SEASONAL FLUCTUATIONS IN URBAN ROOST USE BY BRAZILIAN FREE-TAILED BATS (*TADARIDA BRASILIENSIS*) IN A HIGHWAY OVERPASS, SAN ANGELO, TEXAS

A Thesis

Presented to the

Faculty of the College of Graduate Studies of

Angelo State University

In Partial Fulfillment of the

Requirements for the Degree

MASTER OF BIOLOGY

by

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December 2015

Major: Biology

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ACKNOWLEDGMENTS

Firstly, I would like to give my utmost gratitude and appreciation to my two advisors, Dr. Loren K. Ammerman and Dr. Robert C. Dowler, for their amazing guidance and support in carrying out this project. They both saw my dedication and great love for this particular bat species and gave a tremendous amount of advice, encouragement, and instruction that I needed to complete this research. I would also like to thank Dr. Nicholas J. Negovetich for assisting and guiding me through the many statistical analysis tests that needed to be conducted for this project. On the same note, I would like to give my many thanks to my peers and loved friends, Clint Morgan, Katie Kuzdak, Citlally Jimenez, Erin Adams, Krysta Demere, and Grayson Allred, for their continuous help and support during this time. They spent countless hours with me at the overpass roost helping me tag and capture bats, and record data. They also supported me through multiple conference presentations and research talks.

Secondly, I would like to thank my friends and family, especially my parents and those from Team Chip Tae Kwon Do Centers, who have supported me and given me such encouragement through my years as a graduate student. I would not have been able to undertake this task without them. I also would like to extend many thanks to Dr. Thomas E. Lee, Jr., my undergraduate research advisor and mentor for many years.

Thirdly, I would like to give my gratitude to Darin Carroll and Ann Maxwell for contributing to this project by sending me their past collected data from 20 years previously. They were an amazing help and never missed any of my emails. I would not have completed a major part of this study without their assistance and willingness to share their work with me.

My sincerest thanks are extended to Mr. Gary Enos of Texas Department of Transportation for supplying me with the structural information and original documents for the development and building of the Foster Road overpass. I would also like to extend my gratitude to the Angelo State University Head of the River Ranch Research Grant for providing the funding, and Texas Parks and Wildlife for providing the permit that made it possible for me to conduct this research.

ABSTRACT

I surveyed a large population of *Tadarida brasiliensis* roosting in a highway overpass in San Angelo, Tom Green County, Texas to determine roost use and seasonal patterns of occupancy. I compared occupancy patterns observed in 2014 to those observed when the site was last surveyed in 1995. Population counts and roost use were documented from February 2014 through February 2015. Bat populations ranged from 0 during some winter counts to an estimated high of 191,795 individuals in August. Rainfall affected roosting conditions. During times of precipitation, large numbers of bats temporarily vacated the roost, but they returned when conditions improved. I discovered that this roosting location for *T. brasiliensis* serves as a maternity roost during the summer. Compared to a previous study conducted on the same roost in 1995, there were similar trends in seasonal occupancy. I concluded that the colony at this roost fluctuates predictably year-round.

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INTRODUCTION

The Brazilian free-tailed bat *Tadarida brasiliensis* is one of the most widely distributed mammalian species in the Western Hemisphere and the most common species of bat occurring in Texas (Schmidly et al. 1977; Wilkins 1989; Ammerman et al. 2012). In Texas, Brazilian free-tailed bat populations are known to be valuable economical resources based on their consumption of an estimated 250 tons of agricultural insect pests each night (McCracken 1996, Cleveland et al. 2006). Additionally, Brazilian free-tailed bats are known to occupy and utilize man-made structures such as bridges and highway overpasses as day roosts in order to seek refuge from predators and inclement weather while resting (Davis and Cockrum 1963; Keeley and Tuttle 1999; Sgro and Wilkins 2003; Horn and Kunz 2008). In Texas, the use of anthropogenic structures is likely a recent and possibly expanding practice (Ammerman et al. 2012). Previous research has documented populations of Brazilian free-tailed bats using highway overpasses as day roosts in eastern and central Texas (Keeley and Tuttle 1996; Sgro and Wilkins 2003; Keeley and Keeley 2004; Allen et al. 2009; Allen et al. 2010; Turmelle et al. 2010; Allen et al. 2011). In these studies, male and female bats were observed roosting in bridges and highway overpasses during the spring after returning from their overwintering locations. In most of these locations (and other types of anthropogenic roosts in similar studies), female bats departed to maternity roosts by May or June to give birth, and returned to their spring roosts with their volant offspring in the fall before migration season (Davis and Cockrum 1963; Fraze and Wilkins 1990; Sgro and Wilkins

2003; Keeley and Keeley 2004; Scales and Wilkins 2007). Glass (1982) suggested that southward migration season for Brazilian free-tailed bats takes place from August to November. Sgro and Wilkins (2003) and Scales and Wilkins (2007) observed fluctuations in roost use during these previously reported migratory periods, suggesting that the use of bridges and other anthropogenic roosts normally used in spring and summer were serving as stopover locations for overwintering transient bats. At anthropogenic roosts, male bats generally preceded females in spring migration, and female bats were generally more numerous after April upon arriving in the spring and in August after returning from a summer spent elsewhere. Additionally, no neonates were observed during these studies and juveniles were only seen at the roosts by August after returning with adult female bats (Fraze and Wilkins 1990; Sgro and Wilkins 2003; Scales and Wilkins 2007).

According to Keeley and Tuttle (1999) Brazilian free-tailed bats roosting in bridges and highway overpasses seek refuge in expansion joints and other such crevices that are 2.0-2.5 cm wide and 30.5 cm or greater in depth. They tend to use overpasses constructed from concrete that are at least 3 m from the ground (Keeley and Tuttle 1999). Keeley and Tuttle (1996; 1999) noted that any evidence of storm-water draining along the lengths of expansion joints, or other crevices that may offer roosting space for bats, indicated that crevices were not properly sealed, and that ultimately, such bridges should not be considered as ideal roosts due to roost flooding. Although most urban Brazilian free-tailed bat colonies in Texas are <100 individuals (Keeley and Tuttle 1996; 1999), some authors have observed that day roosts in highway overpasses can exceed numbers well into the thousands (Keeley and Tuttle 1996, Keeley and Tuttle 1999; Sgro and Wilkins 2003, Keeley and Keeley 2004).

Although several central and eastern Texas bridge roosts have been previously studied, there have been no extensive studies involving bridge-roosting populations of Brazilian free-tailed bats in western Texas. This area (the Central Great Plains ecoregion) is characterized primarily by arid conditions with low amounts of annual precipitation, and croplands (dominant crops include cotton, sorghum, and wheat), scattered low trees (mostly mesquite (*Prosopis glandulosa*) and juniper (*Juniperus spp*.) brushland), shrub savannas and flat grasslands (Omernik and Griffith 2013; Maxwell 2013). The Concho River also flows through this region and supports riparian vegetation. A large population of Brazilian free-tailed bats roosting in a highway overpass located in San Angelo, Tom Green County, Texas (Central Great Plains) was previously monitored by A. Maxwell and D. Carroll in 1995-1996, in which population fluctuations were observed and recorded each month. At the time, it was not yet known if both males and females utilized the overpass roost, how bats utilized the roost, and if it was a seasonal stopover roost or a permanent population of individuals. The overpass, also known as the Foster Road overpass, was built in 1982, and residents of San Angelo suggest that the overpass has been occupied by Brazilian free-tailed bats for the past 30 years. The purpose of this study was to monitor a large population of Brazilian free-tailed bats roosting in the Foster Road overpass to determine roost use and seasonal patterns of occupancy, as well as compare occupancy patterns observed in 2014 to those seen when the site was last surveyed in 1995. I hypothesized that seasonal patterns of roost use would be similar from year to year, and that there should be no significant change in roost occupancy between 1995 and 2014. Further, I hypothesized that rainfall was a variable that affected population trends, roosting, and emergence behaviors.

MATERIALS AND METHODS

Site Description.—A population of *T. brasiliensis* was surveyed in a highway overpass at Foster Road and Highway Loop 306 in Tom Green Co. in San Angelo, Texas (31°24’38.2”N, 100°27’24.4”W). The overpass ran from north to south and was supported by three concrete columns (positioned at the bases of north and south embankments and in the median of Loop 306; Fig. 1). The overpass measured 73.11 m in length,15.85 m in width and 4.97 m in height. The overpass was divided into four sections, labeled I (11.30 m long), II (24.83 m long), III (25.58 m long), and IV (11.40 m long). Bats roosted in the 11 joint openings that ran along the length of the overpass (Fig. 2). The joint openings varied in width and depth, measuring an average of 27 cm in depth, and were roughly 4.3 cm wide along their entire length.

Bat Sampling.—Sampling visits to survey population size and roost occupancy at the overpass took place once a week from February 2014-February 2015. During each sampling visit, I used a bright LED flashlight to illuminate the length of each of the 11 joint opening crevices starting from section I and ending at section IV and recorded the areas of roost occupancy. For each section of the bridge, I calculated percent occupancy by estimating the total amount of filled space by bats for the 11 crevices. In the previous study conducted in 1995, population estimates were determined by marking 15.2 cm segments along each expansion joint and counting the total number of bats that were roosting in each. I repeated these methods for this study. Not all areas occupied held the same number of bats, but the estimation documented the possible maximum number of bats that could be roosting at the overpass given the areas of the overpass occupied by bats. The total population estimate for each sample date was recorded and compared across the year and to population estimates

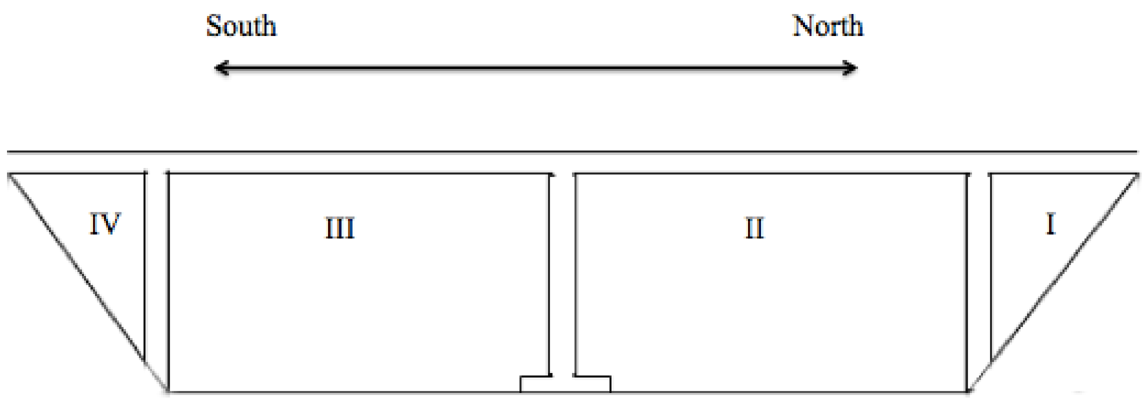

FIG. 1.—Layout of the Foster Road overpass in San Angelo, Tom Green Co., Texas. For sampling, the overpass was divided into four sections, in which sections II and III were areas over the 4-laned divided highway running east and west, and sections I and IV were over north and south embankments.

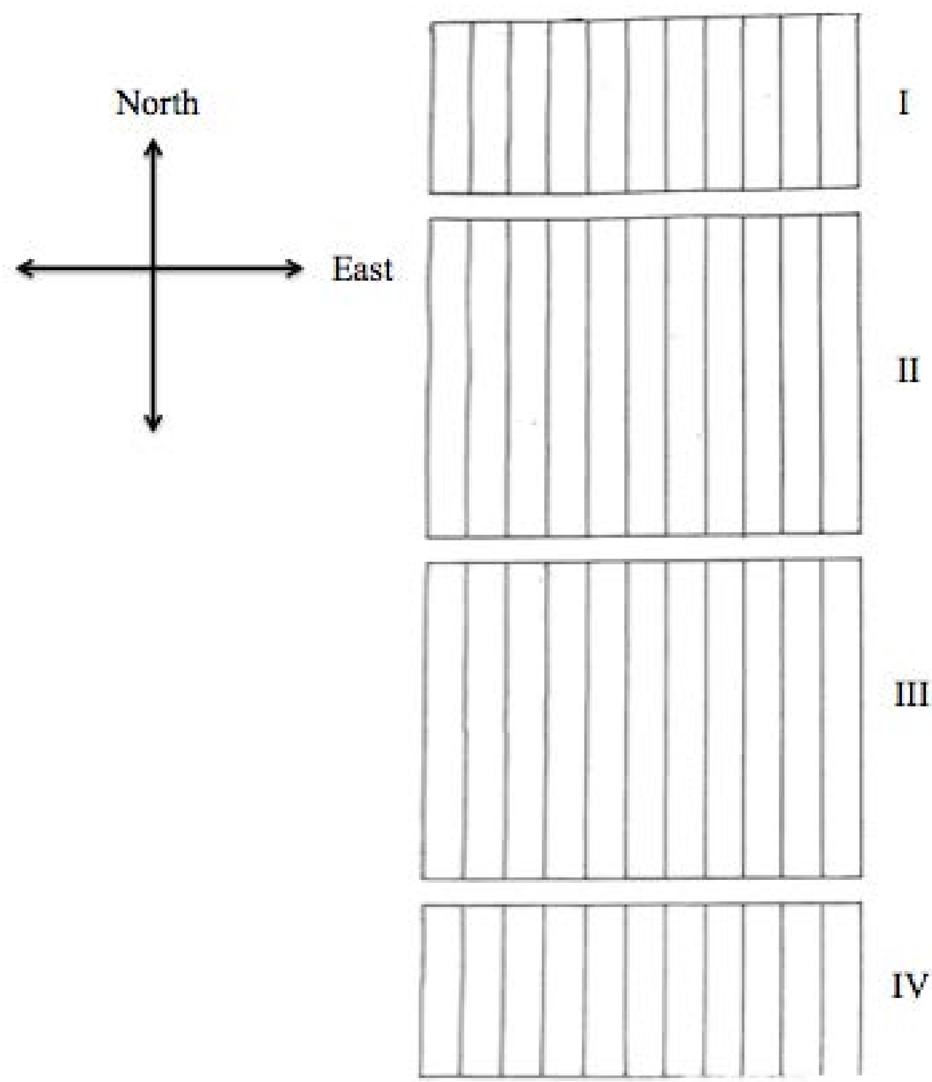

FIG. 2.—Layout of the four divided sections of the Foster Road overpass, San Angelo, Tom Green Co., Texas showing the 11 joint openings running north and south. Bats roosted in the crevices of each joint opening (represented by the 11 black spaces per section in the figure).

taken in 1995. In order to survey roost use by different sexes, I removed a sample of individual bats from the roost once a week during the daylight hours. Because of the amount of traffic and the unreachable areas in sections II and III, I could only capture bats from the crevices above embankment areas in sections I and IV. When a bat was removed from the roost, its sex and reproductive condition (noted any descended testes in males or enlarged nipples in females) were recorded. Before releasing, I tagged each bat on the back with a strip of Hi Viz high intensity grade reflective tape (Direct Products (UK) Limited, Clitheroe, England) based on sex; males were tagged with blue reflective tape and females were tagged with pink reflective tape. I applied the reflective tape to the fur of the bats with adhesive super glue so it remained in place presumably until the bat molted by the following summer (Bontadina and Naef-Daenzer 2002; Murray and Kurta 2004). The reflective tape was noticeable while the bats were in the crevices and any evidence of sexual segregation, or roost site switching was noted. Sampling took place in the morning in order to minimize disruption of the nightly roost emergence. I estimated the sex ratio and reproductive condition of the colony using these data. All procedures followed guidelines of the American Society of Mammalogists for use of wild mammals in research (Sikes et al. 2011) and were approved by the Angelo State University Institutional Animal Care and Use Committee (IACUC approval number 14-02).

Nightly emergence.—Evening emergences were recorded once a week. Nightly emergences were recorded for an hour after the time of initial roost exit. I defined a mass emergence wave as a continuous stream-like emergence of a high number of bats lasting anywhere from 10 to 30 min, and I defined a scattered group emergence as a 2-6 bats emerging together and within 15 to 30 sec of one other. On nights where there was no initial mass emergence wave and I only observed scattered group emergences for the duration of the hour, I recorded the time for these emergences, although I did not consider them as waves. I recorded the time of emergence (minutes after sunset), and, from the National Weather Service (www.weather.gov), obtained the average daily temperature (°C), average humidity, barometric pressure (mmHg), and amount of precipitation (cm) for each sampling date at the Foster Road overpass site. The National Weather Service, San Angelo, Texas was located 5.73 km southwest of the Foster Road overpass site.

Statistical analysis.—I noticed that a large number of bats evacuated the overpass when I happened to sample after recent precipitation > 0 cm (within 48 hrs); I questioned if rainfall encouraged temporary population declines, and if more rainfall caused a larger decline in numbers. I used a randomization test (10,000 permutations) to examine the overall percentage change ($\bar{x}$) as a function of precipitation (it rained or it did not rain) for 1995 and 2014. Because I estimated population size and determined rainfall on a weekly basis, I was unable to perform the randomization within each month because of low sample size per month. As such, I grouped the months of February 2014 through August 2014 and September 2014 through February 2015 in order also to eliminate seasonal effects of weather change, as well as spring and fall migration periods. For data collected in 1995/1996, I grouped the months of February 1995 through May 1995, June 1995 through August 1995, and September 1995 through February 1996 because of a much larger sample size due to sampling more than once a week. To further analyze the effects of rainfall, I performed a second randomization test (10,000 permutations) to examine the decline in population as a function of precipitation amount for data collected in 1995/1996 and 2014/2015. I analyzed the relationship between nightly emergence times and nightly weather conditions (humidity, barometric pressure, average daily temperature and precipitation) with logistic regression and simple linear regression models. Akaike's Information Criterion (AIC) was used to determine the most parsimonious model for logistic regression and simple linear regression models. Lastly, I analyzed the relationship between the changes in occupancy patterns in 1995 and in 2014 with a randomized t-test (10,000 permutations). I set $P \leq 0.05$ and analyses were done using R statistical software program (R Development Core Team 2015).

RESULTS

Seasonal population fluctuations.—Bats were recorded at this roost site in all months of the year. Numbers of *T. brasiliensis* steadily increased from spring into summer with a decrease in May and June 2014 (Fig. 3). Numbers were at their highest in the fall before migration. Population numbers decreased substantially by the end of November 2014 and reached near zero numbers by December 2014. Numbers started increasing again by February 2015. The highest population count was collected in August 2014 with an estimate of 191,795 bats, and the lowest count was recorded in January 2014 with 0 bats during 2 weekly samples. On 5 October 2014, an adult male *Myotis velifer* (cave myotis) was captured in section IV, crevice 3 (counting from east to west) of the overpass. It was captured while roosting at the far south end of the overpass within a cluster of roosting *T. brasiliensis*; it was the only *M. velifer* captured during this study.

I noticed that a large number of bats evacuated the overpass when we sampled ≤48 hrs after a recent rain (any measurable precipitation). I observed that when it rained, the joint openings where the bats roosted dripped rainwater. After a period of rainfall, most of the roosting areas of the overpass were wet and any bats that were still present at the overpass had wet pelage. I often found 20-50 wet dead bats under the bridge after a rainfall. At times, I found dead bats still in the joint openings, and bats were usually clumped together, suggesting that they had died while roosting close to one another. During the spring and summer, only adult dead bats were found. After young were born, dead bats included both adults and offspring; however, until offspring were volant, it was difficult to distinguish between pups that died due to falling from the crevices, and pups that died from rainfall events. Roosting numbers recovered by the next week’s sampling date (Fig. 3). The

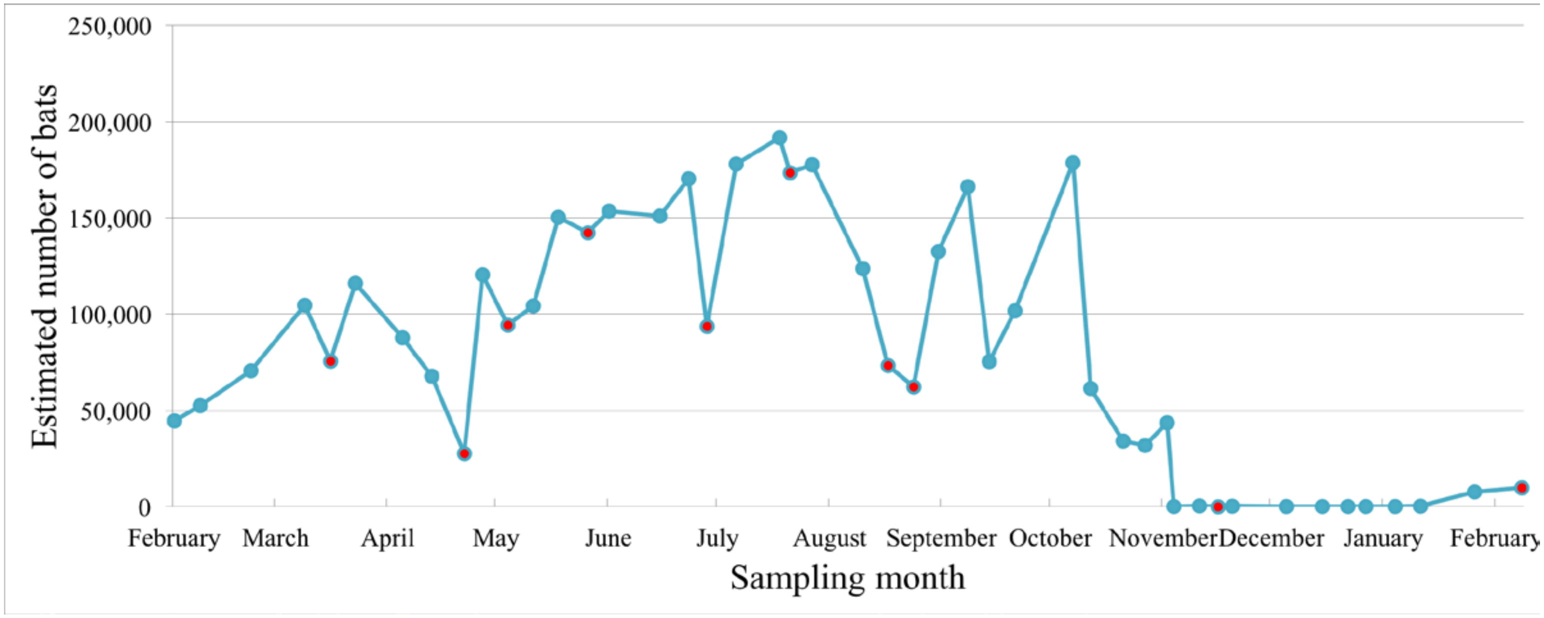

FIG. 3.— Fluctuations in population size of a colony of *Tadarida brasiliensis* roosting at Foster Road overpass, San Angelo, Tom Green Co., Texas from February 2014-February 2015. Red dots indicate sample dates associated with rainfall events (decreases in roost occupancy during sampling dates taking place within 48 hrs of measurable rainfall).

overall average percentage change in weekly population estimates for each month in 2014 showed (with the exception of November 2014) larger declines in population during times of rainfall within 48 hrs prior to sampling censuses than during sampling times without rainfall, suggesting that despite natural fluctuations in population size, rainfall caused a large decline in roosting numbers due to bats temporarily vacating the roost (February 2014-August: 2014: F=23.058, *P*=0.008, $\bar{x}$ (without rain)=7.975, $\bar{x}$ (with rain)=-15.083; September 2014-February 2015: F=8.804, *P*=0.373, $\bar{x}$ (without rain)=3.244, $\bar{x}$ (with rain)=-5.560) (Fig. 4). Although rainfall did encourage roost evacuation by the bats, the results of the second randomization test suggested that there was no evidence for a correlation between amount of precipitation and amount of decline in roosting population (F = 0.317, *P*= 0.564).

I observed tagged bats roosting at other locations in San Angelo, Texas during rainfall events from July-September 2014 (Table 1). Unlike the joint openings at the overpass, these locations appeared to remain free of rainwater during rainy conditions. Secondary roosting sites where I saw tagged bats were located at Arden Road and Highway Loop 306 (31°26’53.7”N, 100°29’32.7”W), the intersection of North Chadbourne Street and West Houston Harte Expressway 87 (31°28’11.19”N, 100°26’29.17”W), and the access ramp at Bryant Boulevard North and West Houston Harte Expressway (31°28’2.61”N, 100°26’43.30”W) in San Angelo, Tom Green Co., Texas. These secondary roosts were all within 7 km N (5.37km, 6.72 km, and 6.36 km respectively) of the Foster Road overpass roost. Because bats only roosted in crevices along each support wall of these highways instead of in the overpasses themselves, roosting space was more limited at each secondary location. Bats were unreachable and were hardly visible at these secondary roosts; as such, it was difficult to determine if both adult and volant juvenile bats were present at these

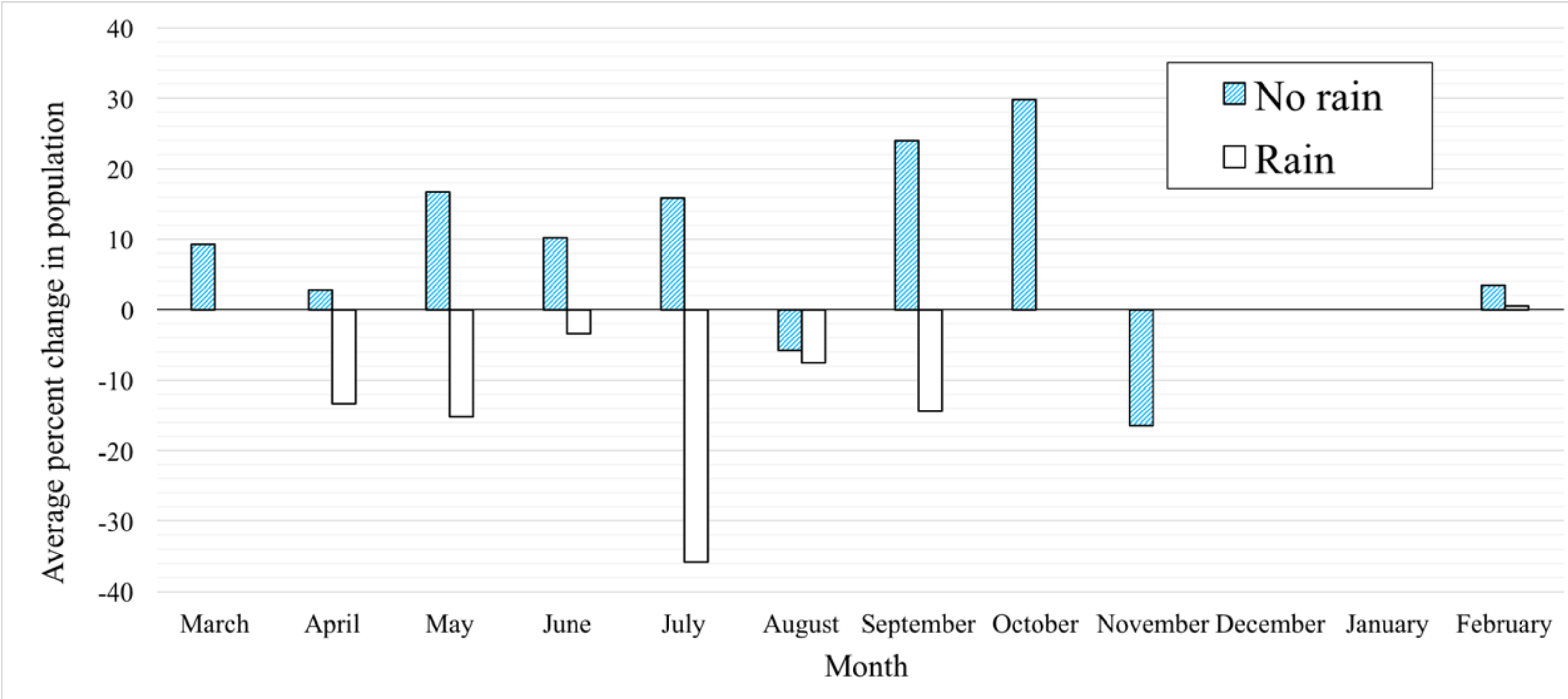

FIG. 4.—Average percentage change in weekly population estimates by month in 2014 with and without rainfall at the Foster Road overpass, San Angelo, Tom Green Co., Texas.

locations. Although bats were seen overwintering (November 2014 through January 2015) at the secondary roosts (3 November, 12 November, 26 November, 9 December, 11 December, 26 December 2014, 18 January, and 26 January 2015), I did not see any that had been tagged at Foster Road overpass.

Male and female occupancy.—I captured 761 bats (442 females and 319 males) from March-October 2014 (Figs. 5 and 6). Although bats were present in reachable areas of the roost in April and May 2014, I was unable to handle bats during that time. I sampled individuals from the overpass roost in April and May 2015 in order to estimate the sex ratio in the spring months. A total of 200 bats (7 non-reproductive females and 193 non-reproductive males) were handled in April and May 2015 (captured bats were not tagged and were released after their sex and reproductive condition were checked). As population numbers began to decline in October 2014, bats were no longer seen roosting in reachable areas in Sections I and IV, and tagging ended in October 2014. I captured adult non-reproductive male bats roosting at the overpass during March, June and July 2014. Male bats dominated the roosting population (with only three female bats captured) early in the year and were mostly replaced by reproductive female bats by the summer. I first captured pregnant female bats by 2 June 2014 and first documented neonates 2 weeks later (16 June 2014). At the time there were hundreds to potentially thousands of neonates present in the embankment sections of the overpass, however the number of neonates was not recorded. I no longer captured any non-reproductive adult male bats at the overpass after 23 July 2014, just before offspring were volant. Female bats were lactating from 8 July-23 July 2014, and after 12 August 2014, I no longer captured any adult females (post-lactating). I only captured

TABLE 1.—Dates in which male and female *Tadarida brasiliensis* tagged with reflective tape were seen at secondary roosting locations in San Angelo, Tom Green Co., Texas during rainfall events. The Bryant secondary roost was only visited once because the heavy amount of traffic on the ramp made accessing the roost dangerous.

Location	Date	Number of tagged bats
Arden Road	15 July 2014	1 female
	12 August 2014	2 females
	8 September 2014	1 female
	15 September 2014	1 female
Chadbourne Street	12 August 2014	3 females
	15 September 2014	4 females
Bryant Blvd.	12 August 2014	2 females, 1 male

volant juvenile offspring until 28 October 2014, when I suspect migration season began and any roosting bats at the overpass were unreachable (Fig. 7).

Nightly emergence.—Bats roosting at the overpass were consistent in emerging within 40 min after sunset (avg=17.7 min after sunset) from February-October 2014, and I only observed 2 emergences from November 2014-February 2015 (Fig. 8). For each sampling date, I observed bats usually exiting from the east side of the overpass and flying south after exiting, although sometimes there were a few bats that exited on the west side of the overpass before flying south. On every sampling date, with the exception of one, I observed a number of bats that did not emerge from the overpass an hour after initial roost exit. I observed bats emerging from the overpass before sunset on 23 November 2014. The bats exited *en masse* from both the east and the west side of the overpass and did not form an emergence wave. Instead, bats circled in the immediate area of the overpass and seemed to scatter in the northwest direction. All roosting areas of the overpass were empty within 17 min of initial roost exit. This was the only time I observed bats exhibiting this kind of emergence behavior. Results of the AIC indicate that emergence was significantly correlated with temperature, and not humidity, barometric pressure or rainfall. However, temperature+humidity (although humidity was not significant) also could be considered an adequate model to use in determining emergence (Table 2). None of the variable models were considered to be significant in determining onset of emergence (Table 3). Temperature, although only significant in determining emergence, can be considered as a minimally adequate model for emergence times.

Occupancy patterns compared.—I observed that both sample years (1995 and 2014) experienced similar population trends around the same time periods, despite some

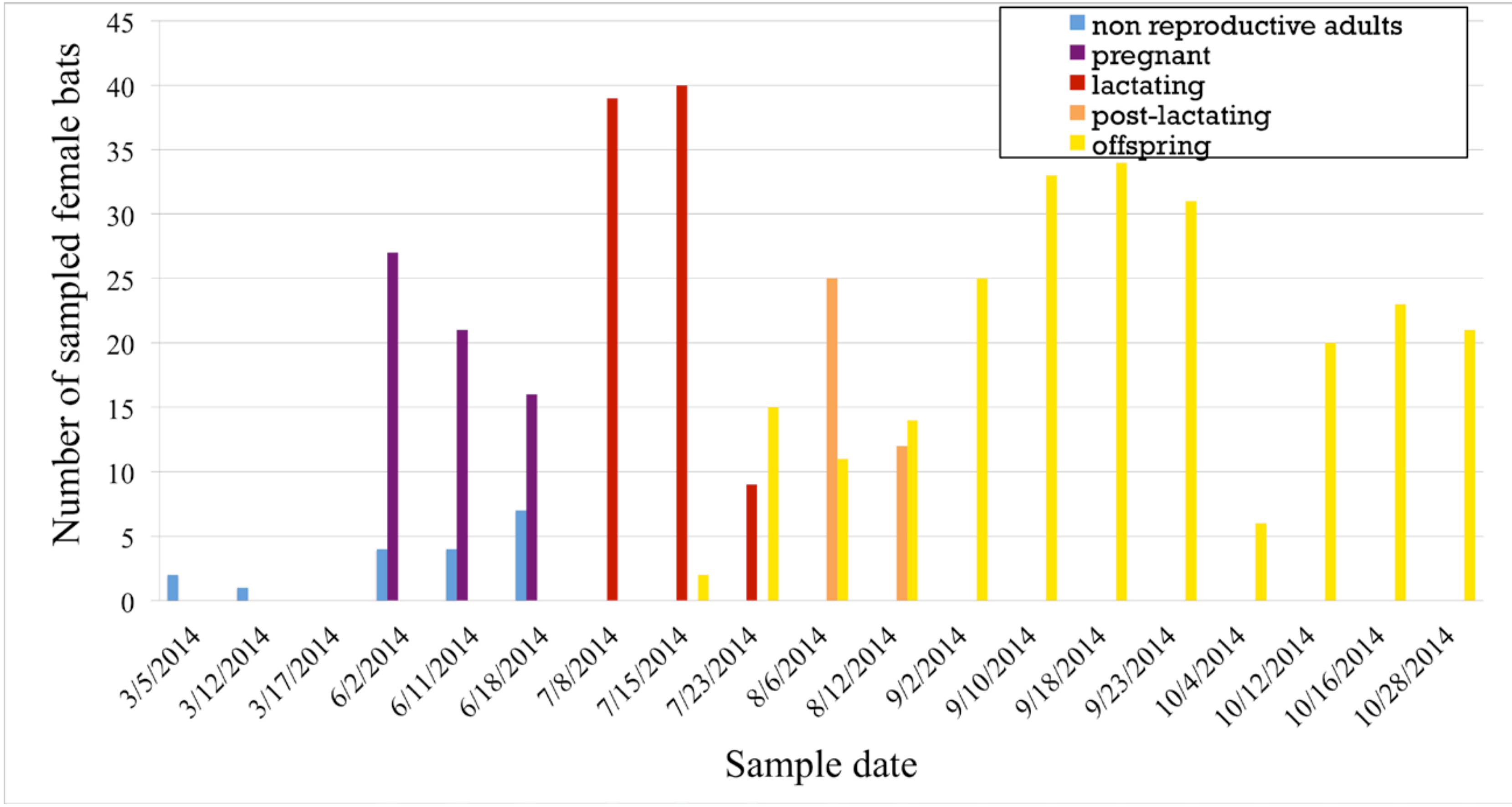

FIG. 5.—Patterns of roost use by female *Tadarida brasiliensis* roosting at the Foster Road overpass, San Angelo, Tom Green Co., Texas. Shown are the frequencies of non-reproductive adult (18 individuals), pregnant (64 individuals), lactating (88 individuals), and post-lactating (37 individuals) females, and non-reproductive female offspring (235 individuals) captured at the Foster Road overpass, San Angelo, Tom Green Co., Texas during the months of March-October 2014. Captured total was 442 female bats.

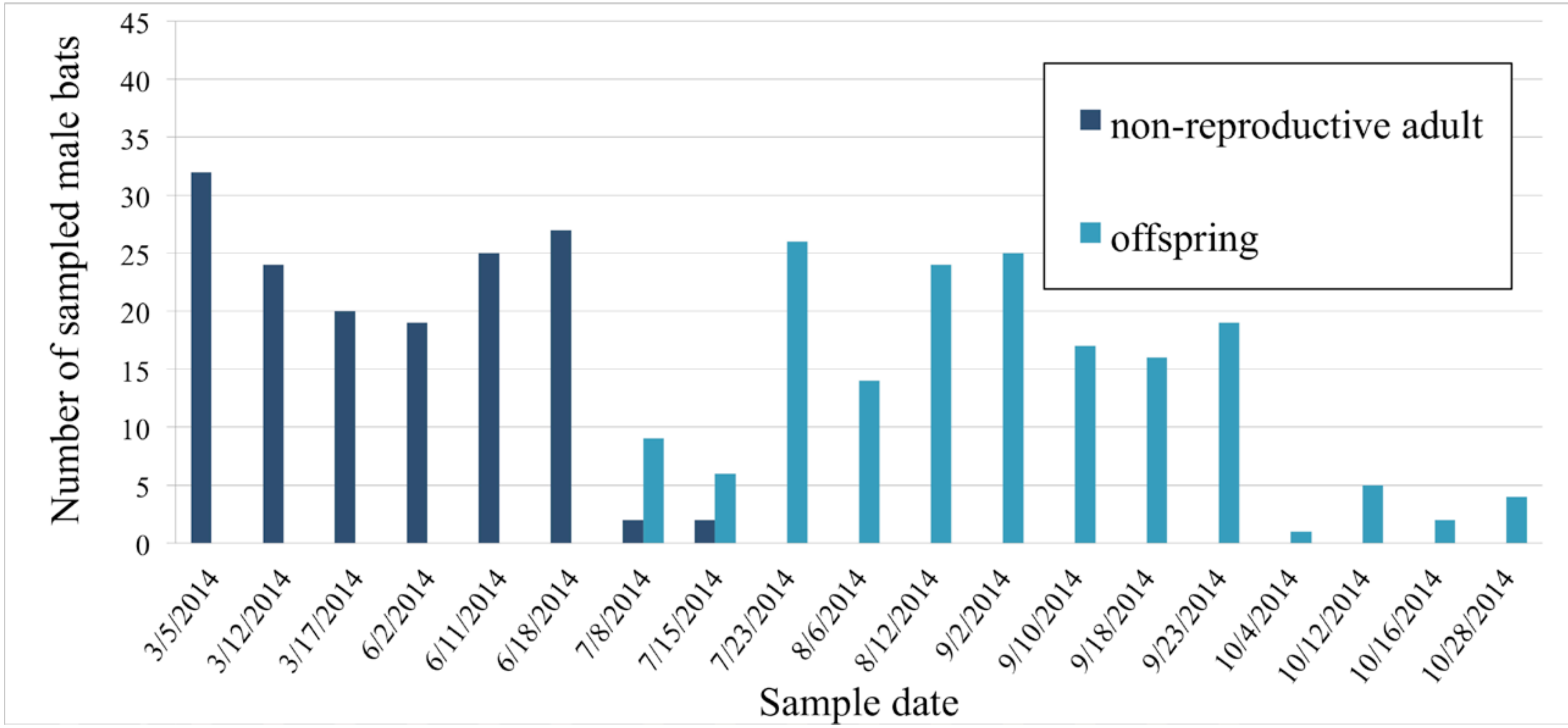

FIG. 6.—Patterns of roost use by male *Tadarida brasiliensis* roosting at the Foster Road overpass, San Angelo, Tom Green Co., Texas. Shown are the frequencies of non-reproductive adult (151 individuals) males, and non-reproductive male offspring (168 individuals) captured at the Foster Road overpass, San Angelo, Tom Green Co., Texas during the months of March-October 2014. Captured total was 319 male bats.

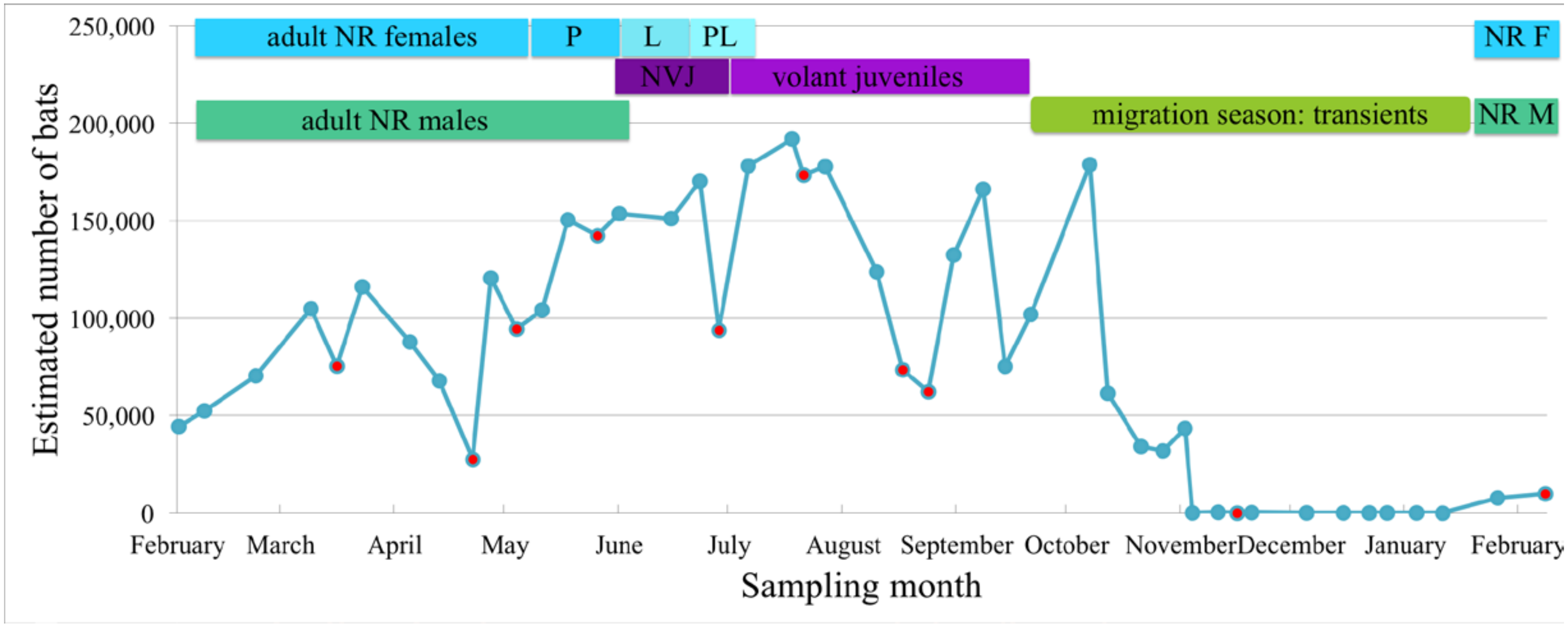

FIG. 7.— Sex and reproductive condition of *Tadarida brasiliensis* roosting in Foster Road overpass, San Angelo, Tom Green Co., Texas relative to seasonal fluctuations in population size from February 2014-February 2015. Bats were not captured in April 2014 or May 2014, however I sampled in April and May 2015 in order to estimate sex ratio during the spring months.

Fluctuations (Fig. 9). In 1995, the highest population count was collected in September with an estimate of 205,236 bats, and the lowest count was recorded in December 1995 with 0 bats; in 2014, the highest population count was collected in August with an estimate of 191,795 bats, and the lowest count was recorded in January 2015 with 0 bats. Results of a randomized t-test suggest that there was no significant difference in roosting population trends between 1995 and 2014 (*P*=0.9106)**.** Similar declines in population numbers were noticed in 1995, and as I observed, these drops in numbers were usually within 48 hr of rainfall. As in 2014, there were larger declines in population during times of rainfall within 48 hrs prior to sampling than during sampling times without rainfall (February 1995-May 1995: F=16.128, *P*=0.006, $\bar{x}$ (without rain)=3.903, $\bar{x}$ (with rain)=-12.225; June 1995-August 1995: F=19.49, *P*=0.014, $\bar{x}$ (without rain)=2.69, $\bar{x}$ (with rain)=-16.80; September 1995-February 1996: F=37.811, *P*=0.073, $\bar{x}$ (without rain)=-4.289, $\bar{x}$ (with rain)=-42.100) (Figure 10). Similarly, roosting numbers in 1995 appeared to recover by the next sampling date as long as there was no record of rainy weather conditions. Results of a randomization test suggested that there was no evidence for a correlation between the amount of precipitation and the severity of decline in roosting population (F =0.404, *P*=0.525). It seems that for both 1995 and 2014, rainfall, regardless of the amount, caused bats to evacuate the overpass and return when roosting conditions bettered. Because of the lack of data for emergence times in 1995, I was unable to compare emergence behaviors between 1995 and 2014.

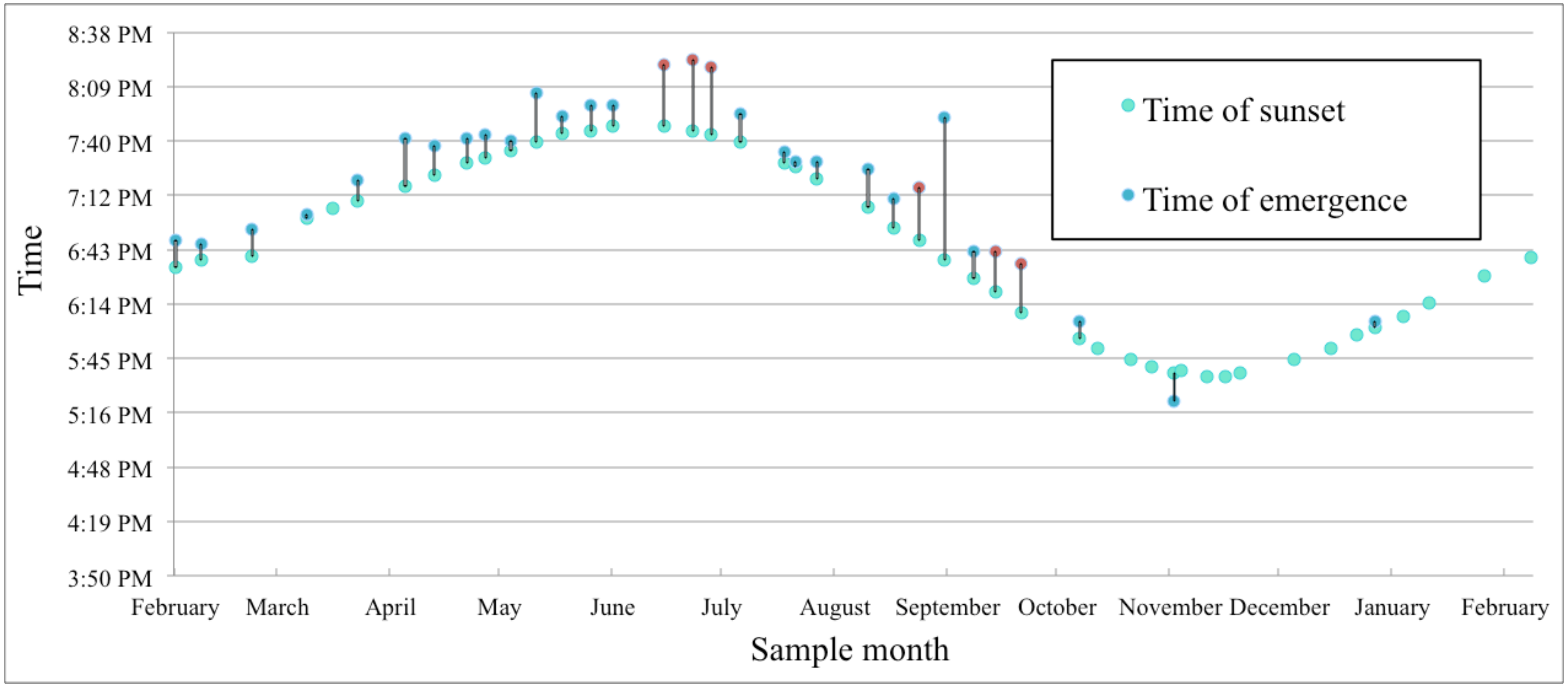

FIG. 8.— Times of sunset and nightly roost emergences for *Tadarida brasiliensis* roosting in Foster Road overpass, San Angelo, Tom Green Co., Texas from February 2014-February 2015. Gaps in emergence times indicate sample dates in which bats did not exit the roost within an hour after sunset. Red dots indicate sample dates in which only scattered group emergences were observed within an hour after sunset. I recorded the initial time for these emergences, although I did not consider them as waves. Daylight savings time was removed.

TABLE 2.— Akaike's Information Criterion (AIC) results in determining the most parsimonious model for logistic regression models analyzing the relationships between nightly emergences (did or did not emerge) of *Tadarida brasiliensis* from Foster Rd. bridge, San Angelo, Tom Green Co., Texas and nightly weather conditions (average daily temperature (°C), average humidity, barometric pressure (mmHg) and precipitation (cm)).

Model	AIC
Temperature+humidity+barometric pressure+rainfall	28.57
humidity+barometric pressure+rainfall	42.87
Temperature+ +barometric pressure+rainfall	29.17
Temperature+humidity+ +rainfall	26.58
Temperature+humidity+barometric pressure	26.96
Temperature+humidity*	25.03
Temperature+ +barometric pressure	27.22
Temperature+ +rainfall	28.18
Temperature*	26.26
humidity	57.49
barometric pressure	39.21
rainfall	60.71
1	60.09

TABLE 3.— Akaike's Information Criterion (AIC) results in determining the most parsimonious model for logistic regression models analyzing the relationships between flight times (minutes after sunset) of *Tadarida brasiliensis* from Foster Rd. bridge, San Angelo, Tom Green Co., Texas and nightly weather conditions (average daily temperature (°C), average humidity, barometric pressure (mmHg) and precipitation (cm)).

Model	AIC
Temperature+humidity+barometric pressure+rainfall	171.17
humidity+barometric pressure+rainfall	170.98
Temperature+ +barometric pressure+rainfall	170.78
Temperature+humidity+ +rainfall	169.19
Temperature+humidity+barometric pressure	169.55
Temperature+humidity	167.55
Temperature+ +barometric pressure	258.95
Temperature+ +rainfall	169.1
Temperature*	167.34
humidity	167.36
barometric pressure	259.85
rainfall	260.04
1	168.2

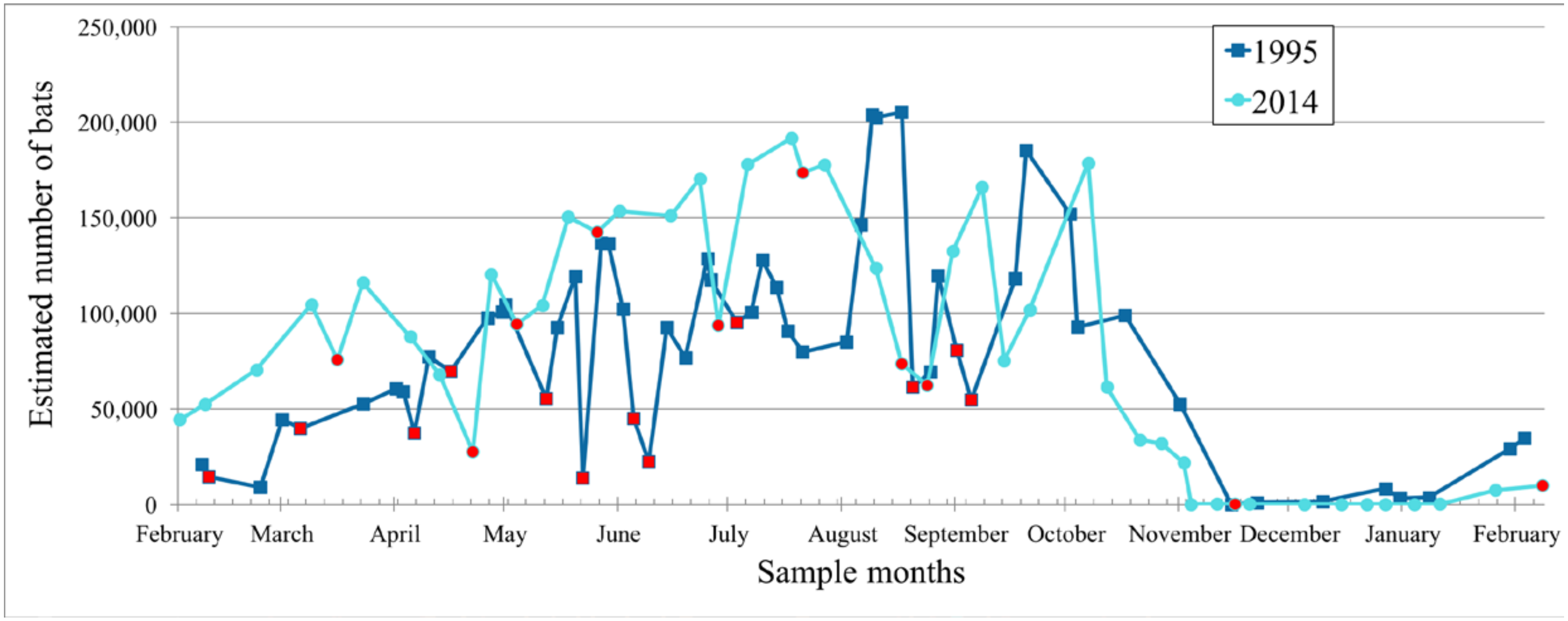

FIG. 9.— Fluctuations in population size of *Tadarida brasiliensis* roosting at the Foster Road overpass, San Angelo, Tom Green Co., Texas in 2014-2015 compared with 1995-1996. Red dots indicate sample dates associated with rainfall events when large numbers of bats were observed to temporarily vacate the overpass due to wet roosting conditions.

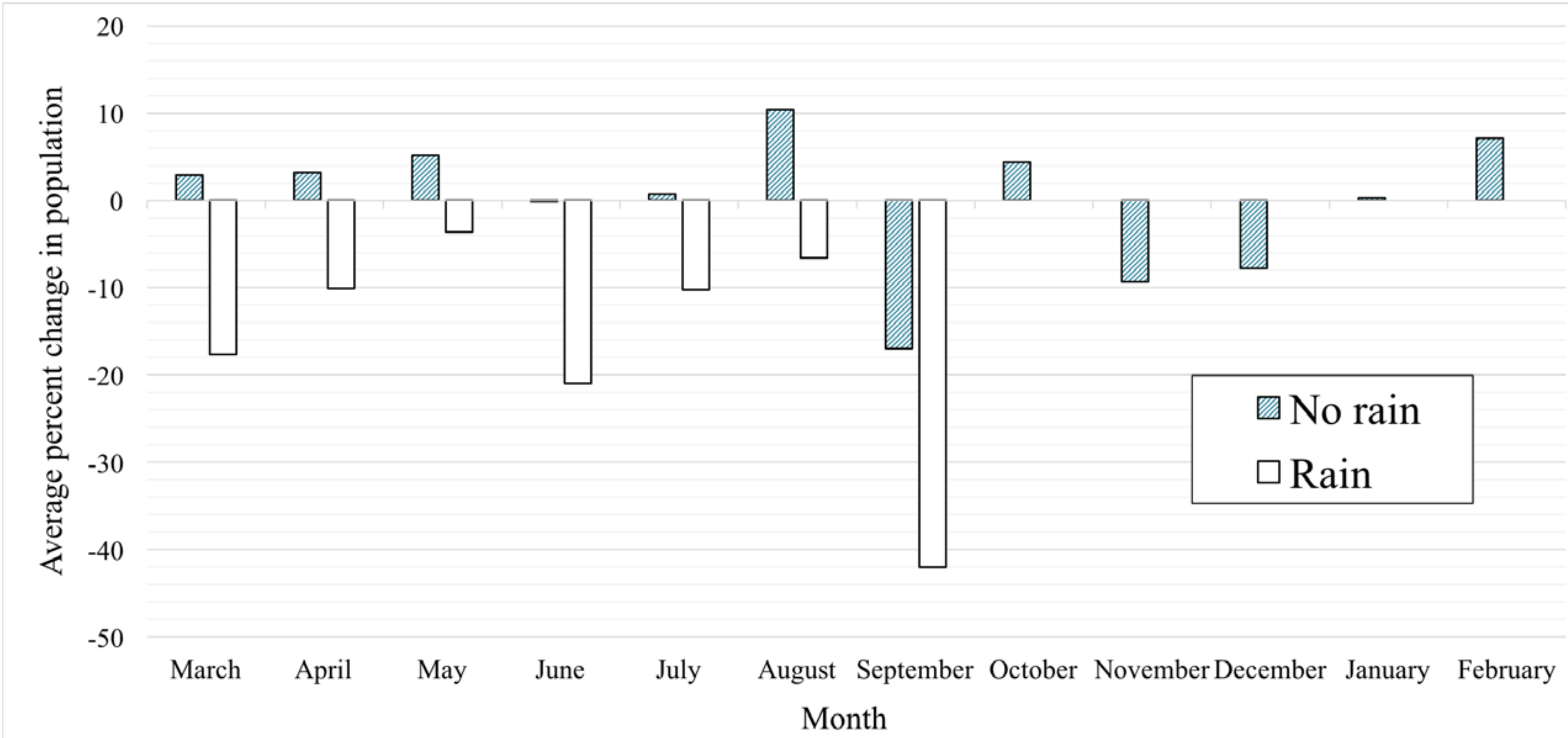

FIG. 10.—Average percentage change in weekly population estimates by month in 1995 with and without rainfall at the Foster Road overpass, San Angelo, Tom Green Co., Texas.

DISCUSSION

My results suggest that Foster Road overpass is used as a stable roost site for *Tadarida brasiliensis* year-round, and seasonal patterns of roost use appear to be consistent across years. Rain events caused roost evacuation although there is no evidence to support that the amount of rainfall was related to the severity of declines in roost occupancy. Bats vacated the overpass and appeared to roost at other sites that offered protection and relief from poor weather conditions when the overpass was wet, and bats returned when roosting conditions at the overpass improved. The amount of rainfall recorded during this study was measured at the weather station, which might have been too far away (5.73 km southwest) from the overpass to report accurate measurements of precipitation that were actually received at the roost location. Future research that measures the direct presence of rainfall at the overpass is needed in order to more accurately determine the relationship between rainfall and roost evacuation. I suggest that the Foster Road overpass is the largest local Brazilian free-tailed bat colony in the Concho Valley, and is able to hold many more bats than at any of the secondary roosts; however, the secondary roosts serve as necessary alternative sites throughout the year.

The few tagged bats seen at the secondary roosting locations during rainfall events suggest that bats roosting primarily at the Foster Road overpass relocate and move among several roosts (other than the three I found) located in and around San Angelo, Texas. Scales and Wilkins (2007) experienced a similar situation in that tagged individuals moved beyond the roosts located in their study area. They suggested that *T. brasiliensis* often use a primary roost, and occasionally switch to other roosts in a local area, but more commonly switch to roosts located outside of the area. Scales and Wilkins (2007) also observed that male bats exhibited a lower percentage of recaptures at switched roosts, suggesting that male bats are more faithful to primary roosts and some secondary roosts within the local area than are female bats. This likely explains why I observed more tagged female bats (14 individuals) than male bats (1 individual) at the secondary roosting locations (Table 1); male bats might have switched to different roosting areas, or might have stayed at the larger roost because some bats were observed roosting at the overpass during rainfall.

Results of model simplification using AIC support that the onset of emergence is influenced by temperature and humidity. I observed bats exiting the overpass later than 20 min after sunset on some sampling dates in June, July, September, and October 2014 (Appendix) when the temperature averaged 30°C and humidity was ≥20%. Frick et al. (2012) and Reichard et al. (2009) suggested that the timing of emergence varies with surface temperatures and that nocturnal moth activity is positively associated with temperatures in that warmer nights correspond with higher prey availability. As such, they predicted that bats could emerge later in the evening on warm nights and still meet energetic needs. Because of warm temperatures (exceeding 27° C) and moderate humidity (≥20%) at sundown during some nights during the months of June-October 2014 (refer to Appendix), it is likely that bats were able to emerge later in the evening and still meet energetic needs.

Flight times close to sunset (avg=10.6 min after sunset) during July and August 2014 likely were because of newly volant offspring and lactating female bats needing to meet increased energetic demands (Lee and McCracken 2001). Kunz and Anthony (1996) noted that newly volant bats had poorer flying ability and suggested that they might have different emergence patterns from those of adults. They noted that young *Myotis lucifugus* (little brown bat) typically began to emerge nightly from their roost at the age of 18-23 days and when they did emerge, they emerged separate from adult bats, most likely to be able to perfect flight and echolocation skills without the acoustic clutter from adults within the first 2 weeks of their first flights. Lee and McCracken (2001) observed high proportions of juvenile Brazilian free-tailed bats emerging early in relative to sunset during mid-summer presumably due to their slower and less agile flight, as well as to minimize acoustic clutter from adults. In contrast, Kunz (1974), Kunz and Anthony (1996) and Duverge et al. (2000) mentioned that when freshly volant, other species of young bats were observed emerging later than adult bats in order to forage without the interference of mature bats, but started to emerge earlier as the bats grew older and their flight skills improved. Reichard et al. (2009) also mentioned in their study that young Brazilian free-tailed bats delayed their emergence flights when freshly volant until they were older and could emerge with adult bats.

In studies concerning emergence times, it was noted that emergence activity of adult bats is influenced by sex and reproductive condition (Humphrey 1971; Lee and McCracken 2001; Reichard et al. 2009; Frick et al. 2012). They noted that high proportions of reproductive Brazilian free-tailed bat females tended to leave early in nightly foraging flights because of the increased demands for energy, water, and nutrients, and in contrast, non-reproductive and post-lactating females and males tended to emerge from the roost later in the evening presumably because they had lower energetic demands. Lee and McCracken (2001) suggested that the advantage to later flight patterns in non-reproductive and/or juvenile bats appeared to be a reduction in the risk of predation, which is particularly important to Brazilian free-tailed bats because their emergence and morning return flights extend into the daylight hours.

Reichard et al. (2009) suggested that precipitation and colder temperatures contributed to nightly disparities of Brazilian free-tailed bats in their study. They observed an emergence that took place 95 mins before expected time one night after 2 nights of colder weather where ambient temperatures were 0.6°C and 2.2°C, respectively. They suggested that since the colder temperatures likely decreased insect availability and limited foraging success, and possibly led to high energy costs associated with thermoregulation, the return to more typical ambient temperatures likely prompted earlier than normal foraging bouts. They also mentioned that although no rainfall occurred on their sample nights, any rain on previous nights may have similar effects on emergence times. I only observed 2 emergences from November 2014-February 2015 (23 November 2014 and 17 January 2015), when temperatures were low (ranging from 1.9°C-13.8°C). It was to be expected that bat emergence activity would be limited, and that bats could compensate for increased energetic costs of colder temperatures by using torpor, and having disparate emergence patterns like I observed on 23 November 2014, when temperatures warmed from previous nights. Although precipitation was not considered a significant predictor of this study, previous studies have reported that heavy rainfall delayed the onset of emergence and decreased nightly activity in many species of insectivorous bats (Erkert 1982; Kunz and Anthony 1996; Thomas and Jacobs 2013). Rain was possibly not selected to be an accurate predictor for the onset of emergence for this study because there was either no or very little rainfall on most of my sampling nights.

Other than some minor fluctuations, roost occupancy trends were similar between 1995 and 2014. I observed that the population data collected in 1995 also showed sharp declines during rainy conditions, suggesting that the bats have been using the behavior of roost evacuation for some time at the overpass. A lack of statistical significance for changes in the September-February group for both years might reflect the natural decline in numbers as bats left the roost for migration season, and as such, samples without rain had similar population decline to samples with rain. Despite rainfall events, the trends in population numbers (increase in numbers from spring into summer with a decline in May and June and high numbers in the fall before migration) I observed at the Foster Road overpass are similar to those seen at other anthropogenic roosts in Texas (Fraze and Wilkins 1990; Sgro and Wilkins 2003;Scales and Wilkins 2007). However, patterns of seasonal activity appeared to differ from those in other studies. In other anthropogenic roosts, females were observed with males in spring through May before departing to maternity roosts to give birth and returning with volant offspring in the fall before migration (Davis and Cockrum 1963; Fraze and Wilkins 1990; Sgro and Wilkins 2003; Keeley and Keeley 2004; Scales and Wilkins 2007). At the Foster Road overpass, I observed many more males than females roosting from early spring into May, with males becoming outnumbered with pregnant females presumably arriving from spring roosts. Females gave birth and left after offspring matured, and volant juvenile offspring left with the fall migration. I suspect that bats that roost at the overpass during the migration and winter months are not summer residents because none of the 761 tagged bats were seen after the end of October 2014. At times, the reflective tape tags fell off prematurely from the bats, usually when and where the bats were roosting. I was able to still note where those bats were roosting when the tags fell off based on where I found the tags on the ground. Many of the bats that lost tags were recaptured (the bats had faded pelage where the tags once were) and tags were reapplied. Recaptured bats were not re-included in the sample.

Keeley and Keeley (2004) suggested that bridge and overpass roosts may serve as ideal sites for courtship and mating during the spring months and that there may be some intrinsic characteristics of bridges that make them favorable sites for mating such as the ability of males to move easily among groups of females roosting in the crevices. During their study, Keeley and Keeley noted that males significantly outnumbered females during the 2 weeks before the mating period (early March 1998) and had descended testes until about 4 weeks after the mating period (21 March-5 April, 1998). I am uncertain if copulation occurs at the Foster Road overpass. If copulation does occur, it most likely occurs in the unreachable sections (II and III) of the overpass, and I was unable to capture any reproductive males.

The Foster Road overpass roost site appears to be a stable and important maternity site during the summer and early fall months. Although there are several known maternity roosts located in caves across Texas (Wilkins 1989), few maternity colonies are located in bridges (Keeley and Tuttle 1999). Known maternity colonies located in bridges include the Ann W. Richards Congress Avenue bridge in Austin, Texas (Keeley and Tuttle 1999, Bloschock 2007), Waugh Drive bridge in Houston, Texas (Keeley and Tuttle 1999; Bloschock 2007), the Salado culvert in Salado, Texas (Keeley and Tuttle 1999; Bloschock 2007), East Elm Creek bridge in Medina County, Texas (Allen et al. 2009; Allen et al. 2011; Turmelle et al. 2010), the Seco Creek Bridge in Uvalde County, Texas (Allen et al. 2009; Allen et al. 2011; Turmelle et al. 2010), the Brandi Lane bridge (Keeley and Keeley 2004), and the McNeil overpass in Round Rock, Texas (Allen et al. 2010, 2011; Turmelle et al 2010).

In Texas, it was thought that limestone caves were probably the structures most used and preferred by Brazilian free-tailed bats as maternity roosts because they have the necessary microclimates to maintain the elevated temperatures required for the development of offspring (Wilkins 1989; Allen et al. 2010; Caire et al. 2014). Caire et al. (2014) suggested that maternity roosts of Brazilian free-tailed bats must have not only suitable microclimates, but also ample roosting space to support thousands of females and their offspring, and access for emergence. Allen et al. (2010), however, reported that bridge roosts in some cases provide better conditions (such as more stable roosting temperatures and easier access to local foraging areas such as well-lit parking lots and croplands) for raising bat pups than cave roosts.

Over the past few decades, Brazilian free-tail bats have begun to rear pups in the crevices of pre-cast concrete bridges, suggesting that there are certain benefits from roosting in bridges in spite of potential drawbacks such as noise pollution, air pollution, and human disturbance (Horn and Kunz 2008; Allen et al. 2010). Horn and Kunz (2008) suggested that such benefits could include warmer and more stable temperatures, as well as a reduction in competition for roosting space. Allen et al. (2010) also observed that adult reproductive female bats living in bridges appeared to be in better body condition (lower ectoparasite loads, lower cortisol levels, and larger body size) than those bats living in caves (Allen et al. 2009; Allen et al. 2010; Allen et al. 2011). Allen et al. (2010) suggested that bats living under bridges have shorter nightly foraging commutes (closer proximity to prime foraging sites in agricultural areas) than those roosting in caves, which would allow pregnant females to allocate more resources for fetal growth and milk production and spend less energy on foraging. As such, pups born and raised in bridge roosts tend to be larger at birth and grow at a faster rate than pups born at cave roosts (Allen et al. 2010).

Although the Foster Road overpass meets previously reported preferences for roosting Brazilian free-tailed bats such as roosting crevices that are at least 2.0-2.5 cm wide and 30.5 cm or greater in depth constructed from concrete at least 3 m from the ground (Foster Road overpass roosting crevices are 4.97 m from the ground) (Keeley and Tuttle 1999), the overpass is not habitable during rainy conditions. Only volant bats are able to vacate during rainy weather and non-volant bats and bats that remain at the roost are susceptible to death during heavy precipitation, particularly during times of rainfall accompanied with cold temperatures. The lack of an efficient drainage design is the cause for storm-water draining from the overpass' joint openings, making roosting areas uninhabitable during rainy weather conditions (Carmichael and Gager 2009).

The Foster Road overpass is structured with open-type concrete crevices that lack efficient joint sealers that would otherwise prevent storm-water drainage below the bridge deck. G. Enos (San Angelo District Design and Bridge Engineer at Texas Department of Transportation) mentioned that the crevices between the box beam spans at the overpass were fixed during construction and that the overpass does not actually have expansion joints (Fig. 11). He explained during an interview (16 April 2015) that the joint seals to prevent storm-water drainage must have degraded over the years due to lack of maintenance. Despite a lack of a drainage structure, it seems that the bats have adopted behaviors in order to minimize the effects of rain conditions at the overpass.

In Texas, the increasing population of Brazilian free-tailed bats in urban areas could have economic benefits, especially in west and central parts of the state where cotton farming is prevalent, because Brazilian free-tailed bats are known to consume agricultural pests (Cleveland et al. 2006; Maxwell 2013). During this study, I never observed the overpass at 100% occupancy. This could be because some areas of the overpass might not be available to the bats for roosting as a result of the lack of maintenance within the expansion joint openings such as the sections that have peeling and falling wood that was part of the original foundation of the overpass that continue to erode. I believe that renovating the expansion joint crevice openings will improve the accessibility of these areas and will allow for more roosting space for bats. I also suggest that rehabilitation of the Foster Road overpass is needed so that it will drain storm-water properly. Furthermore, I believe that further investigation into the microclimates used by bats in the overpass, and an of mortality rates during rainfall events are needed in order to more thoroughly understand how *T. brasiliensis* are using this urban roost site.

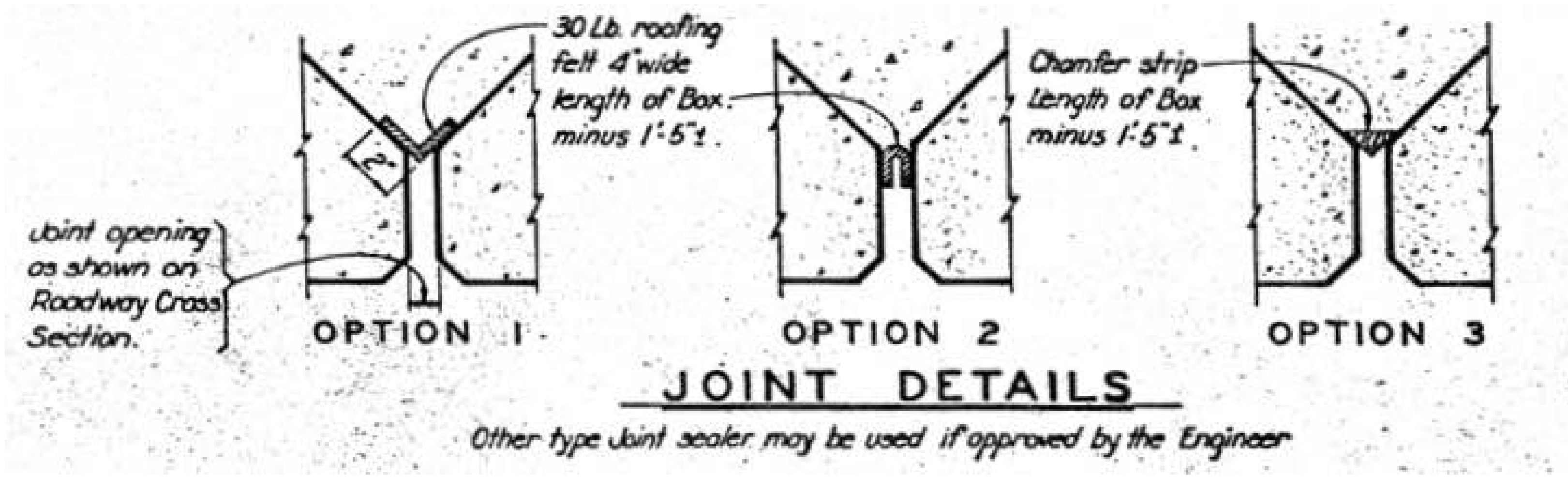

FIG. 11.—The Foster Road overpass joint opening details from the original construction plans supplied by the Texas Department of Transportation. The joint sealer used to prevent storm-water drainage has degraded from years of not being properly maintained. Joint sealer can be reapplied to stop storm-water from draining into the crevices where the *Tadarida brasiliensis* roost.

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APPENDIX

Estimated occupation percentage, estimated number of bats, time of sunset, onset of emergence, average daily temperature, temperature at emergence, average humidity, barometric pressure, and amount of precipitation (National Weather Services), for each sampling date at the Foster Road overpass from February 2014-February 2015. Missing values indicate dates when I did not observe any roost exit, and bolded emergence times indicate dates in which only small, scattered emergences were (instead of an initial mass emergence wave) observed.

Date	Estimated occupation percentage	Estimated number of bats	Time of sunset	Onset of emergence (minutes after sunset)	Average daily temperature (°C)	Temperature at emergence (°C)	Humidity	Barometric pressure (mmHg)	Precipitation (cm)
2/22/2014	20.4%	44,360	6:34 PM	14	18.61°	25°	17%	29.79	0.00
3/1/2014	24.5%	52,373	6:40 PM	6	21.39°	26.11°	18%	29.82	0.00
3/15/2014	32.4%	70,372	7:40 PM	14	15.56°	21.11°	19%	29.71	0.00
3/30/2014	48.1%	104,581	8:00 PM	2	20.28°	23.89°	25%	29.89	0.00
4/6/2014	34.8%	75,531	8:05 PM	-	13.33°	-	67%	29.83	0.43
4/13/2014	53.5%	116,050	8:09 PM	11	19.44°	28.33°	18%	29.61	0.00
4/26/2014	40.4%	87,589	8:17 PM	25	20.56°	28.89°	36%	29.51	0.00
5/4/2014	31.2%	67,768	8:23 PM	15	26.11°	31.67°	7%	29.85	0.00
5/13/2014	12.7%	27,549	8:29 PM	13	11.11°	11.67°	69%	30.28	0.20
5/18/2014	55.4%	120,446	8:32 PM	12	25.28°	30°	26%	29.86	0.00
5/25/2014	43.4%	94,297	8:36 PM	5	20.83°	20°	34%	29.78	6.00
6/1/2014	48.0%	104,185	8:40 PM	26	28.06°	31.67°	68%	29.94	0.00
6/8/2014	69.2%	150,371	8:45 PM	9	26.39°	26.67°	58%	29.85	0.00
6/16/2014	65.8%	142,277	8:46 PM	14	27.78°	29.44°	44%	29.86	0.53
6/22/2014	70.6%	153,463	8:49 PM	11	26.94°	29.44°	58%	29.78	0.00
7/6/2014	69.5%	151,027	8:49 PM	**32**	27.78°	32.22°	32%	29.90	0.00
7/14/2014	78.9%	170,332	8:46 PM	**38**	30°	33.89°	21%	29.89	0.00
7/19/2014	43.1%	93,689	8:44 PM	**36**	27.78°	28.89°	72%	29.90	1.50

Date	Estimated occupation percentage	Estimated number of bats	Time of sunset	Onset of emergence (minutes after sunset)	Average daily temperature (°C)	Temperature at emergence (°C)	Humidity	Barometric pressure (mmHg)	Precipitation (cm)
7/27/2014	82.4%	177,907	8:40 PM	15	30.84°	35.56°	35%	30.00	0.00
8/8/2014	87.3%	191,795	8:29 PM	6	31.39°	36.67°	21%	29.81	0.00
8/11/2014	79.8%	173,500	8:27 PM	3	28.89°	23.89°	57%	30.02	0.03
8/17/2014	81.9%	177,685	8:21 PM	9	28.89°	27.22°	63%	29.92	0.00
8/31/2014	57.5%	123,622	8:06 PM	20	29.44°	34.44°	33%	29.82	0.00
9/7/2014	33.8%	73,447	7:55 PM	15	24.44°	26.67°	60%	30.01	0.03
9/14/2014	28.6%	62,244	7:48 PM	**28**	25.56°	27°	69%	30.10	0.03
9/21/2014	61.1%	132,375	7:38 PM	75	24.17°	27.22°	56%	30.01	0.00
9/29/2014	76.5%	166,073	7:28 PM	14	23.61°	27.78°	39%	29.91	0.00
10/5/2014	34.7%	75,227	7:21 PM	**21**	21.67°	32.78°	20%	29.71	0.00
10/12/2014	48.0%	101,821	7:10 PM	**26**	22.78°	27.22°	44%	29.65	0.00
10/28/2014	82.2%	178,618	6:56 PM	9	19.44°	23.33°	38%	30.04	0.00
11/2/2014	28.3%	61,373	5:51 PM	-	20°	-	50%	30.06	0.00
11/11/2014	15.6%	33,865	5:45 PM	-	6.67°	-	39%	30.17	0.00
11/17/2014	14.7%	31,862	5:41 PM	-	1.67°	-	27%	30.44	0.00
11/23/2014	20.0%	43,446	5:38 PM	-5	12.22°	21.67°	19%	29.61	0.00
11/25/2014	0.0%	45	5:39 PM	-	10°	-	21%	30.24	0.00
12/2/2014	0.0%	145	5:36 PM	-	10.28°	-	70%	30.14	0.00

Date	Estimated occupation percentage	Estimated number of bats	Time of sunset	Onset of emergence (minutes after sunset)	Average daily temperature (°C)	Temperature at emergence (°C)	Humidity	Barometric pressure (mmHg)	Precipitation (cm)
12/7/2014	0.0%	25	5:36 PM	-	10°	-	65%	30.25	0.08
12/11/2014	0.0%	160	5:38 PM	-	15.28°	-	75%	30.11	0.00
12/26/2014	0.0%	50	5:45 PM	-	13.89°	-	28%	29.79	0.00
1/5/2015	0.0%	0	5:51 PM	-	7.5°	-	36%	30.39	0.00
1/12/2015	0.0%	0	5:58 PM	-	2.78°	-	88%	30.40	0.00
1/17/2015	0.0%	20	6:02 PM	3	10.56°	17.78°	21%	30.17	0.00
1/25/2015	0.0%	25	6:08 PM	-	10.28°	-	29%	30.22	0.00
2/1/2015	0.0%	105	6:15 PM	-	5.28°	-	59%	30.15	1.32
2/16/2015	3.4%	7,509	6:29 PM	-	8.06°	-	45%	30.12	0.00
3/1/2015	4.5%	9,893	6:39 PM	-	1.94°	-	93%	30.29	0.08

BIOGRAPHY

Stephanie G. Martinez attended Abilene Christian University in Abilene, Texas from August 2008 to August 2013 where she earned a Bachelor of Science in Biology. As an undergraduate, Ms. Martinez took part in the McNairs Scholar program and conducted individual research with Dr. Thomas E. Lee, Jr. involving a small population of urban *Tadarida brasiliensis*. The results of this study were presented at Texas Society of Mammalogists held in Junction, Texas as a poster, and it later was published by the Southwestern Naturalist in December 2013. Ms. Martinez then continued her education at Angelo State University from June 2013 to December 2015 where she earned a Master of Science degree in Biology. During her time at Angelo State University, Ms. Martinez attended the Texas Society of Mammalogists, the Southwestern Association of Naturalists and the North American Symposium for Bat Research meetings for two consecutive years where she presented the results of this thesis project. This thesis was written and completed to fulfill thesis requirements for that M. S. program.