Shoreline Foraging Activity by Gray Bats (*Myotis grisescens*) and Northern Long-eared Bats (*Myotis septentrionalis*) on Grand Lake, Oklahoma

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Abstract: Shoreline foraging activity of the endangered gray bat (*Myotis grisescens*) and threatened northern long-eared bats (*Myotis septrionalis*) on Grand Lake, Oklahoma was assessed using acoustic sampling. Activity was surveyed in summer 2015 and 2016 along six mobile boat transects using Anabat acoustic detectors. Four transects using stationary detectors were also used in 2016. A total of 34,593 calls were detected for 9 bat species. The tri-colored bat (*Perimyotis subflavus*) and gray bat were the most frequent, combining to make up ≈ 90% of the total calls. The gray bat was recorded in five of the six mobile routes with call abundance highest within 8 km of maternity caves, specifically Drowning Creek, Elk River, and Three Fingers Cove. In contrast, most calls on stationary transects were found on Duck Creek and Honey Creek. The northern long-eared bat was the least detected species, comprising <0.4% of the total calls. A single call was detected during mobile surveys, occurring in 2015 on the northern shore of Drowning Creek. Stationary transects were more successful with calls for this species with most calls found on Drowning Creek and Honey Creek. In total, 293 locations were found to support foraging activity across nine species. More specifically, 48 locations were identified as foraging habitat for the two imperiled bat species (28 gray; 20 northern long-eared). Such spatial data provides the potential for identifying habitat factors needed for effective conservation for these species.

Introduction

Data are lacking for at-risk bat species in Oklahoma that use mesic, forest, or aquatic habitats. Additionally, few studies within the state have assessed the effects of anthropogenic disturbance on bats that forage in riparian habitats on manmade reservoirs. The volant nature of bats allows them access to multiple habitats, which may decrease their dependence on any single habitat. How specific bat populations respond to changing anthropogenic landscapes, therefore, is needed for effective habitat management (Arnett, 2003). The goal of this study was to assess the foraging activity of bats along shoreline habitat of Grand Lake, Oklahoma. Data garnered from this analysis will guide future landscape management aimed at conserving these species. Particular focus is directed toward two imperiled bat species – the endangered gray bat (*Myotis grisescens*) and threatened northern long-eared bats (*Myotis septrionalis*). The gray bat was once widespread in the southeast, but has been listed as endangered since 1976. The species is cave-obligate and many caves in the region serve as refugia. Maternity caves are used by adult females and their newborn pups. Bachelor caves are used by adult males and yearlings of both sexes and are typically within 35 km of maternity caves. Females and juveniles join males in July and August. This aggregation prior to fall migration may serve to aid young bats in learning routes to foraging areas and hibernacula caves (Tuttle, 1976). Gray bats disperse nightly from caves and may travel over long distances to forage on flying aquatic insects along streams and lakes (Decher and Choate 1995). Bats from maternity caves in Delaware and Ottawa Counties likely travel to Grand Lake to feed. The northern long-eared bat is widely distributed in eastern North America. Due to declines caused by white-nose syndrome, the species was listed as threatened in 2015. This species roosts singly or in colonies within cavities and crevices of living and dead trees during the summer months. Rare individuals have also been found roosting in manmade structures, like barns and sheds. Winter months are spent hibernating in caves and mines (Caseres and Barclay, 2000). The species was first reported in Oklahoma in the mid-20th century in Adair, Delaware, and LeFlore Counties (Glass and Ward, 1959). Our knowledge of its distribution in Oklahoma, however, remains largely anecdotal.

Methods

Study site. Grand Lake o' the Cherokees (aka Grand Lake) is a manmade reservoir located on Grand River in northeastern Oklahoma. Formed in 1940 by construction of Pensacola Dam, the reservoir comprises a 19,000-hectare impoundment with around 2,100 kilometers of shoreline. It is the first of two successive reservoirs located along the river created and operated by the Grand River Dam Authority (GRDA). The Ozark Plateau covers about 103,000 km^2 in the central United States with elevations between 260-460 m above mean sea level (Huffman 1959). The area is dominated by outcrops of alternating layers of limestone and flint and sandstone conducive to cave formation. Multiple caves are located within 20 km of the lake perimeter with four found within 2.5 km. Vegetation on upland slopes is predominantly blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), black hickory (*Carya texana*), and winged elm (*Ulmus alata*). Coralberry (*Symphoricarpus orbiculatus)* and sassafras (*Sassafras albidum*) comprise a sparse shrubby understory. Riparian areas in lowlands are dominated by silver maple (*Acer saccharium*), river birch (*Betula nigra*), American elm (*Ulmus americana*), cottonwood (*Populus deltoides*), sycamore (*Platanus occidentalis*), and various oak species (*Quercus* spp.). Sporadic openings of managed grasslands are used for agriculture (Blair and Hubbell 1938; Harvey et al. 1981). The Grand Lake ecosystem has been impacted by a long history of human influence. Much of the region surrounding this 100 km-long lake has been a popular residential and tourist destination since the lake's creation. Privately-owned land is generally located within feet of the water's edge and much shoreline habitat has been altered by residences, boat docks, and other structures. This is compounded by thousands of tourists that visit the lake annually months for water sports, fishing tournaments, and other recreation. Water quality issues have also figured prominently in recent years. The watershed is dominated by a variety of crop and animal agriculture which produce chemical and organic waste that drain into the lake. Heavy metals in mine drainage from Picher, OK have also been detected in lake sediments.

Acoustic surveys. Bat shoreline activity by bats was assessed in the summer of 2015 and 2016 using mobile and stationary acoustic sampling. Acoustic sampling employs special frequency detectors to record the subsonic echolocation calls used by bat species during nightly foraging (O'Farrell et al., 1999). Each species possess a unique set of calls that can be subsequently identified by computer software with high accuracy. Acoustic sampling techniques for assessing bat activity have been used for over 40 years and are now well established. Mobile boat surveys adapted methodology used for auto-based road surveys (Roche et al., 2011; Whitby et al., 2014). Six routes in proximity to known bat cave colonies were selected for surveying – Three Fingers Cove, Drowning Creek, Elk River, Duck Creek, Honey Creek, and Horse Creek (See Figure 1 and Appendix 1). Routes were sampled once each summer within the period from late May through July for a total of 12 mobile surveys. Two Anabat receivers (Titley Electronics, Australia) were employed during each mobile survey. An Anabat SD2 ultrasound bat detector was mounted on the boat bow with the microphone directed forwards, 5-15° off vertical. Another Anabat detector was mounted in the stern with a detached microphone

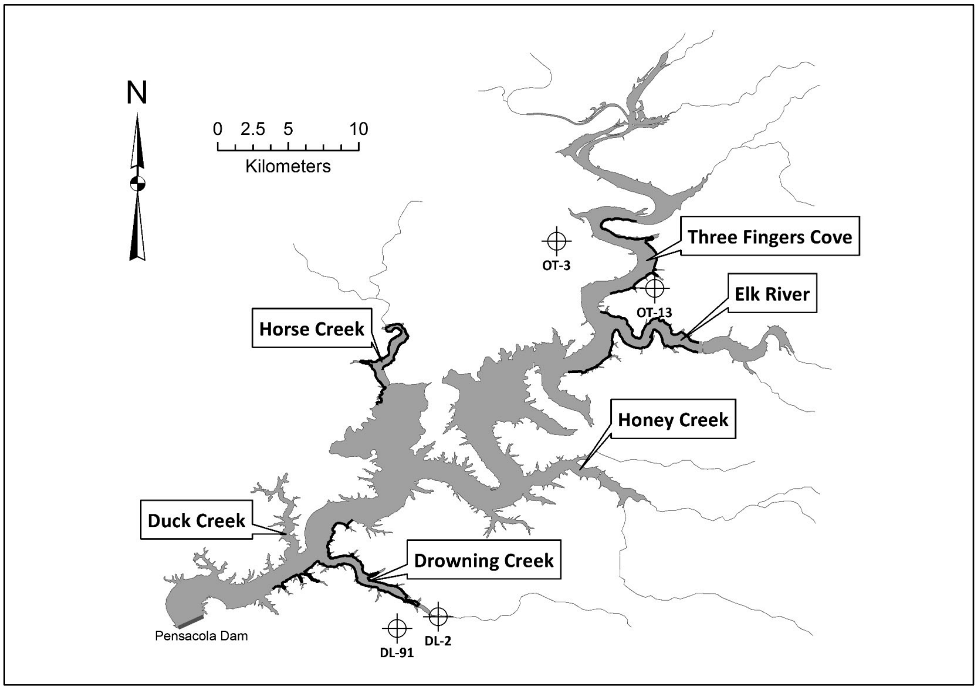

Figure 1. Schematic of Grand Lake showing the locations of 2015-2016 acoustic bat surveys. Dark black lines indicate boat routes used for mobile sampling transects. Bat roosting caves are denoted with cross-hairs symbol and U.S. Fish and Wildlife identifier code.

directed vertically. GPS antennas recorded the geographic coordinates for each call. Surveys were conducted on nights with low wind (< 24 km/h), no rain, and ambient temperatures >60°F. Recording was started 20 minutes after sunset in 2015, but was increased to 60 minutes in 2016. The later start time was adopted to potentially increase bat encounters. Routes were driven at 9.5-11 km per hour with each detector recording continuously for a 90 minute duration. This speed was chosen to lessen the effect of wind and wave noise on detections. Boats steered a course as close to the shoreline as surface and subsurface features allowed. Most routes required significant maneuvering around boat docks and other manmade structures. Larger tributaries along the main route were explored, if possible. Stationary Anabat Express units were also deployed in 2016 at three locations. Two of these, Duck Creek and Honey Creek, were not surveyed by mobile routes in either survey year. The southern shore of Drowning Creek was surveyed using both mobile and stationary units in 2016, but surveys were not performed concurrently. Stationary surveys monitored activity for six consecutive nights (1800-0600 hr) at five locations along each transect separated by at least 400 m (See Appendix 2). Call data files were processed with Analook software (Titley Electronics) to filter ambient noise. Echolocation calls were identified to species using BCID 2.7 software (Bat Call Identification Inc.). This computerized application interacts with the ANABAT recorders and allows users to automate the identification process of a high volume of calls of North American bats.

Results

A total of 34,593 identifiable echolocation calls were recorded for nine bat species during the two years of surveys. Of these, 274 calls were recorded on mobile surveys (Table 1) and 34,319 calls were recorded on stationary surveys (Table 2). Stationary surveys detected nine species: big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), gray bat, little brown bat (*Myotis lucifugus*), northern long-eared bat, evening

Table 1. Summary of bat echolocation calls by species and transect recorded on mobile shoreline surveys in summer 2015 and 2016.

Transect Location	Species									Total
	Gray	*Northern Long-eared*	*Tri-colored*	*Silver-haired*	*Red*	*Evening*	*Hoary*	*Big Brown*	*Little Brown*	
Drowning Creek S.	3	0	26	0	0	0	0	0	0	29
Drowning Creek N.	5	1	80	4	2	0	0	0	0	92
Elk River S.	5	0	21	1	2	3	0	0	0	32
Elk River N.	1	0	11	0	0	0	0	0	0	12
Horse Creek	0	0	18	0	0	0	0	0	0	18
Three Fingers Cove	29	0	50	0	8	4	0	0	0	91
Total	**43**	**1**	**206**	**5**	**12**	**7**	**0**	**0**	**0**	**274**
% of Calls	**15.7**	**0.4**	**75.2**	**1.8**	**4.4**	**2.6**	**0**	**0**	**0**	**100**

Table 2. Summary of bat echolocation calls by species and transect recorded on stationary shoreline surveys in summer 2015 and 2016.

Transect Location	Species									Total
	Gray	*Northern Long-eared*	*Tri-colored*	*Silver-haired*	*Red*	*Evening*	*Hoary*	*Big Brown*	*Little Brown*	
Drowning Creek	870	30	13,141	80	123	2,596	81	72	42	17,035
Duck Creek N.	1,468	2	5,573	45	141	131	21	10	25	7,416
Duck Creek S.	146	4	1,388	56	232	150	12	12	23	2,023
Honey Creek	1,397	24	5,264	77	602	386	15	18	62	7,845
Total	**3,881**	**60**	**25,366**	**258**	**1,098**	**3,263**	**129**	**112**	**152**	**34,319**
% of Calls	**11.3**	**0.2**	**74.0**	**0.8**	**3.2**	**9.5**	**0.4**	**0.3**	**0.4**	**10.0**

bat (*Nycticeius humeralis)*, and tri-colored bat (*Perimyotis subflavus*). Mobile surveys recorded six of these, failing to detect any calls for the big brown bat, hoary bat, or little brown bat. The tri-colored bat and gray bat were the most frequently recorded species for both survey methods. The tri-colored bat comprises 75.2% and 74.0% of the calls for the mobile and stationary surveys, respectively. The gray bat comprised 15.7% and 11.3% of these calls. The northern long-eared bat was the least detected species in both survey methods, comprising only 0.2-0.4% of the total calls.

The northern shore of Drowning Creek recorded the highest call abundance of the six mobile survey routes. Two routes, Drowning Creek North and Elk River South, recorded the highest species richness, recording five species and six species, respectively. The gray bat was recorded in five out of the six mobile routes. Call abundance for this species was highest within 8 km of maternity caves, specifically Drowning Creek, Elk River, and Three Fingers Cove. The northern long-eared bat, on the other hand, was only detected once among the two seasons of mobile surveys. This call was recorded in 2015 on the northern shore of Drowning Creek. The southern shore of Drowning creek recorded the most calls of the four stationary transects, nearly equaling the number of calls of the other three transects combined. All stationary transects detected calls for the nine species recorded during the study. Gray bat calls were most abundant on Duck Creek North and Honey Creek, with 1,468 and 1,397 calls, respectively. For the northern long-eared bat, a total of 60 calls were recorded at nine of the 19 stationary sample points. These calls were most abundant on Drowning Creek and Honey Creek, with 30 and 24 calls, respectively.

Conclusions

The efficacy of mobile versus stationary acoustic methods for bat detection has been shown to vary in different habitats (Fischer-Phelps et al., 2017; Tonos et al., 2014; Whitby et al., 2014). In this study, stationary detectors positioned at 19 fixed locations for a period of 6 nights detected a total of nine bat species. Mobile surveys detected three fewer species, but required fewer sampling events than stationary transects (12 versus 19). The three species not detected by mobile surveys were highly rare in the stationary surveys, each comprising no more than 0.4% of the total call volume. Stationary surveys also detected a much higher volume of calls, recording more than a 120-fold increase over mobile surveys. The frequency of calls by species, however, was generally the same for both survey methods. The tri-colored bat (74-75.2%) and gray bat (11.3-15.7%) were the most frequently detected species for the mobile and stationary surveys. Similarly, the northern long-eared bats was the least frequent (0.2-0.4%) in both methods. A key advantage of mobile surveys for bat conservation is that spatial location can be recorded for each call, thus allowing for a more comprehensive assessment of bat activity with spatial habitat variability.

Foraging activity along riparian habitat was highly different among the two imperiled species. The endangered gray bat was highly ubiquitous among recorded calls, second only to the tri-colored bat. Four caves within 2.5 km of the lake perimeter serve as refugia for this cave-obligate species, with three of these confirmed to house maternity colonies. Gray bat call volume was found to be highest within 8 km of these maternity caves. The high prevalence of bat detections in proximity to these caves substantiate management stakeholder predictions that riparian habitat on Grand Lake is essential foraging grounds for these colonies. These three maternity caves are currently monitored and protected by GRDA as part of the agency's conservation efforts for this species, but the spatial extent to which the bat forages along the Grand Lake shoreline was heretofore speculative. Gray bats exhibit strong competitive-adaptive habits to foraging on night-flying aquatic insects along streams, rivers, wooded riparian habitats, and edges of impoundments (Tuttle, 1976; Decher and Choate, 1995; Brack and LaVal, 2006). Gray bats predate largely on mayflies which swarm in enormous numbers during the warm months in portions of Grand Lake. Preferred bat foraging habitat may, therefore, correlate closely with conditions that promote high mayfly abundance.

The threatened northern long-eared bat, in contrast, was the least detected species in the study. Six caves within 20 km of Grand Lake provide some form of refugia for this species. Northern long-eared bats forage in a variety of habitats including forests, forest edges, and riparian zones. Consequently, suitable foraging grounds are likely found closer to cave locations than Grand Lake. Whether the scarcity of calls detected for this species reflect habitat preference or a general rarity of this species in the region, however, is not known.

In total, 293 shoreline locations were found to support foraging activity across nine bat species. More specifically, 48 locations were identified as foraging habitat for the two imperiled bat species (28 gray bat; 20 northern long-eared bat). The association of specific habitat parameters with these preferred feeding grounds, however, has not yet been determined. Of key interest for conservation-related measures is the effect of human-caused habitat alteration on bat activity. Quantitative measures of shoreline alteration for Grand Lake is challenging, if non-existent. It is evident, however, that significant portions of the shoreline have been altered for a variety of residential and commercial purposes. Consequently, a spatial analysis of foraging activity relative to natural and manmade habitat parameters is recommended for effective shoreline management. Such parameters could include: 1) vegetation species composition, 2) vegetation structure (canopy density, stem height, stem density, basal area), 3) land use types (natural/developed), 4) water properties (depth, temperature, movement, dissolved oxygen, nutrient loads, pollution), and 5) artificial light intensity.

These GPS referenced calls can be used to potentially define spatial habitat variations that are preferred or avoided by different species of bats in general, and federally imperiled species specifically. We recommend using a GIS-based approach that combines spatial data from ground surveys and remote sensing to index habitat parameters. GIS-habitat mapping indices coupled to GPS referenced call data presented in this study, can ultimately be used for predictive shoreline habitat management decisions for federally imperiled species of bats by the Grand River Dam Authority and its stakeholders.

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Appendix 1. Geographic coordinates for starting and ending points for each mobile survey route.

Transect	Point	Latitude	Longitude
Drowning Creek South	1	36.484	-94.892
	2	36.492	-94.913
	3	36.509	-94.934
	4	36.510	-94.951
	5	36.501	-94.928
Duck Creek North	1	36.537	-94.971
	2	36.556	-94.985
	3	36.549	-94.970
	4	36.562	-94.975
	5	36.525	-94.967
Duck Creek South	1	36.554	-94.983
	2	36.549	-94.975
	3	36.536	-94.974
	4	36.555	-94.980
	5	36.524	-94.971
Honey Creek	1	36.575	-94.787
	2	36.580	-94.778
	3	36.577	-94.784
	4	36.573	-94.786
	5	36.578	-94.779

Appendix 2. Geographic coordinates for each stationary sampling point by transect.

Transect	Point	Latitude	Longitude
Drowning Creek South	Start	36.482	-94.888
	End	36.493	-94.981
Drowning Creek North	Start	36.483	-94.887
	End	36.538	-94.930
Elk River South	Start	36.645	-94.710
	End	36.633	-94.793
Elk River North	Start	36.652	-94.709
	End	36.672	-94.772
Three Fingers Cove	Start	36.683	-94.766
	End	36.730	-94.749
Horse Creek	Start	36.612	-94.915
	End	36.634	-94.911