Using Radar to Investigate Changes in Migratory Behaviors of Mexican Free-tailed Bats in Southern Texas

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2022-23 ESS SUPER Program

Skills for Undergraduate Participation in Ecological Research

Instructor: Dr. Stacy Lynn

TA: Sean Geer

Date of Completion: April 28, 2023

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Abstract

In the Southern US, many insectivorous bat species, like the Mexican free-tailed bat (*Tadarida brasiliensis*), play key roles in agroecology, providing pest-control services to local farmers. However, the ecology of *T. brasiliensis* in this region are understudied, with a majority of knowledge coming from studies conducted on Bracken Cave roost outside of San Antonio, Texas. To address this gap in knowledge, this study utilized weather surveillance radar data collected from 2000-2020 to investigate changing emergence patterns of *T. brasiliensis* across various roosting locations in Southern Texas. Specifically, this study aimed to differentiate these emergence patterns between naturally occurring roosting locations and urban roosting locations. Urban roosts were found to emerge at later times than natural roosts. This research demonstrates the potential for new studies on the *T. brasiliensis* ecology and behavior on broad spatial scales, and how those patterns change over time.

Introduction

The Mexican free-tailed bat (*Tadarida brasiliensis*) is a nocturnal, insectivorous, migratory mammal hailing from the Americas (Wiederholt et al., 2013). Every year, populations breeding in northern latitudes undergo a vast migration from their wintering homes in northern Mexico to their breeding homes in southwestern United States, mainly in Southern Texas, but some going as far North, Colorado, California and Oklahoma (Wiederholt et al. 2013). The purpose of this migration is for pregnant females to give birth, and find an adequate climate and food source to raise their young (Danielson et al. 2022). Southern Texas has large populations of coleopteran (beetles) and lygaeid (seed bugs) insects, which is *T. brasiliensis*' main food source (Whitaker et al., 1996). This makes Southern Texas an area with great congregations of Mexican free-tailed bats, including the largest known roost, Bracken Cave near San Antonio, TX (Stepanian et al. 2018).

Figure 1: Picture of Mexican free-tailed bats flying out of their roost (Mark MacEwan, 2015).

Agriculture in the Southern United States is largely dependent on *T. brasiliensis*' ability to consume vast amounts of harmful insects on farms. In some cases, Mexican free-tailed bats save farmers around $3 million in pest suppression/ecosystem services (Wiederholt et al., 2013). Single roosts in Southern Texas provide ecosystem services valued at over $1 million on average (Wiederholt et al., 2013). Farmers are not the only people who receive benefits from Tadarida Brasiliensis though, as ecotourism is increasing in importance and popularity.In just 11 viewing sites in a study conducted in 2013, Mexican free-tailed bats provided $6.51 million of ecotourism value (Wiederholt et al., 2013). Beyond their obvious economic importance, *T. brasiliensis* also provides important biological services, which holds the most value in the Southern most summering regions of Southern Texas (Wiederholt et al., 2013).

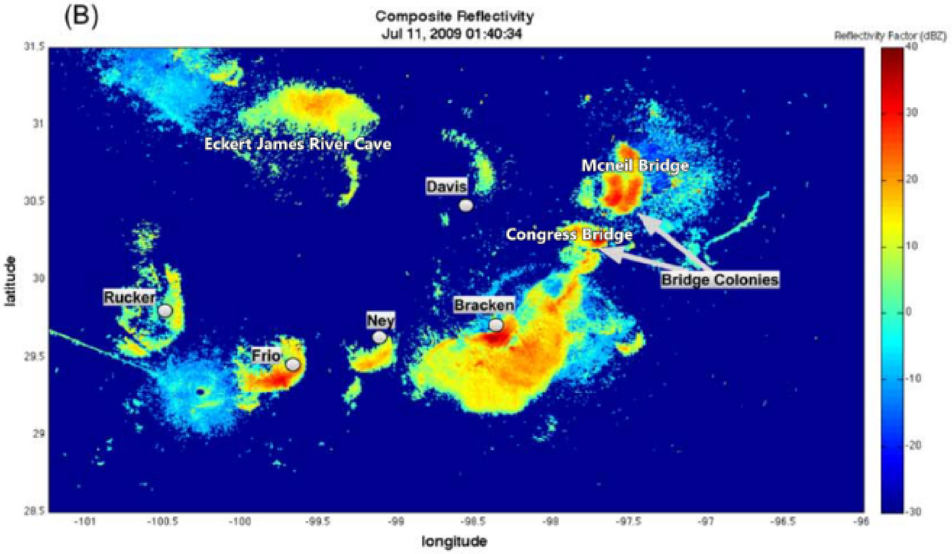


Figure 2: Composite image of RADAR data from all 4 radar stations.

Mexican free-tailed bats will most often roost in large caves, or rock formations, but in recent years, they have begun roosting in urban settings such as highway overpasses, bridges, and other enclosed city areas (Scales and Wilkins, 2007). In these urban environments, Scales and Wilkins (2007) observed more roosts overwintering as fidelity and emergence patterns changed due to decreasing availability of insects caused by increasing temperature and humidity. Changes in roost fidelity and emergence time will impact the amount of time available to forage. This can have a large impact on these bats, particularly during the summer season when they are raising young and thus need to accrue large amounts of food. However, there is a lack of information on the impacts living in urban environments has on Mexican free-tailed bats on a large scale. Our study aims to expand on previous studies by investigating changes in Mexican free-tailed bat emergence times between urban and natural roosts across South-central Texas.

Texas Parks & Wildlife, CONANP, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS

Figure 3: Map of study area in Southern Texas with the four RADAR stations and the fourteen known major roosts used in this study outlined. Roosts are symbolized by habitat type: natural and urban roosts.

Research Questions and Hypotheses

Research Question 1: How does Mexican Free-tailed Bat emergence time during the summer season vary between urban and natural roosting sites in Southern Texas, and how does that change over time?

Hypotheses: Based on a study conducted by Scales and Wilkins, we hypothesize that bats in urban settings will remain in their roosting locations for longer during the day.

- The study examined the migration patterns and movement between roosts of a population of bats in Southern Texas residing in urban roosts.

Methods

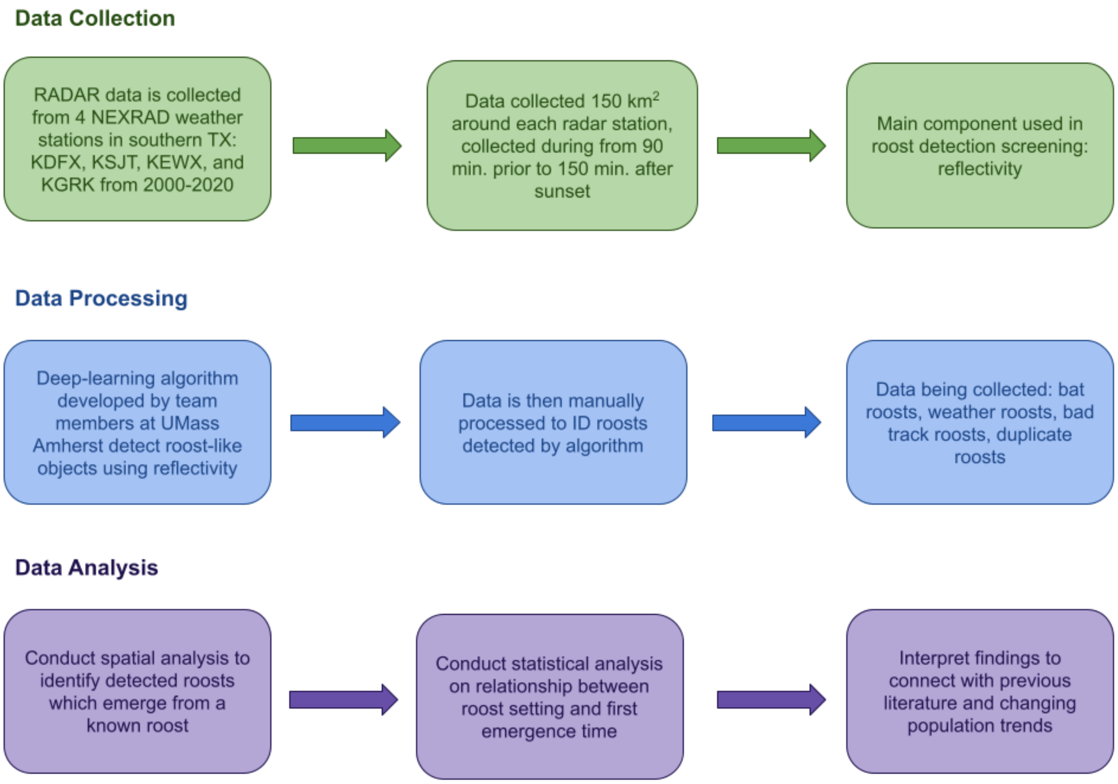


Figure 4: Flow chart of data collection, processing, and analysis to demonstrate the progression of our methods to answer our research questions concerning changes in Mexican free-tailed bat ecology in South-central Texas.

Data Collection

Data was collected from four weather stations over the course of 20 years: the KDFX, KEWX, KGRK, and the KSJT weather stations in Southern Texas. Each of these stations collected weather data (reflectivity) using US Next-Generation Radar (NEXRAD) technology, allowing data to be collected 150 km from each station, from 21 UTC (Coordinated Universal Time) to 3 UTC of the following day. These radars operated on the 159 S-band, at a 10.71 cm wavelength, and at frequencies between 2.7 GHz and 3.0 GHz. Scans lasted from 5 to 10 minutes with a spatial resolution of 1 degree azimuths with 1 km range gates from 2000 to 2008, and 0.5 degree azimuths with 250 m range gates after 2008.

Data Processing

To process the weather data, a deep-learning algorithm developed by the University of Massachusetts Amherst (Figure 4) was used. This algorithm utilizes a Faster R-CNN (Convolution Neural Network) to predict the probability of roost presence based on the size, distance from one of 43 reference points, and reflectivity of clusters. The above mentioned reference points range from 16x16 m to 512x512 m. After the data is processed by the algorithm, SUPER students processed the data again to identify any missed, or misidentified roosts that the algorithm might have misprocessed. The students followed a set of rules, outlining specific phenomena in roost emergence or notes about the weather for the day. Specific rules can be seen in Appendix 1. The reprocessed data is then exported as a csv file and saved on both a local hard drive and a shared Google Drive folder.

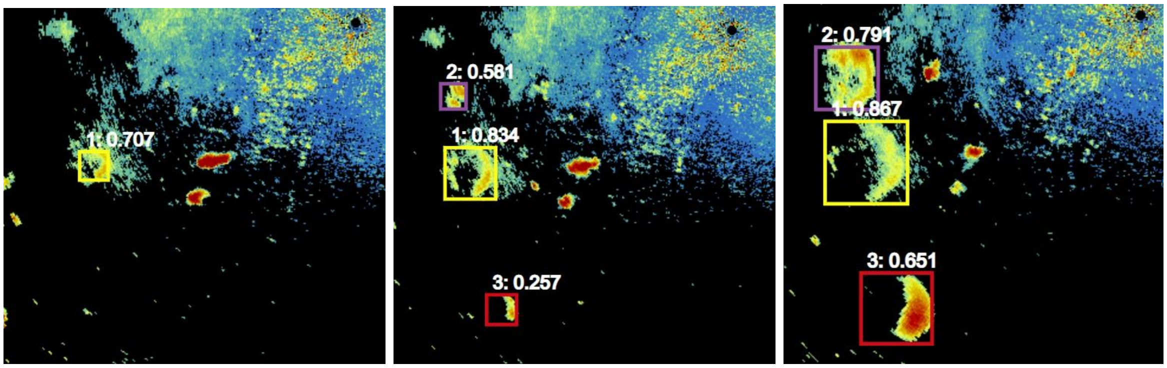


Figure 5. Example of emergence pattern from NEXRAD reflectivity data (3 roost emergences).

Data Analysis

To detect emergence time differences in trends, the data was limited to June-August, which was considered the summer season. This was done due to the summer season being the season with the highest density of bats. Bounding boxes which were classified as non-roosts, duplicate roosts, bad tracks, weather roost, AP (anomalous propagation) roost, or unknown-noise roost were excluded from analysis. Prior to analysis, eight roosts were included in analysis as known *T. brasiliensis* roosts in the study area. SUPER students identified six additional known roosts than what was previously included in analysis by observing emergence locations and cross referencing with roosting locations from Texas Parks and Wildlife (Texas Parks & Wildlife).

Spatial analysis was conducted in ArcGIS Pro and assigned observed roosts to the fourteen known roosts (Figure 3). Data being joined was limiting to the first emergence of each observed roost. Buffers were then created around the fourteen known roosts. Three different sizes of buffers around the known roosts were used to ensure the most data was encapsulated inside each buffer. Most roosts were given a 15 km buffer. Due to the closeness between Rucker and

Stuart Bat Cave, 10 km buffers were utilized for those roosts. Two other roosts, Devil's Sinkhole and Eckert James River Cave, were given 25 km buffers due to the spread-out nature of points which belonged to these roosts. This was most likely due to the fact that both roosts were on the edges of the NEXRAD radar station's view. A Spatial Join was then performed on the first emergence points and buffers around the known roost locations. This allowed the roosts to be identified as occurring within an urban or natural setting. Observed emergences that were not considered a known roost were not used in analysis. Students then used R to conduct a linear regression analysis on changes in emergence times during the summer season between urban and natural roosts across all 20 years. The results of the spatial and statistical analyses were then cross referenced to previous literature (Figure 4) to determine significant findings.

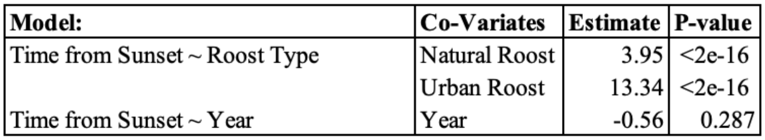
Results

A total of 36 batches of Radar data was used, collected from four stations and spanning from 2000-2020. Each batch consisted of a year's worth of data from a single radar station. To ensure evenness of data used in analysis and time constraints, only even years were processed (with the exception of 2008 and 2016, which were not used in this analysis). All four stations from each year used in analysis were processed.

Data from 14 known roosts were used in analysis. 9 'natural' roosts, 4 'urban' roosts (all consisting of roosts formed under bridges), and one 'natural man-made' roost, which was a man-made bat cave called the Chiroptorium on the Bamberger Ranch Preserve in Blanco Co, TX (Tuttle 2016). Due to the fact that the Chiroptorium is made from gunite concrete (Tuttle 2016), which could impact bat behavior in similar ways that roosting under concrete bridges would, this sight was included in the urban roosts.

Emergence Time

- Emergence times between urban roosts and natural roosts in the summer season were statistically significant, with urban roosts emerging later than natural roosts (p-value = 2.2e-16).
- Emergence times between urban and natural roosts during the summer season did not increase or decrease to a statistically significant degree as the years progressed (p-value = 0.2867).



Model:	Co-Variates	Estimate	P-value
Time from Sunset ~ Roost Type	Natural Roost	3.95	<2e-16
	Urban Roost	13.34	<2e-16
Time from Sunset ~ Year	Year	-0.56	0.287

Figure 6: Table showing results of linear regression analyses between time from sunset and roost type/year. Time from sunset, meaning the minutes from local sunset when the roost first emerged, was the variable used for emergence time in these analyses. Roost type was shown to have a significant effect on emergence time (p-value = <2e-16) while changes in year did not (p-value = 0.287). Additionally, urban roosts were estimated to emerge later after sunset than natural roosts in the linear regression model.

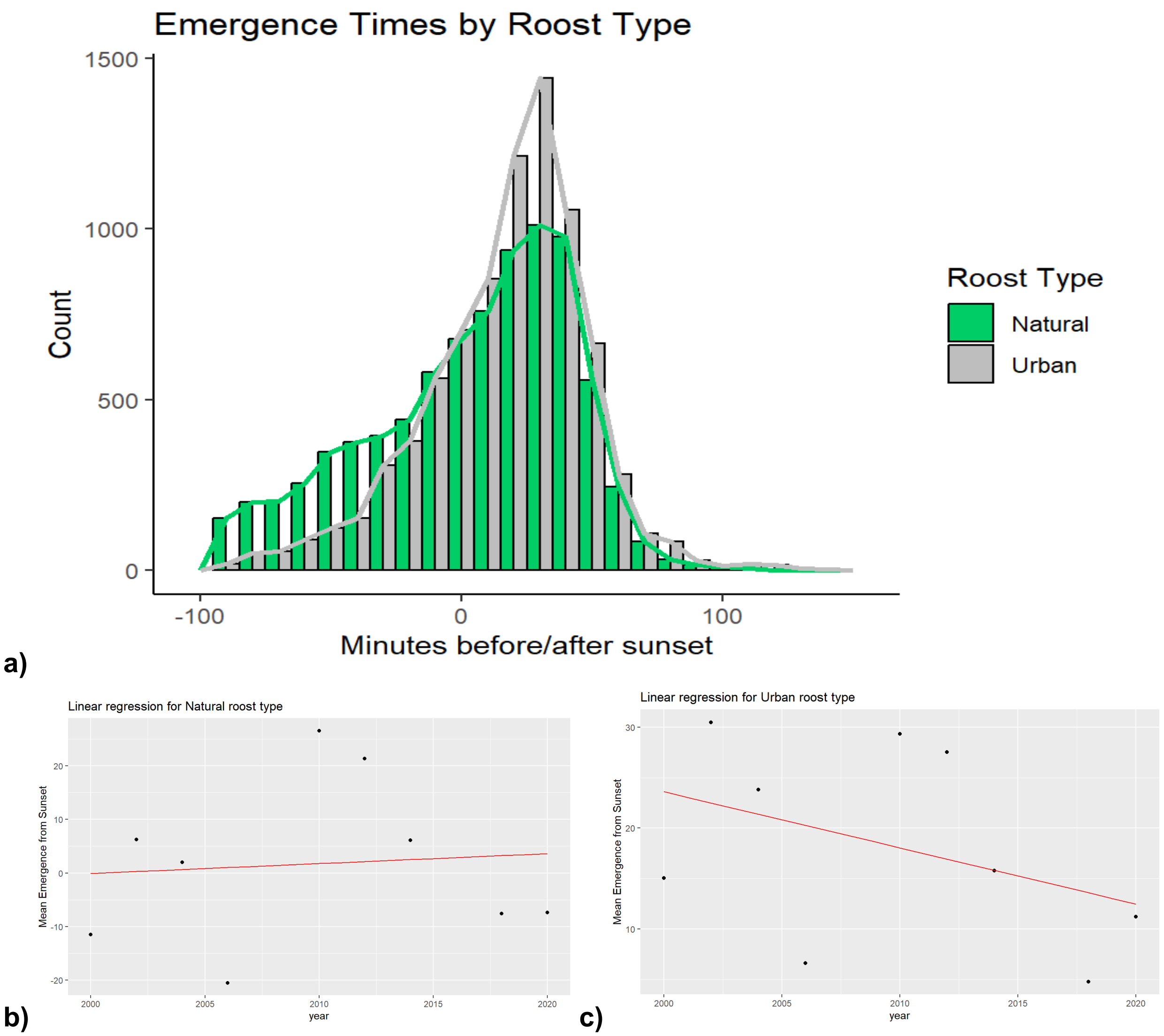


Figure 7: (**a**) Histogram depicting cumulative number of emergences of Natural and Urban roosting locations across all years (2000-2020 even years) at various times before (negative numbers) and after (positive numbers) sunset (p-value = 2.2e-16). (**b**) Linear regression depicting mean emergence time from sunset across all years for natural roosting locations. (**c**) Linear regression depicting mean emergence time from sunset across all years for urban roosting locations (p-value for both b and c = 0.2867).

Discussion

Our hypothesis that *T. brasiliensis* will remain in their roosting locations longer and emerge later in the evening was supported. As seen on Figure 7a, urban roosts will emerge later in the evening, most often around 40 minutes after sunset. This is consistent with Scales and Wilkins' findings and is likely due to decreasing availability of insects from increased heat and humidity, as stated in their study. However, this could also result from light pollution as it is more concentrated in cities. This could confuse the bats' sleep cycle and cause them to think it is earlier than it actually is. More research is necessary in this field.

This study was limited by inconsistencies in the screening software in which several roosts were never identified and thus the emergence time for those roosts could not be recorded. Radar data is limited in visibility by weather and anomalous propagation, causing several missed days in the dataset. As seen in Figure 3, there was more data for natural roosts than urban roosts. Further research with even larger sample sizes is needed to better understand relationships between bat ecology and roost site. The largest limiting factor of this study was the absence of metadata in the beginning stages of this project, which led to the exclusion of reflectivity data in the dataset. This greatly reduced the potential of the analysis, as relative density of roosts could have been derived from this reflectivity data. Density of bats would have greatly improved the visualization of emergence time differences between urban and natural roosts, and would have expanded the potential knowledge on *T. brasiliensis* ecology gained from this study. Future research using this dataset with the inclusion of reflectivity data is crucial to better understand changing trends (such as changes in emergence time or overwintering) within this population.

As *T. brasiliensis* begins to remain in their roosts for longer, they have less time to feed. This has implications both for the species and for the agricultural workers in the area. If they eat less, the pups will have less potential to grow and learn to fend for themselves. This could lead to population declines. However, future research including insect data in these urban environments is needed to truly understand this phenomenon. This later emergence can also affect insecticide usage on nearby farms. With less insects being consumed due to less feeding time or lower populations, these farmers will need to increase their insecticide use. Increased insecticide use leads to lower overall soil health, which has large effects on the entire ecosystem.

Conclusions

We were able to support our hypothesis that urban roosts have later emergence times. This was shown in Figure 7a in which urban roosts will emerge later overall and in a more concentrated fashion. This study was a good example of how important metadata is. With limited access to the available data and miscommunications as to what the data was, the scope of this project was greatly reduced. By communicating what data is and including metadata attached to the shared data sets, especially in interorganizational research, students are presented with a wider range of possibilities in their study.

Above all, the results of this study posit that urban roosts facilitate conditions favorable for *T. brasiliensis*. In a world that continually becomes more urbanized, this provides hope for *T. brasiliensis* populations in areas which may be losing natural roosting habitats to land conversion. However, potential impacts from living in these urban environments, like later emergence times, could have wide ranging impacts on these species and the ecosystem they live in.

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Acknowledgements

Tao Liu (Fish, Wildlife, and Conservation Biology, CSU) assisted in the data screening process.

Wenlong Zhao, Zezhou Cheng, and Gustavo Perez at the University of Massachusetts Amherst created the machine-learning algorithm which was used for the initial screening of the data used in this study.

This project was completed as part of the Ecosystem Science and Sustainability SUPER Program (Skills for Undergraduate Participation in Ecological Research) under the supervision of Dr. Stacy Lynn.

Appendix 1: Methods Outline

1. Data Collection
    a. Data was collected from four weather stations in Southern Texas: KDFX, KEWX, KGRK, and KSJT
    b. Data was collected over the course of 20 years (2000-2020)
    c. 150 km from station, collecting 21 UTC to 3 UTC of following day
    d. Collected from US Next-Generation Radar (NEXRAD)
        i. 159 S-band radars operated by NOAA
        ii. Operate at 10.71 cm wavelength and 2.7-3.0 GHz frequency
        iii. Volume scan from 5-10 minutes
        iv. Spatial resolution increased in 2008 to 0.5 degree azimuths with 250 m range gates (from 1 degree azimuths and 1 km range gates)
        v. Changed to duel-polarization after 2013
    e. Radar is measuring reflectivity

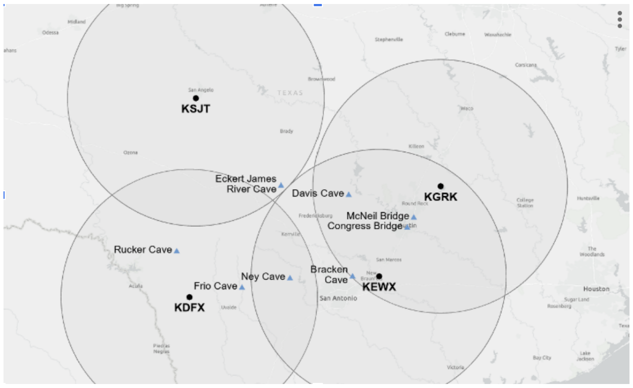

Figure 1: Map of the study area, including the four radar stations collected our data and the eight known roosts within the 150 km radius of the radar stations

2. Data Processing
    a. Automatic detection/tracking of roosts from deep-learning system
        i. Built on Faster R-CNN (Convolutional Neural Network): predicts probability of roost presence depending on size and distance to reference point
            1. 45 reference anchors ranging in size from 16x16m to 512x512m
        ii. Tracking algorithm from Ren et al, 2017
    b. Manually edited processed data in a screening process under the following rules
        i. Keep the analysis a priority
        ii. Record days when you see double rings - day note AND track note "dr" - especially at KEWX station
        iii. Weather day note

            1. "aw" - adverse weather - day with >50% weather - throw out the data on that day
            2. "ww" - workable weather - >50% weather but we are keeping the data on the day
        iv. If there is a huge roost missing (not detected in a day without any day note) - add "miss" to the day note
        v. Use the "tab" on the keyboard to rotate between detections
        vi. Don't hesitate to use "bad-tracks" so we can keep only the first few detections in the analysis
        vii. Very important to use "weather-roost" when you see weather is contaminating ANY part of the track
        viii. Keep in mind that the "first emergence time" may not be accurate for roost tracks
    c. Uploaded .csv file of fully edited data into a personal hard drive as well as a shared google document
    d. Used a shared google sheet to ask questions about tracks, keep track of time dedicated to screening, and take notes
3. Data Analysis
    a. Data will be the csv's containing the processed radar data for each batch year and radar station (36 total csv's)
    b. July and August will represent the summer season.
    c. Analysis will be completed in R and ArcGIS
    d. Analysis in ArcGIS will assign roosts observed by the radar stations to known roosts
        i. We will run a intercept or spatial join tool to identify the roosts observed by the radar stations that are the eight known bat roosts (see: Figure 1).
            1. This will be done using the coordinates of these known roosts and the coordinates of first occurrence of each recorded roost
            2. This analysis will result in two new fields being added to the data tables: one for the name of the roost and one describing whether the roost is a urban or natural roost.
    e. We will use R to perform analyses on first emergence time, roost setting (urban or natural), and year
        i. Linear regression models will be conducted between the emergence time and roost type or year
4. Data Interpretation
    a. We will be looking for significant ($\alpha < 0.05$) findings in the statistical analyses run (linear regression, t-tests, and ANOVA)

        i. These tests will help us to either reject or fail to reject the null hypothesis.

b. We will visualize the data (changes in population density throughout the year, changes in emergence time, emergence times and population density change in natural and urban roosts) using a series of graphs.
    i. This will help to visualize the findings of the statistical analysis.