem to arouse to drink and rehydrate (Fisher and Mannery 1967; Speakman and Racey 1989; Thomas and Cloutier 1992; Thomas and Geiser 1997). Small bats, such as little brown bats (*Myotis lucifugus*), need 30 min to warm before flight (Yalden and Morris 1975). Human disturbance is largely responsible for non-spontaneous arousals which deplete fat reserves (Fenton 1997; Johnson et al. 1998; Speakman et al. 1991; Thomas 1995a) and may cause abandonment of traditional roosts (Kunz 1982; Pearson et al. 1952).

Arousals caused by ambient temperature changes outside the cave and human disturbance are less common in eastern pipistrelles located deep within caves. Arousal may occur so bats can assess ambient conditions periodically and then move within a cave or leave altogether (Schmidly 1991). Some bats arouse and switch locations within the cave, possibly to avoid environmental change (Ferrara and Leberg 2005; Ransome 1968, 1971; Sendor et al. 2000; Yalden and Morris 1975) or move to nearby caves or roosts (Griffin 1940; Guthrie 1933b; Whitaker and Rissler 1993). Also, eastern pipistrelles will copulate during hibernation (Carter 1970; Tidemann 1982).

Pipistrelle bats leave hibernation in all winter months on warm nights (Avery 1985) to replenish fat reserves by feeding on available insects. Eastern pipistrelles may not sense changes in temperature outside of caves; however, bat activity shows a negative

correlation with barometric pressure, meaning bats may sense pressure changes (Paige 1995). When barometric pressures are low, insects are most abundant unless it is raining (Rydell 1990). Thus, when insects are flying on warmer nights with decreased barometric pressure, eastern pipistrelles may emerge from torpor to forage for insects, which allows them to conserve energy and forage without losing fat reserves (Paige 1995). Various pipistrelle species, including eastern pipistrelles, forage on warm nights (above 10°C) during hibernation (Avery 1985; Barrett-Hamilton 1910-11; Geluso 2007; Kunz 1982; Moffat 1904; O'Farrell et al. 1967; Ransome 1968; Venables 1943; Vesey-Fitzgerald 1949; Whitaker and Rissler 1992).

The amount of time a bat spends out of torpor along with frequency of arousals can affect the amount of energy expended (Speakman et al. 1991; Thomas 1995b). Arousal is energetically costly because some fat reserves are metabolized to allow torpid bats to be physiologically active; however, if a bat can leave the hibernaculum and feed, it can replenish energy loss, and if a bat switches to a warmer area to hibernate, it metabolizes less fat tissue to maintain internal temperature above freezing (Johnson et al. 1998). The amount of fat reserves depends upon the size of insect populations, which is influenced by weather (warm and dry) in late summer and early autumn, when bats develop body fat (Ewing et al. 1970; Johnson 1969; LaVal and LaVal 1980). The major cause of mortality during hibernation is starvation at end of winter due to reduced fat reserves (Beer and Richards 1956; Ransome 1968). Arousals from hibernation can take up to 80-90% of fat reserves or energy (Thomas et al. 1990).

Survival rates differ between sexes and ages of bats (Lebreton et al. 1992). Females lose more weight during hibernation than males, but usually enter hibernation

with more fat reserves, presumably to support a developing fetus (Yalden and Morris 1975). All pipistrelles have the highest fat content when entering hibernation and lowest fat content at termination of hibernation (Ploskey and Sealander 1979). Fat is slowly metabolized over 6-8 months of hibernation. Pipistrelles metabolize around 10-30 days of stored fat per arousal (Tuttle 1991). Body mass of eastern pipistrelle males decreases from September to April (39% loss) and females from September to March (29% loss) (Fitch 1966). During this period, body temperature of males decreases sharply from January to February; whereas, body temperature of females diminishes from November to January and remains constant until April, when they usually leave a hibernaculum and gestation begins (Fitch 1966).

Eastern pipistrelles are obligate hibernators for extended periods even in warm climates, such as Texas and Florida (McNab 1974) and must hibernate to ensure proper fetal development (Yalden and Morris 1975). Copulation occurs in late summer and early fall with a delay in fertilization and ovulation until emergence in spring (Oxberry 1979; Racey 1979; Schmidly 1991; Thompson 2006; Wimsatt 1969). During hibernation, spermatozoa remain dormant but viable in the female's reproductive tract (Folk 1940; Gates 1936; Wimsatt 1942, 1944; Yalden and Morris 1975). This delay in ovulation and sperm storage allows maximum time for young to mature, fly, and develop fat reserves for their first winter and allows females to regain breeding condition (Schmidly 1991). Females give birth annually to usually two well-developed pups in spring (Schmidly 1991; Wimsatt 1945). Juvenile bats have reduced survival in their first year, but these yearling bats will determine the reproductive age structure of the population (Davis 1966; Sendor and Simon 2003). Mortalities during the first winter are

often due to smaller fat reserves (Davis 1966; Johnson et al. 1998). However, winter survival overall should be high for the species due to their low reproduction rates (Schmidly 1991; Tuttle and Stevenson 1982).

During hibernation, eastern pipistrelles have physiological and reproductive demands placed on stored fat reserves. The survival and reproductive potential of the species requires little or no disturbance during hibernation. Otherwise, females cannot delay gestation and ensure suitable nutrients for young in spring. However, Gorman Cave is open for public tours during hibernation, which has the potential to increase stress on hibernating bats in the cave. Human disturbance can cause an entire bat population to abandon a hibernaculum even when natural resources are still available. Human disturbance, commercialization and vandalism of a hibernaculum can alter cave microclimate and cause declines in winter populations as in the gray bat (*Myotis sodalis*) (Brady et al. 1983). In Britain five human visits per winter reduced a bat population by 50% (Stebbing 1965). However, in a highly commercialized cave visited in high numbers in winter 1991, the gray bat population tripled over a 10-year span (Brack et al. 1991). Decreasing the number of human visits to hibernacula may not substantially lower survival rates of bats because losses might have occurred naturally; but if the number of human visits increases past a certain threshold and winter length is long, human visitation could be detrimental to survival (Boyles and Brack 2009). Therefore, it is important to study eastern pipistrelles during hibernation to assess influences from human disturbance.

An increase in stress on bats during hibernation from human disturbance could increase their internal temperature causing more arousals. When bats are warm, they not

only use more fat reserves, but they also need more food. Because Gorman Cave is a tourist cave, the oscillations of visitors could cause disruptions of torpor in bats resulting in elevated internal temperatures and depletion of fat reserves at an increased rate. If eastern pipistrelle females experience increased arousals, productivity may decline because less energy is available for developing fetuses. Myers (1978) theorized the larger size of females allows maintenance of lower internal temperatures while in torpor. Therefore, if females arouse during hibernation, it could take more energy for females to recover and re-enter torpor than males. During arousal from torpor, bats could increase food consumption as a compensation for energy expenditures related to arousal and re-entrance into torpor, although food is already scarce during winter.

Bats spend over half their lives using roosts and, therefore, are highly affected by the roost environments (Kunz 1982; Vaughan and O'Shea 1976). Knowing how internal temperature of bats is affected by the roost environment may assist in understanding which caves or other roost structures to protect and how to manage them. Roost surveys provide information for determining the status of various species (Sherwin et al. 2003). Roost selection is based on several factors, such as temperature, humidity, airflow, light intensity, protection from predators, proximity to foraging areas, and take-off-height (Gaur 1980; Hill and Smith 1984; Kunz 1982; McCracken 1989; Morrison 1980; Tuttle and Stevenson 1981). Microclimate has a strong influence on bats. The distribution of caves with a suitable internal ambient temperature range can determine the distribution of cave-dwelling bats (Raesly and Gates 1987; Thomas 1995a; Tuttle and Stevenson 1978).

The extent of disturbance affecting a bat species is often measured by sex ratio. To determine the effect of disturbance on the sex ratio of a species, an expected ratio is

compared to observed numbers in a cave. Unfortunately, the sex ratio of eastern pipistrelles is unclear or unknown. Consequently, data for comparing sex ratio to determine the possible negative effects of human disturbance on a population cannot be determined. This affects abilities to manage a population to increase numbers. The increasing effects of white-nose syndrome on bat populations are also important to consider. Populations of various bat species worldwide are declining from this epidemic, and if the sex ratio of a bat species is unknown, it will be extremely difficult to verify whether sexes are equally affected by a disease and to apply wildlife management techniques to stabilize or increase the population. Bat populations have declined and habitat loss of suitable winter and summer roosts have increased over the last decade (Kalcounis-Rüppell et al. 2005; Veilleux et al. 2003). A decrease in any animal population usually means more management activities should be applied to females than males to increase production in the population, but if the sex ratio is unknown, it is extremely difficult to manage for an optimum number of females.

The objectives of my study were to determine (1) any differences in internal temperature of male and female eastern pipistrelles during hibernation, (2) temporal differences in internal temperature of male and female pipistrelles during hibernation, (3) whether internal temperatures of male and female pipistrelles were affected by ambient temperature, location in cave, and temporal presence, (4) the sex ratio of eastern pipistrelles in Gorman Cave during hibernation, and (5) whether the sex ratio changes temporally during hibernation.

## CHAPTER II

### MATERIALS AND METHODS

*Study Site.*---Gorman Cave, a publicly toured cave owned and operated by Texas Parks and Wildlife Department, is located in Colorado Bend State Park 48 km west of Lampasas, Texas in San Saba and Lampasas counties. The cave is 914 m in length and 8 m at its highest point (Elliott 2009; Fig. 1). There are two west-side entrances which overlook the Colorado River. Gorman Cave is used as a winter hibernaculum for eastern pipistrelles, which forage mostly in forests along waterways (Barley 1923; Broders et al. 2001; Davis and Mumford 1962; Fujita and Kunz 1984; Sandel et al. 2001; Schmidly 2004) making this area a prime habitat for the species. The cave has large calcite crystals covering the walls and a small stream running through it (Elliott 2009). The addition of a running stream in the cave decreases the chance of dehydration in bats during winter (Speakman and Racey 1989). Gorman Cave is divided into two parts by a bat gate installed to protect cave myotis (*Myotis velifer*) maternity colonies. The study area extends from the entrance to the bat gate, a distance of about 300 m (Fig. 2).

*Marker Placement.*---In the study area of the cave, 17 markers were drilled into walls at unequal distances to record locations of bats within the cave (Fig. 2). Markers were placed, so at any point at least two markers could be seen. This meant areas with

sharp curves may have markers placed closer together than straighter sections of the cave. Markers were positioned to assist in the location of a bat anywhere in the cave using triangulation. The first marker was located approximately 15 m past the main entrance and the last marker, number 17, was located at the bat gate.

*Collection and Tagging Methods.*---Eastern pipistrelles were collected an average of two times per month from November 1995 to early March 1996, early November 1996 to early March 1997, and early November 1997 to early March 1998. During these times, any new untagged bats were implanted with a Passive Integrated Transponder (PIT). During collecting, all surfaces in the 300-m stretch were searched for bats including ceiling, walls, ledges, crevices, and inside soda straws (2-8 cm in diameter). Bats were collected by hand when possible, by padded tongs when located inside a soda straw or crevice, or by dislodging from high locations onto a cloth pad on top of a telescoping pole. Collected bats were individually tagged and released before the next bat was collected to minimize handling time.

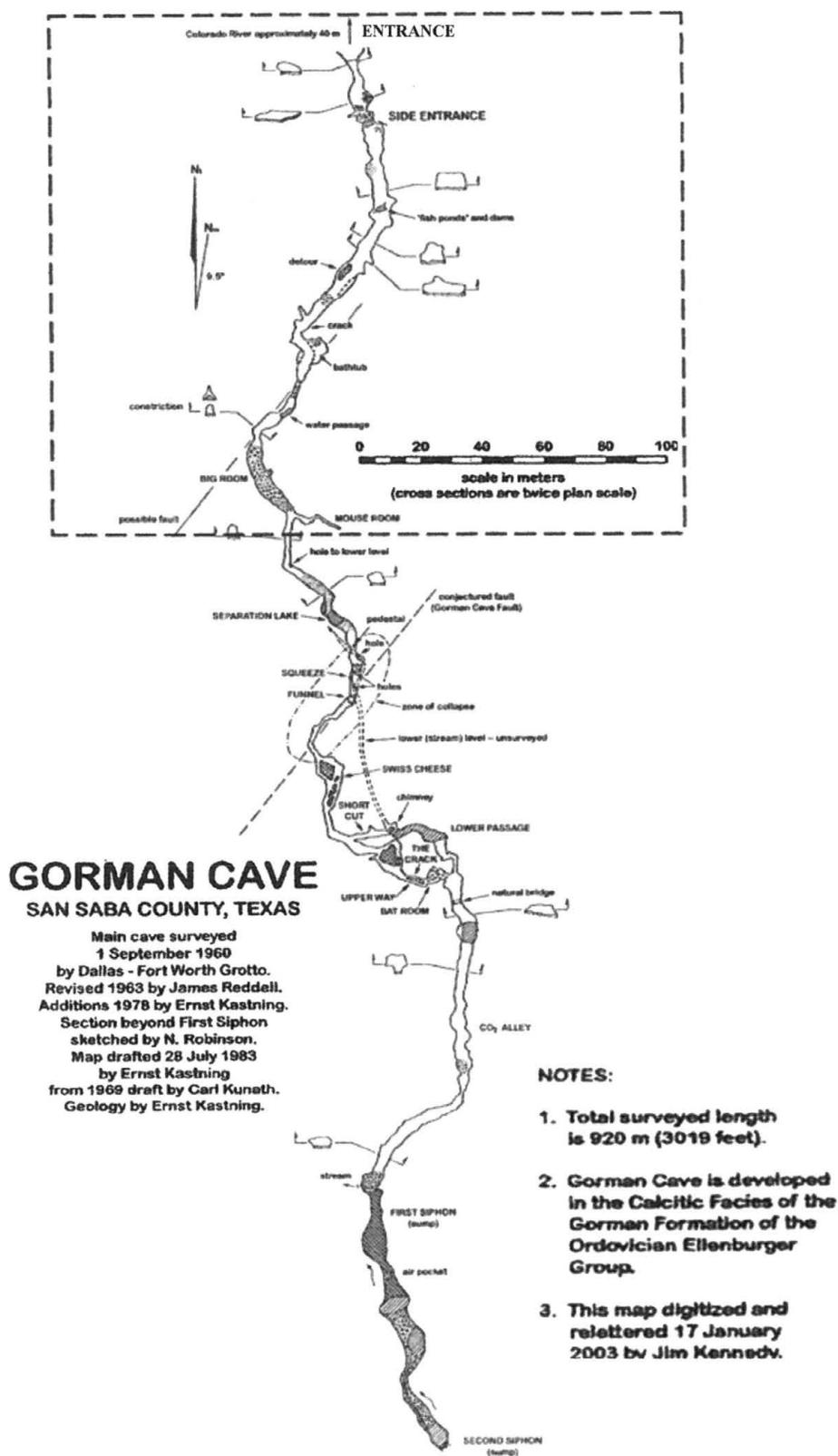


Figure 1. Map of the 914-m Gorman Cave system. The cave is divided into two sections by a bat gate. This commercialized cave is located in Colorado Bend State Park, 48 km west of Lampasas, Texas in San Saba and Lampasas counties.

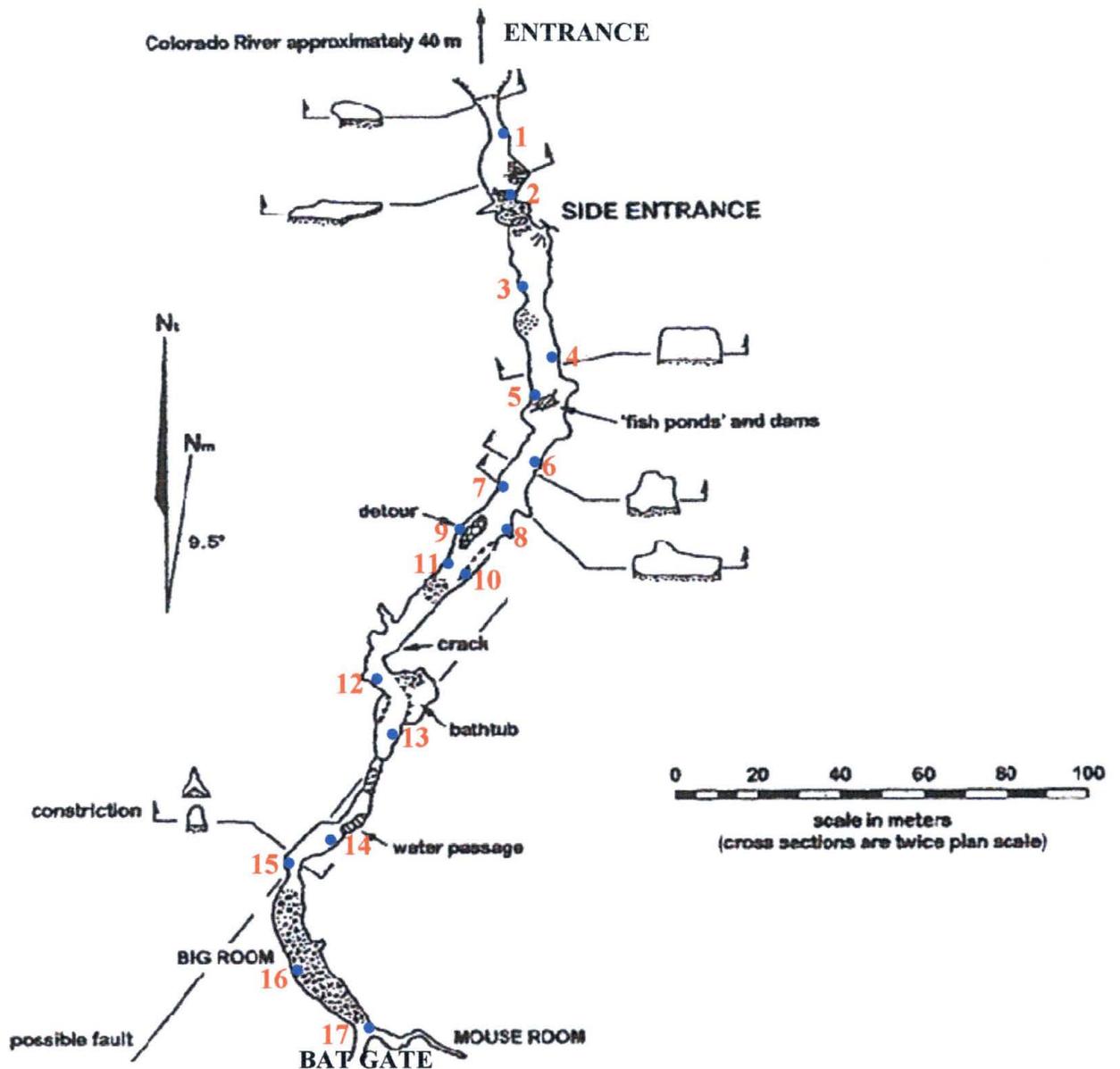


Figure 2. Enlarged map of Gorman Cave. Map indicates the 300-m cave section used in the four-year study. This commercialized cave is located in Colorado Bend State Park, 48 km west of Lampasas, Texas in San Saba and Lampasas counties. To determine a reference point for bats in the cave 17 markers were used (shown in red).

Prior to implantation with a Passive Integrated Transponder (PIT), internal temperature was recorded by a mercury rectal thermometer and weight with a Pesola spring scale (10 g Model, Pesola AG, Baar, Switzerland). Bats were placed into a cloth bag, weighed together, bat released, bag weighed, and difference in weight was recorded as the bat's weight. An attempt was made to capture every eastern pipistrelle found in the cave during sampling days (searching time often exceeded 10 h) to verify and record the bat's identity by scanning with an AVID Mini TrackKer PIT tag reader (AVID, Norco, CA). If a bat was out of reach, the PIT tag reader was placed on a telescoping pole to conduct the scan. When untagged eastern pipistrelles were found, a 12 mm PIT tag with an unique nine-digit identification number (AVID, Norco, CA) was subcutaneously implanted into the lumbar region using a 3 cc syringe with a 12-gauge needle. Each tag was scanned before implantation to ensure proper function. Before implantation, the needle was sterilized by submersion into 70% ethyl alcohol and a drop of Betadine solution (povidone-iodine, 10%). Once implanted, the PIT tag was scanned to confirm function. Any other additional comments about a particular bat (gender and weight), overall condition at time of collection, location of the bat in the cave, location over water or rock or its surroundings were recorded. Substrate temperature was taken at this time with a Raytek<sup>®</sup> Hand-held Infrared Thermometer (Raynger<sup>®</sup> MT4 MiniTemp, EXTECH Instruments, Waltham, MA). The bat was allowed to recover for about 5 min by placing it on a ledge or rock for final recovery and flight.

Torpid bats were only disturbed if untagged. However, location in the cave, general information, and ambient conditions were recorded. Environmental data was collected starting at marker 1 and continued in sequence to marker 17. The temperature

and humidity of the cave were taken at each marker with a digitized Thermo hygrometer (Forestry Suppliers, Jackson, MS). To determine the location of a particular bat in the cave, four pieces of information were recorded: (1) number of the closest marker, (2) distance of bat from marker, (3) angle from bat to marker, and (4) height of bat from floor. The “floor” was defined as the lowest surface accessible to start the measurement. Therefore, a bat located over water had the floor or starting measurement from the surface of the water; and if a bat was over a small ledge blocking access to the ground or over uneven terrain, the starting measurement was taken from the lowest area possible. Location and other information for each bat and recaptures were imported onto an Excel spreadsheet.

*Statistical Analysis.*---Data were compiled from over 550 eastern pipistrelle observations, including recaptured individuals. Without recaptured occurrences, the colony consisted of almost 300 individuals. Different variables were measured each year of the study limiting the majority of data to analysis of sex ratio. For the internal temperature analysis, 55 observations were usable; however, five were performed on recaptured bats and had to be removed randomly with the flip of a coin.

The statistical analysis consisted of five statistical tests. The first two tests were conducted using Program R (R version 2.8.1, The R Foundation for Statistical Computing). First an Analysis of Variance (ANOVA) determined difference in the internal temperature of male and female bats during hibernation and tested differences in temporal internal temperature change. Because the data set was unbalanced, a Type III sums of squares ANOVA was used. In each year, three months (November, December, and January) were sampled, and each month varied in number of individuals collected by

gender. In this test both gender and month were treated as fixed. Test results indicated significant difference ( $\alpha = 0.05$ ) in internal temperature between genders during hibernation, and the interaction was tested to determine temporal difference.

The second analysis used was an Akaike Information Criterion (AIC) univariate analyses. This analysis determined whether internal temperature was affected by different environmental factors. Nine models were used to determine these environmental factors' effect on internal temperature of eastern pipistrelles. Model A was an intercept model to determine whether a factor not considered in this study influenced internal temperature. Model B was a gender model. Model C looked at cave ambient temperature. Model D involved bat height from floor. Model E contained the distance of bat from entrance. Model F involved the bat location in cave, which combined bat height and distance from entrance. Model G was the time of day the sampling occurred. Model H looked at the sampling interval by date and month. Model I was temporal presence, which combined the time of day and sampling interval. Gender was made a dummy variable and time of day was changed to military time. The distance of each bat from the entrance was determined using an enlarged map of Gorman Cave scaled in meters. Locations of markers throughout the cave were placed with a number and a dot to estimate location in the cave. Using a paper scale and a previous study by former Texas State graduate Sara Moren, I converted estimated marker locations to meters. I also estimated distance to the bat gate to estimate size of the study area. Finally I converted sampling dates to a continuous scale. Data consisted of six sampling dates. The first sampling date was given a value of 1, and days between the first and second sampling were counted, so the second sampling could be given a value of 15. This

showed the number of days between the two samplings events was 13. This system of counting was done for all six sampling dates to make data more comprehensive and to have a logical sampling interval. Because sample size was 50 individuals, the AIC was corrected for small sample ( $AIC_c$ ). Results were used to find the best fit model for the data, which was selection of the model with the lowest  $AIC_c$ . The difference in  $AIC_c$  between the best-fitting model and alternative models was compared to determine if the model with the lowest  $AIC_c$  was the strongest model. Competing models were determined by having differences below 2. The Akaike weights were also used to determine how well each model fit data and plausibility of the model. Once a model was selected, a summary of that model and the adjusted  $R^2$  determined the amount of variation in internal temperature affected by that factor ( $\alpha = 0.05$ ).

The third analysis was a Principal Components Analysis (PCA) using the program SAS/STAT (SAS Institute Inc., Cary, NC), and graphing results using Sigma Plot (Systat Software Inc., San Jose, C). Multivariate analysis assessed the eastern pipistrelles' preference for particular environmental factors, which determines correlations among environmental factors. The factors used for PCA analysis were the same altered data as for the  $AIC_c$  analysis. Gender a dummy variable, and all other continuous factors (cave ambient temperature, bat height from floor, distance of bat from entrance, time of day sampled, and sampling interval) were  $z$ -scored transformed.  $Z$ -score transformation was performed by taking the number for each observation of a factor minus the mean of the population divided by the standard deviation of the population for that factor. These factors were  $z$ -scored because all factors varied in units and in range. These factors were then run through a PCA. The resulting principal components that explained the most

variation were plotted along with the strongest positive and negative loadings. Then the PCA results were separated into internal bat temperatures  $< 20^{\circ}\text{C}$  and those  $>$  or  $= 20^{\circ}\text{C}$ . Finally, three different 2-sample  $t$ -tests ( $\alpha = 0.05$ ) assessed the relationship between internal temperature versus the linear combinations of PC axes I-III.

Number of male and female bats present in the cave was determined for the entire study without recaptures or repeated bats recounted in each year and in each month. If total number of individuals was  $< 5$ , the month was not included in the analysis due to an inadequate sample size. The sex ratio of eastern pipistrelles in the hibernaculum was tested using a chi-square goodness of fit test. For this test, number of observations was compared to the number of expected observations. Because the sex ratio of eastern pipistrelles and most other bat species is unknown, I assumed an expected ratio of 1:1 because it is the sex ratio of most organisms. The degrees of freedom were calculated as the number of categories minus one, which for all the different tests run was 2 (number of genders) minus 1. The chi-squared values were used along with degrees of freedom to determine its  $p$ -value ( $\alpha = 0.05$ ) (Conner and Hartl 2004). The null hypothesis tested was no difference between number of male and female bats present in the cave. The alternative hypothesis was a difference in number of male and female bats present in the cave.

The last analysis was a chi-squared test of independence for change in the temporal sex ratio during hibernation. This test compared each year's data without recaptures to determine any difference in the overall Gorman Cave sex ratio. The analysis was also used to compare years for temporal change in sex ratio during hibernation. This was done, without recaptures, by testing each month over the study to

determine whether sex ratio changed between the same month each year. I also tested across each year by comparing the sex ratio across months within the same year. For this analysis, I expected a 1:1 sex ratio. The degrees of freedom were calculated similarly except if there was more than one category being tested, such as month, the two categories of degrees of freedom would be multiplied together. For example, if there were four years and two genders, the degrees of freedom would be 4 minus 1 multiplied by 2 minus 1 equaling 3. The chi-square and the calculated degrees of freedom were used to estimate the  $p$ -value ( $\alpha = 0.05$ ). The null hypothesis was no difference in number of male and female bats present or events were dependent. The alternative hypothesis was a difference in the number of male and female bats present or the events were independent.

*Permits.*---This study conducted on eastern pipistrelles in Gorman Cave was under permits from the Texas Parks and Wildlife Department (SPR-0890-234) and the Institutional Animal Care and Use Committee (5Q6DDW).

## CHAPTER III

### RESULTS

The ambient temperature inside Gorman Cave ranged from 10.4-24.9°C with 50-98% relative humidity during the four-year study. Locations of eastern pipistrelles on the ceiling ranged from 56-458 cm in height from the floor from 3 November 1996 to 4 January 1997. Heights for females ranged from 56-458 cm ( $\bar{x}$  = 152.6 cm, SE = 16.7041). Males had a smaller range of 70-402 cm in height but had a higher mean height ( $\bar{x}$  = 207.4 cm, SE = 19.5815). The overall height of bats sampled during the four-year study ranged from 2-850 cm. Eastern pipistrelles occurred throughout the front section of the cave 15 m from the entrance to 222 m near the bat gate. Locations for females ranged 15-180 m from the entrance ( $\bar{x}$  = 104.56 m, SE = 9.0316) and males ranged 52-222 m ( $\bar{x}$  = 124.52 m, SE = 7.8715), placing them slightly further from the cave entrance.

Temperatures inside the cave ranged from 15.2-21.1°C in ambient temperature from 3 November 1996 to 4 January 1997, when bats' internal temperatures were being sampled. Internal temperatures for females ranged from 15-31°C ( $\bar{x}$  = 19.9°C, SE = 0.7985) and males ranged from 17.8-31.1°C ( $\bar{x}$  = 20.368°C, SE = 0.6062). Female bats showed an average difference of +/-2.1°C and males +/-1.96°C above or below the

ambient cave temperature. However, eastern pipistrelles showed no detectable difference ( $F_1 = 0.006$ ,  $p = 0.94$ ; Fig. 3) between sexes in internal temperatures during hibernation in Gorman Cave. No interaction ( $F_2 = 0.057$ ,  $p = 0.95$ ) was apparent between month and gender, and internal temperatures of males and females did not change temporally or over months during hibernation (Fig. 4). During peak months of hibernation (November–January) in 1996-97, the internal temperatures of male and female bats in Gorman Cave remained the same.

An examination of effects of other environmental factors on internal temperature indicated bat distance from the cave entrance had a strong effect (Model E based on low  $AIC_c = 264.6486$ ; Table 1). Differences between the various models'  $AIC_c$  values indicated another possible competing model. Model C ( $AIC_c = 265.0341$ ) was a strong competing model due to a difference of only 0.3855148. Model C measured the effect of ambient temperature on the response variable. When the Akaike weights were considered, Model E had a stronger fit for the data (about 44%) than Model C (36%). Although Model E showed a significant effect on the internal temperature of eastern pipistrelles, the amount of variation explained by this model was very low, only about 14%. This means bat distance from cave entrance alone was not the main factor affecting internal temperature throughout hibernation.

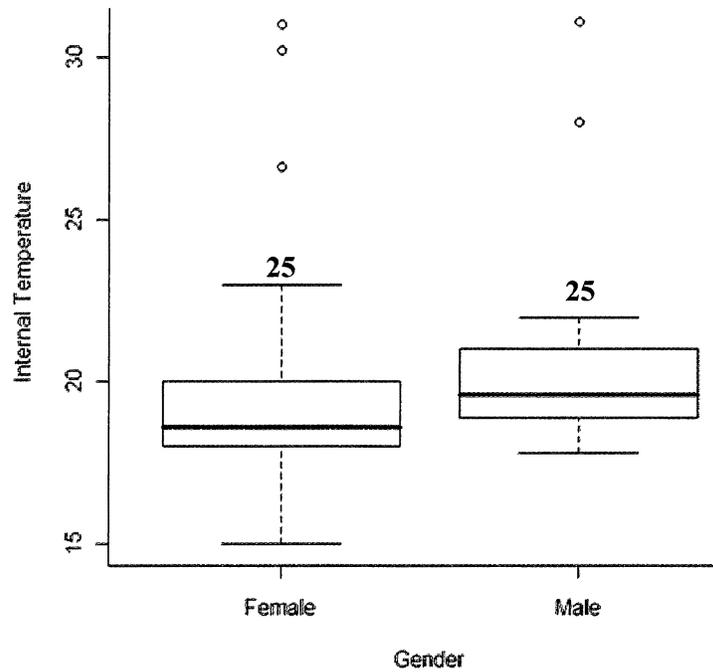


Figure 3. Internal temperature as affected by gender. The horizontal line within each box plot represents the median score, and the box encloses 50% of the observations around the median. The upper and lower vertical lines signify the highest and lowest values, not outliers or extreme scores. The outliers are signified by the open circles located above each box plot. The sample size is indicated by the number above each box. The total population size analyzed was 50.

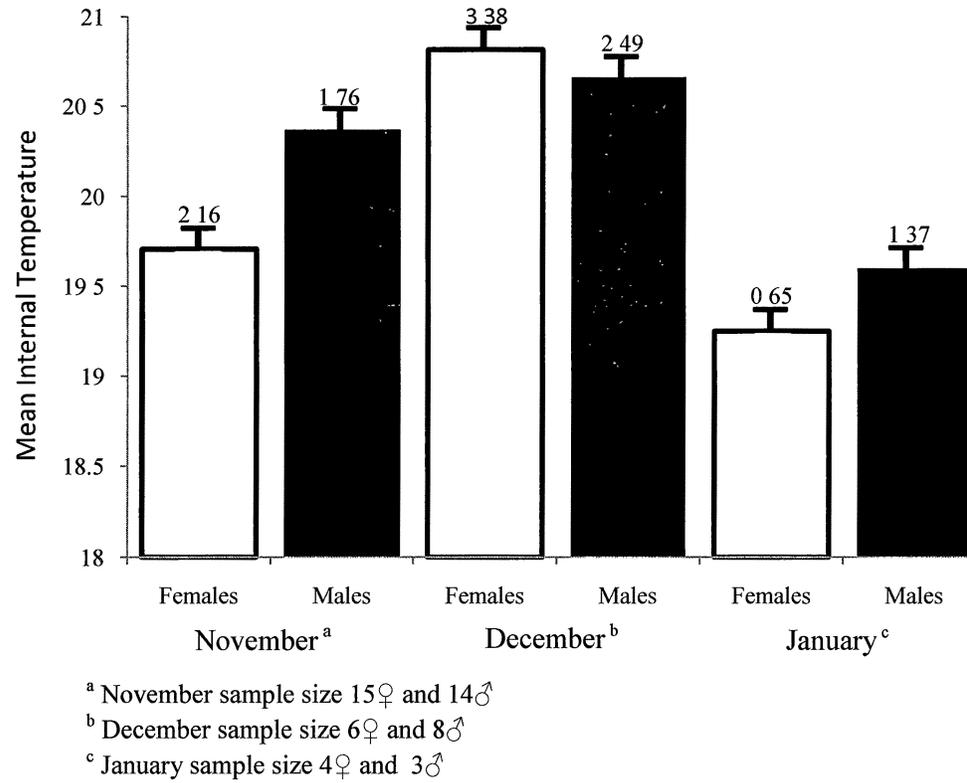


Figure 4. The internal temperature in response to month. The mean average internal temperature of male versus female eastern pipistrelles during peak hibernation months. The white represents females and the black signifies males. The numbers above each of the bars shows the 95% confidence interval for each gender in each of the three months.

Table 1. Akaike Information Criterion adjusted for small sample size ( $AIC_c$ ) for nine models, environmental factors (variables), number of parameters (K), and Akaike weight. Lower  $AIC_c$  and higher Akaike weights represent best supported models.

Models	Variables	$AIC_c$	K	Akaike Weight
A	Intercept	270.8683	2	0.019568522
B	Gender	272.9082	3	0.007056630
C	Ambient Temperature	265.0341	3	0.361766780
D	Height from Floor	272.7815	3	0.007517906
E	Distance from Entrance	264.6486	3	0.438674269
F	Bat Location	266.8926	4	0.142841277
G	Time of Day	272.6626	3	0.007978465
H	Sampling Interval	272.6274	3	0.008120251
I	Temporal Presence	273.0799	4	0.006475900

The AIC<sub>c</sub> analysis addressed each variable's effect on internal temperature individually, but in wild bat populations several variables may affect bats at the same time. The Principal Component Analysis explained the effects of environmental variables in Gorman Cave with respect to eastern pipistrelles location throughout the cave. Principal components I-III accounted for 83% of variation in environmental variables (Fig. 5). The first principal component (PC I) contributed 37% of total variation. The strongest positive loading on PC I was time of day sampling occurred (0.61); the strongest negative loading was bat distance from entrance (-0.62). The second principal component (PC II) accounted for 28% of total variation. The strongest positive loading on PC II was ambient temperature of cave (0.59); the strongest negative loading was the sampling interval (-0.57). The third principal component (PC III) explained 18% of total variation. The strongest positive loadings on PC III were height from the floor (0.67) and gender (0.49); the strongest negative loading was ambient temperature of cave (-0.45). The two sampled *t*-test for PC I showed a difference ( $p = 0.049$ ) between bats with lower internal temperatures ( $< 20^{\circ}\text{C}$ ) when compared to bats with higher ( $\geq 20^{\circ}\text{C}$ ) internal temperatures. When PC II and PC III were analyzed there was no difference ( $p = 0.106$ , and  $p = 0.325$ , respectively).

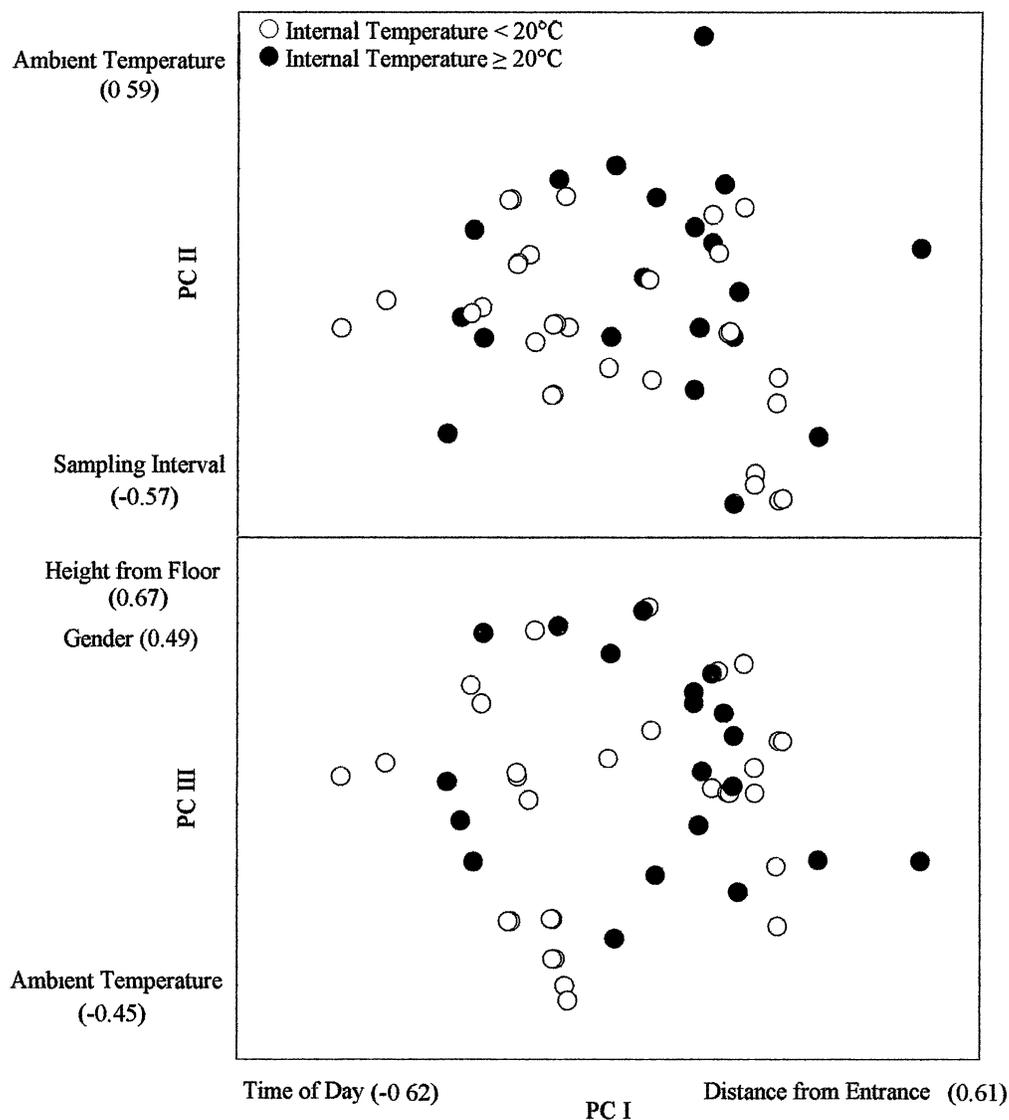


Figure 5. Principal Components Analysis of environmental variable plots of principal component axes I, II, and III for eastern pipistrelles during hibernation in Gorman Cave. The number in parenthesis represents negative or positive loadings for each environmental variable. Open circles signify internal bat temperatures below 20°C and closed circles represent internal bat temperatures above 20°C. The sample size was 50.

The sex ratio of eastern pipistrelles in the hibernaculum at Gorman Cave was determined to be 1:1 (not including recaptures) during the four-year study, which supported the assumption of an expected sex ratio of no remarkable difference ( $\chi^2_1 = 0, p = 1.00$ ) in the number of males and females present in the cave at any time. When the four years were broken down into separate years and compared for difference in sex ratio (no recaptures) between years, there was no remarkable difference ( $\chi^2_3 = 4.3662, p = 0.26$ ). When every month per year (without recaptures) and each year as a whole (no recaptures) were analyzed individually, a significant difference occurred only for March 1997 ( $\chi^2_1 = 8.334, p = 0.004$ ) and the year 1995 ( $\chi^2_1 = 3.92, p = 0.05$ ). The sex ratio was not significantly different for all other years and months with sufficient sample sizes (Table 2).

The temporal sex ratio of the population (not including recaptures) for each month sampled across years showed only a difference in sex ratio for March ( $\chi^2_1 = 8.334, p = 0.004$ ). All other months tested had no remarkable differences, and February was not testable due to a lack of data across years. When the sampled months within each of the four years was analyzed temporally for each year of the study, only years 1995 ( $\chi^2_1 = 4.66, p = 0.038$ ) and 1997 ( $\chi^2_3 = 11.3304, p = 0.01$ ) showed differences in number of male and female bats present over months within the year. Year 1996 showed no difference ( $\chi^2_3 = 1.9816, p = 0.58$ ) in the expected 1:1 sex ratio, but 1998 could not be tested due to a lack of data for some months. It should be noted that whenever there was a significant difference in the number of males and females present in the cave, the ratio always favored females (Table 2).

Table 2. Sex ratios of eastern pipistrelles in Gorman Cave by year and month. The  $\chi^2$  results under each month represent the change in the same month across years. The within year values represent the change across months within the same year. Data not tested due to a small sample size of  $< 5$  are represented by a "N/A." Sex ratios are shown as male : female.

Month	Year			
	1995	1996	1997	1998
	18 : 32 $\chi^2_1 = 3.92$ $p = 0.05$	62 : 58 $\chi^2_1 = 0.1334$ $p = 0.99$	51 : 53 $\chi^2_1 = 0.038$ $p = 1.00$	43 : 48 $\chi^2_1 = 0.2748$ $p = 0.60$
January $\chi^2_1 = 0.6464$ $p = 0.42$	N/A	1 : 1 N/A	40 : 43 $\chi^2_1 = 0.1084$ $p = 1.00$	42 : 49 $\chi^2_1 = 0.538$ $p = 0.48$
February N/A	N/A	29 : 23 $\chi^2_1 = 0.692$ $p = 0.40$	N/A	N/A
March $\chi^2_1 = 8.334$ $p = 0.004$	N/A	9 : 9 $\chi^2_1 = 0$ $p = 1.00$	6 : 21 $\chi^2_1 = 8.334$ $p = 0.004$	2 : 2 N/A
November $\chi^2_2 = 4.2396$ $p = 0.14$	4 : 11 $\chi^2_1 = 3.26$ $p = 0.07$	14 : 19 $\chi^2_1 = 0.7576$ $p = 0.39$	8 : 10 $\chi^2_1 = 0.222$ $p = 0.66$	N/A
December $\chi^2_2 = 4.598$ $p = 0.12$	14 : 21 $\chi^2_1 = 1.4$ $p = 0.25$	21 : 26 $\chi^2_1 = 0.532$ $p = 0.50$	8 : 16 $\chi^2_1 = 2.666$ $p = 0.12$	N/A
Within Year	$\chi^2_1 = 4.66$ $p = 0.038$	$\chi^2_3 = 1.9816$ $p = 0.58$	$\chi^2_3 = 11.3304$ $p = 0.012$	N/A

## CHAPTER IV

### DISCUSSION

Gorman cave had warm temperatures (16.8-21.1°C) deep inside the hibernaculum. Eastern pipistrelles were distributed throughout the cave and not just in warmer interior sections. The ambient temperature of the entire study site ranged from 10.4-24.9°C during the four years. Female pipistrelles were located slightly closer to the entrance than males, and females maintained lower internal temperatures than males. Female eastern pipistrelles occupied areas with a mean ambient temperature of 17.8°C and cooler internal temperatures than ambient temperature. Males occupied areas with a mean ambient temperature of 18.4°C and had internal temperatures slightly above ambient temperature. Internal temperature of eastern pipistrelle males and females in Minnesota with a much colder winter than central Texas generally averaged +/-2.0°C above or below the ambient cave temperature (Swanson and Evans 1936) similar to my findings. My analysis was unable to detect a differentiation in eastern pipistrelles' internal temperature based on gender during hibernation (Fig. 3) or over months (Fig. 4). The lack of intersexual differences in internal temperature in eastern pipistrelles could be due to their similarity in size (Fitch 1966). During hibernation, bats most often remain in torpor. There are no studies indicating a difference in the reaction to disturbance based on gender; so in a publicly toured cave, such as Gorman Cave, if bats are disturbed by

humans, there should be no difference in internal temperature by gender.

The strongest effect on internal temperature, in this study, resulted from a bat's distance from the cave entrance (Table 1). If a cave is warmer (Brack and Twente 1985; Yalden and Morris 1975), bats use less energy to stay warm (Johnson et al. 1998); and, with the small size of eastern pipistrelles, it explains preference for the greater distances from the entrance and warmer parts of the cave. When ambient temperature equals a bat's internal body temperature, no metabolic energy is allocated to maintain body temperature (Yalden and Morris 1975). Ambient temperature appeared to have a strong effect on the internal temperature of the bats, based on its low  $AIC_c$  making it a competing model. Although it is well known that the temperature of a cave generally increases as you get farther from the entrance, our cave varied internally. The temperature appeared to not be a continuous gradient; having areas of warm temperatures and some that were even warmer, with cold pockets scattered throughout. However, ambient temperature was warmer near the bat gate located at the end of my study site than at the entrance of the cave. Ambient temperature and substrate temperatures have a strong influence on internal temperature and metabolic rate of bats in a hibernaculum (Humphrey 1978; McNab 1974). Big brown bats (*Eptesicus fuscus*) maintained internal temperature at 7°C and had an internal temperature 0.5°-1°C higher than ambient temperature. At an ambient temperature of -2.4°C bats can be 1.5°-4°C warmer, never falling below -1.5°C (Swanson and Evans 1936).

The PCA results (Fig. 5) indicated internal temperatures  $\geq 20^\circ\text{C}$  for eastern pipistrelles were more affected by distance from the cave entrance, which correlated with  $AIC_c$  results. The *t*-test results showed bats sampled earlier in the day and greater

distances from the entrance in the cave, had warmer internal temperatures; whereas, bats sampled later in the day and closer to the entrance had lower internal temperatures. A possible explanation for this may be temperatures outside the cave become lower as it gets later in the day and temperature fluctuations outside the cave can cause changes in ambient temperatures inside the cave. As distance from the cave entrance increases, bats tend to shift position deeper into the cave, and the internal temperature increases. Thus, warmer ambient temperatures meant warmer internal temperatures for bats sampled in Gorman Cave from 1996-97. Ambient temperatures of caves naturally increase farther from the entrance and get cooler closer to the entrance. In winter, caves are warmest at greatest distances from the entrance (6°-12°C) (Brigger and Prather 2003; McNab 1974; Rabinowitz 1981; Unger and Kurta 1998).

According to both the chi-square goodness of fit and chi-square test of independence analyses, eastern pipistrelles in Gorman Cave appear to have a 1:1 sex ratio (Table 2) in 1995-98. Other studies conducted in summer found sex ratios of various bat species, including eastern pipistrelles, were disproportionate (Davis 1959b) and often favored males (Davis 1966; Fujita and Kunz 1984). Male-dominated sex ratios in bat species have been found in caves used for hibernation in Germany (Eisentraut 1947), Missouri (Davis 1959b), New England (Griffin 1940, Hitchcock 1950), New York (Wimsatt 1945), northeastern Alabama (Davis 1959b), Ontario and Quebec (Hitchcock 1950), Pennsylvania (Mohr 1932, 1939, 1945), Texas (Sandel et al. 2001), and West Virginia (Davis 1959b). Davis (1959b) reported a *Pipistrellus subflavus* winter sex ratio of 1:1. In my study significant differences in the sex ratio were skewed toward females. A disproportionate sex ratio skewed toward females in eastern pipistrelles also occurred

at roost sites in southern Louisiana (Jones and Pagels 1968; Jones and Suttkus 1973). Eastern red bats (*Lasiurus borealis*) and eastern pipistrelles sex ratios were male-dominated as juveniles and female-dominated in adults (Miller 2003). The sex ratio in my study was possibly skewed toward females due to higher number of females sampled versus the number of males. This may be due to the fact that females need cooler temperatures to remain in torpor, so that males may be more likely to leave the cave during warmer periods. Jones and Pagels (1968) recaptured more females than males which skewed the sex ratio toward females; whereas, a study by Sandel et al. (2001) recaptured mostly females and the sex ratio was dominated by males.

Additionally, male bats are known to copulate with females before hibernation, during hibernation if females are out of torpor, and after hibernation (Carter 1970; Tidemann 1982). If males are out of torpor, they will leave the hibernaculum; whereas, females must remain in the hibernaculum or return to torpor during hibernation to ensure proper gestation (Yalden and Morris 1975). Male eastern pipistrelles tend to stay in the hibernaculum longer than females, which leave to find a maternity colony (Jones and Suttkus 1973; Sandel et al. 2001). The sex ratio difference in 1995 may have been caused by variances in the weather, or a lack of data. Difference in March 1997 could have been caused by bats leaving the hibernaculum. Sandel et al. (2001) found few bats remained in a man-made hibernaculum in February. Differences in sex ratios for March across years can be explained by males leaving earlier than females or because of a lack of data. Due to a lack of data, differences found between months in 1995 cannot be explained. Any significance attributed to months within 1997 could be the inclusion of March, which tested significant, and all other months showed no difference. It could also

be 1997 had the most data of all years sampled, which may allow a true difference to be detected. In order to further test this newly found 1:1 sex ratio of the Gorman Cave eastern pipistrelles, more research should be done using more consistent and accurate recording methods and collection over a longer time.

More information is needed on what affects bats' internal temperature during hibernation, their selection of hibernacula and what factors are determining the sex ratio, so we can better address species conservation needs with the aid of various types of land and forestry management, including construction of bat gates, protection of caves, and creation of additional man-made roosts. A major problem for my study was an inconsistent amount of data, which can largely be explained by the extreme difficulty in locating all bats throughout the cave during each visit and could possibly be attributed to bats switching to different roosts or relocating to other caves within and around Colorado Bend State Park (Griffin 1940; Guthrie 1933b). Throughout my study there was a notable decrease in the number of bats present in the cave on warmer sampling days then on cooler days. On cooler days bats tended to remain in torpor rather than in flight, which allowed for easier sampling. The amount of gaps in our understanding of bat habitat use is commonly acknowledged (Arnett 2003; Keeley et al. 2003; Miller et al. 2003). All threatened and endangered North American bats are cave-dwelling species or subspecies (Harvey et al. 1999; McCracken 1989; Pierson 1999) and, of these species, 13 are obligate year-round cave users (McCracken 1989). Human disturbance has caused declines in many obligate cave-dwelling bat species (American Society of Mammalogists 1992; Barbour and Davis 1969; Humphrey and Kunz 1976; Johnson et al. 1998; Tuttle 1979; Wegiel and Wegiel 1998). Therefore, bat biologists need to monitor bats to reach

population management and conservation goals. More studies on common bat species, such as *Perimyotis subflavus*, could aid our understanding of bats and allow us to better understand roost selection by bats. These findings could then be used for the management of other bat species and may also help bat biologists manage endangered bat species populations more efficiently.

APPENDIX  
INTERNAL TEMPERATURE DATA

DATE	TIME (hrs)	GENDER	DISTANCE FROM ENTRANCE (m)	HEIGHT FROM FLOOR (cm)	BAT INTERNAL TEMPERATURE (°C)	AMBIENT TEMPERATURE (°C)
3-Nov-96	17.15	Female	145	193	26.6	20.0
3-Nov-96	16.75	Male	192	344	31.1	21.1
17-Nov-96	18.7	Female	15	192	15	15.2
17-Nov-96	18.2	Female	71	137	16	16.2
17-Nov-96	17.13	Female	99	125	16	17.2
17-Nov-96	17.4	Female	99	252	21	16.8
17-Nov-96	16.52	Male	108	402	18	17.6
17-Nov-96	15.92	Male	118	395	21	18.6
17-Nov-96	14.93	Female	140	101	23	17.8
17-Nov-96	13.83	Male	140	70	19	19.2
17-Nov-96	15.42	Male	140	308	20	18.4
17-Nov-96	14.12	Male	145	221	19	18.9
17-Nov-96	14.37	Male	145	174	22	20.1
23-Nov-96	18.5	Female	15	182	18	17.8
23-Nov-96	18.07	Female	30	203	18	18.4
23-Nov-96	17.83	Male	52	230	21	18.6
23-Nov-96	16.77	Female	71	56	20	18.6
23-Nov-96	16.87	Female	71	155	18	18.6
23-Nov-96	17.18	Female	71	127	18	18.6
23-Nov-96	16.87	Male	71	157	18	18.6
23-Nov-96	17.2	Male	71	122	18	18.6
23-Nov-96	17.22	Male	71	116	18	18.6
23-Nov-96	17.5	Male	71	325	19	18.6
23-Nov-96	16.22	Female	99	58	18	18.4
23-Nov-96	15.25	Female	145	113	18	19.6
23-Nov-96	15.42	Female	145	117	31	19.6

DATE	TIME (hrs)	GENDER	DISTANCE FROM ENTRANCE (m)	HEIGHT FROM FLOOR (cm)	BAT INTERNAL TEMPERATURE (°C)	AMBIENT TEMPERATURE (°C)
23-Nov-96	14.75	Male	145	76	20	19.6
23-Nov-96	15.32	Male	145	114	21	19.6
23-Nov-96	14.25	Female	180	257	19	20.4
14-Dec-96	18	Female	71	108	30.2	16.6
14-Dec-96	18.5	Female	71	68	17.6	16.6
14-Dec-96	16.5	Male	99	248	17.8	16.8
14-Dec-96	17	Male	99	152	19	15.9
14-Dec-96	17.5	Male	99	256	19.6	16.9
14-Dec-96	16.08	Female	108	458	18.2	16.8
14-Dec-96	15.75	Female	118	183	18.2	18.0
14-Dec-96	15.25	Female	140	151	18.6	17.9
14-Dec-96	15.25	Male	140	151	20.1	17.9
14-Dec-96	14.25	Female	145	116	22.1	18.1
14-Dec-96	14.42	Male	145	264	28	18.1
14-Dec-96	14.5	Male	145	113	20.2	18.1
14-Dec-96	14.67	Male	145	121	19.6	18.1
28-Dec-96	13.52	Male	222	305	21	19.6
4-Jan-96	13	Female	130	76	20	17.0
4-Jan-96	13.5	Male	130	239	18.9	17.6
4-Jan-96	13.5	Male	130	154	18.9	17.6
4-Jan-96	13	Female	145	128	18.8	17.0
4-Jan-96	13	Female	145	164	18.6	17.0
4-Jan-96	12.25	Female	145	95	19.6	17.0
4-Jan-96	12.5	Male	145	128	21	17.0

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## VITA

I was born in St. Louis, Missouri, in February of 1985. I am originally from St. Louis and moved to Texas in the fall of 2008 to complete my Masters in Wildlife Ecology at Texas State University-San Marcos, Texas. At Texas State I also worked as an instructional assistant in their Functional Biology lab under Dr. Anthony Bosworth. Prior to leaving Missouri, I gained a Bachelor of Science degree in Biology with a focus on organismal, evolutionary, and ecological biology and a double minor in Art and Spanish at Southeast Missouri State University in Cape Girardeau, Missouri. I graduated Magna Cum Laude and as an Honors Scholar. While attending SEMO, I worked as a lab assistant and grader for the Exploring the Universe lab for the physics department under Dr. Michael Cobb. I also studied at the Gulf Coast Research Laboratory in Ocean Springs, Mississippi. As an undergraduate I conducted field research on the foraging habitats of gray squirrels, the nest box use of flying squirrels, and herp-arrays. Throughout my college years, I took on many summer internships and part-time jobs. In 2007 I worked at the World Bird Sanctuary in Valley Park, Missouri, where I cared for and flew raptors. I also conducted field research on the impact of different vegetation-control on song bird nest box use for AmerenUE. In 2008 I worked at Meramec State Park for the Missouri Department of Natural Resources where I was a seasonal naturalist and gave interpretive cave tours, nature hikes, river wades, and created and presented educational programs to the public. In the summer of 2009 I was awarded the Mickey

Leland Internship for Travis County, which allowed me the opportunity to work on and assist in the stewardship of the Balcones Canyonlands Preserve in Austin, Texas, as a Natural Resources Technician for the Texas Transportation and Natural Resources Division. From May 2009 to August 2010 I worked for the San Antonio Zoo's education department as both an educator for their overnight program "Roars and Snores" and as an instructor for their K-1 summer camps. As an undergraduate, I was awarded the Gersbacher Zoology Achievement Award in 2006-07 and 2007-08, the Norman L. Braasch Scholarship in 2006-07 and 2007-08, and the Darwin Fund Scholarship in summer 2006.

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