Use of Box-Beam Bridges as Day Roosts by Mexican Free-tailed Bats (*Tadarida brasiliensis*) in Texas

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Use of Box-beam Bridges as Day Roosts by Mexican Free-tailed Bats (*Tadarida brasiliensis*) in Texas

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Abstract - Bridges provide roost structures for bats in temperate regions of the US, including Texas, where *Tadarida brasiliensis* (Mexican Free-tailed Bats) are common occupants. In March 2018, we documented 1 Mexican Free-tailed Bat with *Pseudogymnoascus destructans*, the fungal causative agent of white-nose syndrome (WNS), in an artificial structure in Texas, thus making the ability to quantify their movements and occupancy critical for understanding WNS ecology. To determine which attributes influenced day-roosting activity by Mexican-Free-tailed Bats, we surveyed for roosting bats 70 box-beam bridges in 21 Texas counties and collected structural, weather, and landscape-characteristic data. We analyzed the data with a stepwise multiple logistic regression model to isolate variables significantly correlated with presence of day-roosting Mexican Free-tailed Bats. Of 70 bridges sampled, 14 (20%) contained day-roosting Mexican Free-tailed Bats and 17 (24%) bridges had signs indicating bat use. In the best-fitting logistic regression model, bridge width, number of spans, and elevation had a positive influence on bat occupancy, whereas average temperature for the month of July 2016 negatively influenced bat occupancy. Bridge age also had a positive influence on bat occupancy, but the effect lessens in older bridges. These data show that structural and environmental characteristics are significant predictors of bridge use by Mexican Free-tailed Bats.

Introduction

Bats in temperate regions roost in both natural (e.g., caves) and artificial (e.g., bridges and buildings) structures (Kunz 1982). Artificial structures have become available to bats recently in evolutionary history. With increasing human activity, these structures have become abundant across the landscape, increasing the availability and diversity of roosting opportunities, serving as surrogates for disturbed or lost natural sites due to human development, and expanding the geographic range of cave-roosting bats into areas without natural caves (Kunz 1982). Roosts protect

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bats during more than half of each day when bats are off the wing and vulnerable to predation (Altringham 1996, Ferrara and Leberg 2005, Kunz 1982, Kunz and Lumsden 2003,Tidemann and Flavel 1987). Favorable roosts provide a thermally stable environment by retaining heat or by preventing the heat loss bats gain by clustering to conserve energy (Kurta 1985, 1986; Trune and Slobodchikoff 1976), and where bats receive protection from adverse weather (Vaughan 1987, Vaughan and Vaughan 1986). Predator avoidance can be accomplished by roosting in narrow, high spaces (Hutchinson and Lacki 2000, Riskin and Pybus 1998), and darker locations that make bats less visible (Riskin and Pybus 1998). Furthermore, some artificial and natural roosts offer conditions that are favorable for mating and rearing of young, with colonial species requiring that roosts hold numerous individuals (Kunz 1982).

Bats use concrete bridges as maternity roosts (Perlmeter 1996), night roosts (Adam and Hayes 2000, Hirschfeld et al. 1977), and day roosts (Bennett et al. 2008, Davis and Cockrum 1963, Felts and Webster 2003, Ferrara and Leberg 2005, Keeley and Tuttle 1999, Lance et al. 2001). The large thermal mass, relative permanence, and capacity to shelter large numbers of bats are potential advantages of bridges as roosts (Trousdale and Beckett 2004). Twenty-four of 45 US bat species have been documented using bridge structures as day and night roosts, yet only an estimated 1% of US highway structures provide ideal day-roost conditions (Keeley and Tuttle 1999). Box-beam bridges with open expansion-joints are used more than any other kind of bridge as day-roosts as they provide numerous crevices of suitable width (Adam and Hayes 2000, Davis and Cockrum 1963, Feldhamer et al. 2003, Keeley and Tuttle 1999). Thus, these bridges can also aid in the spread of *Pseudogymnoascus destructans*, the causative agent of the bat disease, white-nose syndrome (WNS) (Lorch et al. 2011). This threat is greatest along the leading edge of the WNS spread, as these bridges may allow for colony sites to exist in areas that otherwise cannot sustain colony sites in caves.

Tadarida brasiliensis (I. Geoffroy) (Mexican Free-tailed Bat) is one of the most abundant insectivorous bats in the Western Hemisphere (McCracken et al. 1994, Wilkins 1989), and the most common bat species in Texas (Ammerman et al. 2012). They are common bridge-dwellers across the southern US (Keeley and Tuttle 1999, Krutzsch 1955, Scales and Wilkins 2007). In Texas, large colonies of Mexican Free-tailed Bats use expansion joints and other crevice features of highway bridges for their daytime roosts (Keeley and Keeley 2004, Keeley and Tuttle 1999). Although surveys of bridge use by bats has been conducted in Texas (Keeley and Keeley 2004, Keeley and Tuttle 1999, Krutzsch 1955), those studies did not focus on characteristics of day-roost selection of Mexican Free-tailed Bats. Furthermore, with the recent discovery of *P. destructans* on a Mexican Free-tailed Bat in Texas (TPWD 2018) and the rapid expansion of the Mexican Free-tailed Bat range into areas infected with WNS (McCracken et al. 2018), it is crucial to understand how these bats are utilizing bridge structures. Therefore, to learn about the use of box-beam bridges as day roosts, we compared selected attributes of bridges and environmental characteristics of both occupied and unoccupied sites to identify variables that may facilitate bat occupancy. This research will provide insight into conservation efforts of bat colonies occupying bridges, and site selection and design choices of bridges for future planning and management.

Study Area

We selected 21 eastern and southeastern Texas counties (Bee, Brazos, Burleson, Dallas, Ellis, Freestone, Goliad, Hardin, Jasper, Jefferson, Kaufman, Kenedy, Liberty, Live Oak, Madison, Milam, Navarro, Newton, Robertson, San Patricio, Tyler; Fig. 1) to study use of box-beam bridges by Mexican Free-tailed Bats because they contained concentrations of bridges with the box-beam design (Fig. 2). Our study

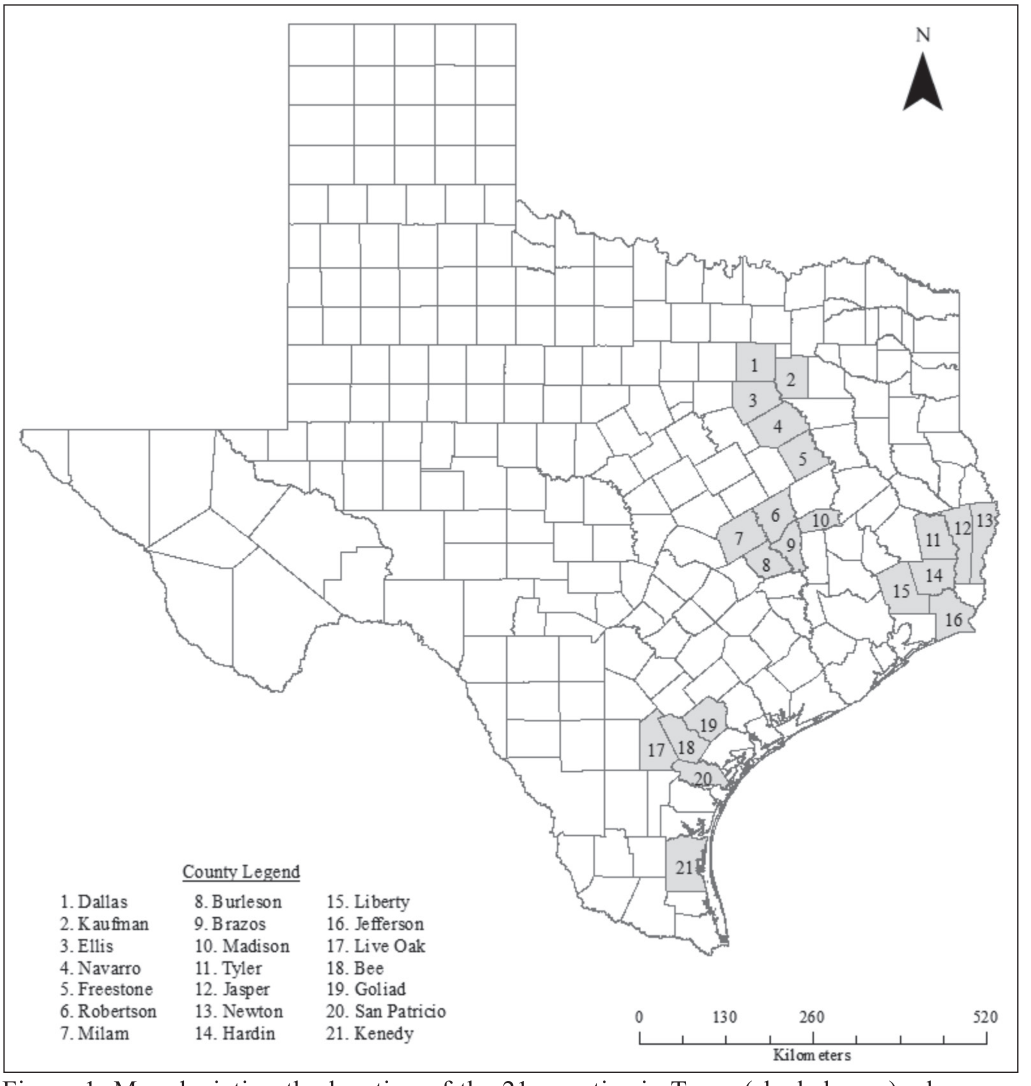

Figure 1. Map depicting the location of the 21 counties in Texas (shaded gray) where we surveyed box-beam bridges between 2 June 2016 and 5 August 2016 for roosting Mexican Free-tailed Bats.

area in east and southeast Texas spanned 12 level-II land-use types, which included commercial and services; cropland and pasture; deciduous forest land; evergreen forest land; herbaceous rangeland; industrial; mixed-forest land; mixed rangeland; mixed urban or built-up; other urban or built-up; residential; and transportation, communications, and utilities (Anderson et al. 1976).

Materials and Methods

We obtained bridge-locality information from the Texas Department of Transportation (TxDOT) bridge database and identified bridge designs likely to have attributes, such as expansion joints, suitable for roosting bats (Adam and Hayes 2000, Davis and Cockrum 1963). From the subset of available bridges (n = 2398), we randomly selected and surveyed 70 concrete, standard box-beam bridges from 2 June 2016 through 5 August 2016.

At each bridge location, we conducted visual surveys between 08:00 and 18:00 for Mexican Free-tailed Bats. A bridge survey consisted of 1 or more investigators visually scanning the underside of the bridge for bats and/or signs of urine staining and guano (Keeley and Tuttle 1999). Depending on the height of the bridge, we used a Black Diamond Icon Headlamp (200 Lumen) or Supernight LED flashlight (17200 Lumen) to illuminate the crevices to locate bats. Mexican Free-tailed Bats typically roost in large colonies; thus, we were able to positively identify bridges where bats were present (Keeley and Tuttle 1999), but we could not accurately estimate or count the number of bats occupying each bridge surveyed due to the variation in bridge size and the depth of crevices. Of the bats documented, we could only identify Mexican Free-tailed Bats with confidence because, to reduce disturbance, we did not remove bats from bridges.

We gathered structural characteristics (i.e., year of bridge construction, length and width of bridge, number of spans, construction material) from the TxDOT bridge database. We considered crevices ideal for roosting bats if they were 0.25–3.0 cm wide and ≥30-cm deep (Keeley and Tuttle 1999). We documented any obstruction (e.g., vegetation) to bat flyways and percentage (%) of the bridge obstructed within 3 m of the bridge (Keeley and Tuttle 1999). We used bridge localities and US Geological Survey (USGS) GIS layers to gather additional information on level II land-use (Anderson et al. 1976) and elevation (meters above sea level) for each site (Table 1). We also obtained average monthly temperature data for June, July, and August from the PRISM Climate Group dataset (http://www.prism.oregonstate.edu/). We determined the distance to water source (e.g., creek, river, stream) at each bridge when water was

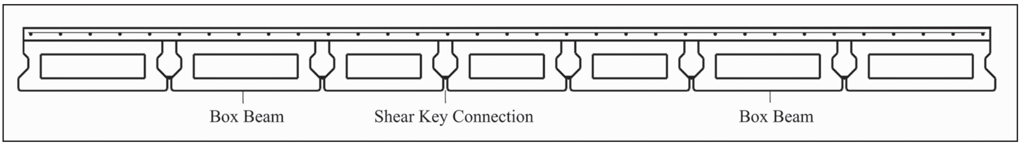

Figure 2. Transverse section of a standard box-beam bridge. Examples of a box beam and a shear-key connection are identified. Figure adapted from Texas Department of Transportation (TxDOT) blueprint of pre-stressed concrete box-beam spans.

Table 1. Descriptions, values or units of measure, and means or frequencies of landscape features, bridge characteristics, and climatic conditions evaluated as potential determinants of Mexican Free-tailed Bat occupancy of bridges in Texas. We modeled bridge age as a quadratic variable (bridge age x bridge age) because of its nonlinearity. We deleted 2 potential determinants (vegetation near bridge and bridge design) which exhibited no variation among the bridges sampled. All vegetation near bridges provided open flight paths and design of all bridges was box beam.

Variable	Definition; value or unit of measure	Mean (min–max) or frequency
Landscape features		
Land use	Land use for level-2 habitat type;	
	1—commercial and services	2
	2—cropland and pasture	30
	3—deciduous forest land	8
	4—evergreen forest land	6
	5—herbaceous rangeland	2
	6—industrial	1
	7—mixed forest land	9
	8—mixed rangeland	4
	9—mixed urban or built-up	1
	10—other urban or built-up	2
	11—residential	3
	12—transportation, communications, and utilities	2
Elevation	Elevation; m	89.14 (2–165)
Distance to water	Distance to water from the bridge; m	154.01 (0–1457)
Flowing water	If water was present at the bridge and flowing;	
	Yes	39
	No	31
Standing water	If water was present at the bridge and standing;	
	Yes	5
	No	65
Bridge characteristics		
Bridge width	Width of bridge; m	20.80 (7.92–32.31)
Bridge length	Length of bridge; m	62.33 (12.19–708.66)
Number of spans	Number of spans	3.47 (1–47)
Bridge age	Years	21.53 (3–87)
Concrete	Was the bridge mainly concrete;	
	Yes	69
	No	1
% obstructed	Obstructed percentage on either side of bridge by vegetation; %	1.71 (0.00–40.00)
Obstruction type	If the obstruction type was vegetation;	
	Yes	5
	No	65
Ideal crevices	If crevices fell within these measurements: 0.25–3 cm wide, ≥ 30 cm deep;	
	Yes	63
	No	7
Climatic conditions		
June 2016 temp.	Average temperature for the month of June 2016; C°	27.42 (26.17–28.16)
July 2016 temp.	Average temperature for the month of July 2016; C°	29.70 (28.47–30.63)
August 2016 temp.	Average temperature for the month of August 2016; C°	28.61 (27.45–29.53)

visibly present. If we could not determine a water source on site, we used GIS layers containing water features (e.g., rivers, streams, lakes) to obtain distance from the bridge to the nearest water source. We considered only major water features that we were confident retained water year-round.

Potential predictors of bridge occupancy

We used landscape features, bridge characteristics, and climatic conditions described in Table 1 as potential explanatory variables promoting bat occupancy under bridges during summer months (June, July, and August) in Texas. We evaluated landscape, weather, and bridge characteristics as determinants of bat occupancy via stepwise multiple logistic regression (Hosmer et al. 2013). As in ordinary regression, collinearity among the explanatory variables can cause problems with parameter estimates and standard errors in multiple logistic regression. To avoid possible collinearity, we used multiple logistic regression to remove most insignificant terms with the highest *P*-value and a large standard error (Gan et al. 2009; Table 1). We then re-estimated the model until the Akaike information criterion score (AIC) (Akaike 1998) and Bayesian information criterion score (BIC) (Schwarz 1978) could not be lowered further. For each of the remaining variables, we calculated the estimated odds ratio which indicated the change in the probability of bat occupancy under bridges that would result from a 1-unit change in the value of the indicated variable. We used Hosmer and Lemeshow's test to check for the model's overall goodness-of-fit. We evaluated the reliability and validity of our models as fair ($0.50 < AUC \leq 0.75$), good ($0.75 < AUC \leq 0.92$), very good ($0.92 < AUC \leq 0.97$), or excellent ($0.97 < AUC \leq 1.00$) based on the value of AUC (Hosmer et al. 2013). We conducted all statistical analyses in SAS 9.4 (SAS Institute Inc. 2013).

Results

We surveyed 70 bridges: 24 in June, 24 in July, and 22 in August 2016. Of the 70 randomly selected box-beam bridges surveyed for presence of Mexican Free-tailed Bats, 14 (20%) were occupied at the time of survey and 17 (24%) showed signs of use by bats. We documented 13 occupied bridges in June, 1 occupied bridge in July, and no occupied bridges in August.

In the final model (L), both AIC and BIC reached their respective minimums (AIC = 26.20, BIC = 40.09; Table 2) after 11 variables had been removed. Hosmer and Lemeshow's goodness-of-fit test indicated no significant difference ($P = 0.43$) between observed and model-predicted occupancy values based on the final model (L). The AUC score of the model was 0.98, which indicated an excellent ability to discriminate between presence and absence of bats. The overall model classified 91% of the bridges correctly regarding presence and absence of bats.

Results of logistic regression indicated the probability of bat occupancy was correlated (estimated odds ratios in parentheses) positively with bridge width (2.4), number of spans (3.3), elevation (1.1), and bridge age x bridge age (1.0) with gradually weaker influence on older bridges, and correlated negatively with and average temperature for the month of July (<0.001) (Table 3). For example, a 2-m increase in bridge width would make occupancy 6.6 times more likely, whereas a 2-y increase in bridge age would make occupancy only 0.776 (1 – 0.112 – 0.112) as likely, after controlling for the other variables.

Discussion

Mexican Free-tailed Bats were more likely to occupy wider box-beam bridges with a greater number of spans. Bats might select roosting sites at larger bridges because these structures provide greater protection from predators and increase roosting potential with more roosting crevices (i.e., availability of crevices and rough substrate) (Ferrara and Leberg 2005, Keeley and Tuttle 1999, Tidemann and Flavel 1987), thus increasing the potential for bats that roost in large congregations, such as the Mexican Free-tailed Bat, to use the bridge as a roost.

Table 2. Results of multiple logistic regression modeling to evaluate landscape and environmental variables as potential determinants of Mexican Free-tailed Bat occupancy of bridges in Texas. Variables are listed in the order they were removed; once removed from the model, we did not return that variable to the model. The minimum value of the Akaike information criterion score (AIC) and Bayesian Information Criterion score (BIC) is indicated by an asterisk (*).

Variable removed	AIC	BIC
None	350.35	420.05
Land use	45.35	81.32
June temperature 2016	43.37	77.09
Concrete	41.37	72.85
Standing water	39.37	68.60
% obstructed	37.37	64.35
Ideal vrevices	35.38	60.12
Obstruction type	33.39	55.87
Distance to water	31.52	51.75
Flowing water	29.57	47.55
August temperature 2016	27.60	43.34
Bridge length	26.60*	40.09*
Number of spans	31.24	40.45
Elevation	34.52	41.35

Table 3. Potential determinants of Mexican Free-tailed Bat occupancy of bridges in Texas as indicated by results of stepwise multiple logistic regression. The estimated odds ratio indicates the change in the probability of bat occupation under bridges that would result from a 1-unit change in the value of the indicated variable. For example, a 1-unit increase in the number of spans signifies that occupation is 3.3 times more likely than before, after controlling for the other variables.

				Odds ratio 95% CI	
Variable	Coefficient	SE	Odds ratio	Lower	Upper
Elevation	0.0895	0.0639	1.094	0.965	1.240
Bridge width	0.8854	0.5999	2.424	0.748	7.855
Number of spans	1.1901	0.9647	3.287	0.496	21.778
Bridge age × bridge age	0.0014	0.0010	1.001	0.999	1.003
July temperature 2016	−8.7281	5.2891	<0.001	<0.001	5.148

Furthermore, larger bridges sustain a diversity of microclimates that provide bats with thermoregulatory benefits (Ferrara and Leberg 2005). By design, box-beam bridges have 1.5-in longitudinal gaps between spans (TxDOT 2006). These gaps, which can be from 2.54–12.7 cm (1.0 to 5.0 in) in length (TxDOT 2006), are crevices in which bats are found roosting (Keeley and Tuttle 1999).

Our results suggest that higher elevation is a positive predictor of bridge use by Mexican Free-tailed Bats. Although we surveyed bridges across a breadth of geography, our elevation range was limited (2–165 m; Table 1) because of our survey-site selection. According to the TxDOT bridge database, the box-beam bridge design is used predominantly in eastern Texas where the elevation does not exceed 200 m; across Texas, elevation can range from 0 m (sea level) to 2667 m. This wide range in elevation may differentially affect the use of box-beam structures across the landscape. Therefore, our results suggesting a correlation between elevation and bridge use likely varies by region and may or may not play an important factor in roost occupancy across the state.

We found a positive relationship between bridge age and bat presence, with the effect lessening in older bridges. This finding is similar to previous literature whereby bridges occupied by bats in Florida were significantly older than bridges without bats (Gore and Studenroth 2005). Reasons for this may include dissimilarity in roosting opportunities within the adjacent landscape (Trousdale et al. 2008) as landscape connectivity may influence animal distributions and movements (Henry et al. 2007). However, Hendricks et al. 2005 reported use of bridges for roosting was generally unrelated to the landscape within 3 km of the structure. Structurally, newer bridges may have less roosting opportunities, as older bridges experience more weathering or heaving vibrations leading to grouting between stones falling out, increasing overall roosting potential.

We found that monthly temperature for July was a negative predictor of bat occupancy. Previous research has suggested that day-roosting bats choose roosts with reduced temperatures, especially during warm weather (Hutchinson and Lacki 2001, Kerth et al. 2001, Riskin and Pybus 1998, Vonhof and Barclay 1997). July had the hottest documented ambient temperatures of any month in our study (Table 1); thus, heat retention may have been greater for those bridges surveyed as well as natural roosts. We conducted surveys once at each site over 3 months. We visited each site only once in July ($n = 24$); bats may have been absent at the time of our surveys due to other factors (e.g., elevation, geographic location). We suggest further bridge surveys be conducted with repeat visits to understand how ambient temperature may influence bridge use seasonally.

Pressure on natural roost sites for bats may increase as the human population in Texas increases. More infrastructure projects are planned to support this growth, which could increase the use of bridges by bats as roosting structures into areas where bats were not previously documented. Furthermore, the use of bridges by bats is likely helping to expand the distribution of Mexican Free-tailed Bats into areas with natural caves and other bats that are susceptible to WNS (McCracken et al. 2018). The movement of Mexican Free-tailed Bats into

WNS-positive sites could hasten the spread of disease by moving the fungus into new, previously uninfected areas, such as the western US or Central America. As a result, additional species may become at risk of disease, or may become carriers for the fungus. With this in mind, it is crucial that we place importance on understanding the structural and environmental factors that influence bat bridge-roosting preferences. This information could contribute to the understanding on how WNS may spread with the aid of anthropogenic infrastructure. Moreover, this information could inform the planning of lasting wildlife-management projects and infrastructure development, which has a positive effect on environmental systems. As such, future research should focus on identifying species-specific factors that drive seasonal bat use of infrastructure.

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