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PILOT TESTING THE EFFICACY OF USING A LOW-POWER ULTRASOUND EMITTER TO DECREASE BAT ACTIVITY

Technical Update, June 2019

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ABSTRACT

High-power ultrasonic emitters have been used to deter bats from occupying airspace near potential hazard areas such as: (1) the rotor-sweep zone of wind turbines, and (2) structures slated for demolition or re-construction. But, high-power emitters require a dedicated energy source to be most effective. This may not be feasible in all habitats, or for lengthy periods of time. Our pilot study examined the effectiveness of using low-power ultrasound emitters to deter bats. We tested low-powered emitters in two locations: (1) an arid environment in southern Arizona dominated by isolated water resources that attract drinking and foraging bats, and (2) a building roost in northeastern Florida, used year-round by bats as a day roost. At the Arizona location low-powered emitters were deployed at three sites, and bat activity was monitored before, after, and during treatment. Activity was compared with two sites where no emitters were used. Bat use of all sites was quantified via direct observation using thermal and night-vision video and by recording echolocation call passes with ultrasonic microphones. Activity was measured as the number of hourly "sips" and "fly-bys" observed in the video footage and by number of "echolocation call passes" recorded by the ultrasonic microphones. At the Florida location, susceptibility of roosting bats to ultrasonic deterrence was quantified using time-lapse photography to measure pre- and post-treatment roosting patterns and compare them with those during treatment.

Results from the Arizona location showed a decrease in bat "sips" per hour on treatment nights compared to non-treatment nights ($f_{1,2} = 38.7$, $p = 0.025$). Also, echolocation call passes per hour decreased during treatment when compared to non-treatment time periods ($f_{1,2} = 7.57$, $p = 0.004$). This effect was consistent among bat species that predominantly use "high-frequency" (HF) echolocation call types and those that use "low frequency" (LF) echolocation call types ($f_{1,2} = 3.55$, $p = 0.05$ (HF), $f_{1,2} = 9.34$, $p = 0.002$ (LF)). Results from the Florida location showed an overall decrease in cluster size within one treatment area, but this decrease was not found to be significant. The monitoring equipment used in this study (thermal and night-vision video, ultrasonic recording equipment, and time-lapse photography) was evaluated for potential use to address regulatory and management projects involving bats. These results may lead to survey protocols that increase operational flexibility for the electric power industry, decrease potential interactions between bats and other commercial activity, and provide management tools to minimize impacts on bats, especially federally listed threatened and endangered species co-occurring on electric power developments.

Keywords

Bats

deterrent

acoustic deterrent

acoustic emitter

bat echolocation

EXECUTIVE SUMMARY

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PRIMARY AUDIENCE:Electric power company environmental managers

SECONDARY AUDIENCE: Bat regulatory and conservation professionals; other commercial sector environmental managers

KEY RESEARCH QUESTION

Research has shown that broadcasting ultrasound will deter bats from the airspace surrounding major developments that otherwise would result in Federally Threatened and/or Endangered Species "take." But, the properties of ultrasound make this a sophisticated process that may not be feasible for small-scale applications. This pilot study tested the effectiveness of a commercially available low-power ultrasound emitter to decrease bat activity within localized bat foraging and roosting areas. It is hoped that the low-powered emitters will be a feasible option for electrical power company environmental managers when faced with safely deterring sensitive species from developments to eliminate "take."

RESEARCH OVERVIEW

Several locations with known bat presence and/or activity were identified to test effectiveness of a low-power ultrasound emitter to discourage bats from entering the broadcast area near known foraging and roosting sites. The ultrasound emitters used in this study were designed to interfere with bat echolocation and cause them to avoid treated areas. Bat activity at treated areas was monitored with time-lapse photography, live-action video, and acoustic recording equipment. Activity at foraging areas was quantified by identifying "sips" and "fly-bys" from video recordings and "echolocation call passes" from audio recordings at habitat resources, and by "presence/absence" observations at roosts. Statistical analyses from treatment sites were performed pre-treatment, during treatment, and post-treatment to quantify the emitter effect on bat presence. Least-square ANOVA and REML in the R package were used for analyses. Survey equipment used in this study was evaluated for potential use during future regulatory and bat management projects.

KEY FINDINGS

At three water resource sites used by bats for drinking and foraging in Arizona, there was a notable decrease in bat activity during treatment with low-powered ultrasonic emitters when compared to non-treatment hours. This is based on a statistically significant difference in the total number of successful sips, and total number of echolocation call passes recorded from the video and acoustic recording assessments.

- Statistical analysis indicated a significant decrease in the amount of "sips per hour" for all three treatment sites ($f1,2 = 38.7$, $p = 0.025$).
- Statistical analysis at the treatment site suitable for this analysis indicated a significant decrease in total echolocation call passes recorded before ultrasound emitters were removed for the night and when removed permanently, when compared to time periods during ultrasonic emitter treatments ($f1,2 = 7.57$, $p = 0.004$).
- Statistical analysis indicated a significant decrease in echolocation call passes for species regardless of whether they used high-frequency or low-frequency echolocation call types, when compared to same time periods with no treatment ($f1,2 = 3.55$, $p = 0.05$ for high-frequency echolocation call passes and $f1,2 = 9.34$, $p = 0.002$ for low-frequency echolocation call passes).

At the bat roost in Florida, the effects of the ultrasonic emitter were inconclusive due to weather and site-specific design limitations. Nevertheless, cluster size within one treatment area of the roost decreased within the broadcast area.

The survey equipment used in this study (thermal and night-vision video, bat acoustic recording equipment, and time-lapse still photography) was evaluated and found to be useful for effectively and efficiently monitoring bat presence/ probable absence, both at roosts and over foraging areas. All equipment proved useful for future bat monitoring projects.

WHY THIS MATTERS

The electric power industry faces federal, state, and local regulatory and management challenges when operating where Threatened and Endangered (T&E) bat species occur. This can limit the geographic and temporal scale where and when certain activities can be conducted. Effective tools and technology to increase operational flexibility for these activities are needed and may be used as valuable management tools to minimize any negative impact on bats and commensurate negative consequences for electric power developments. Low-powered ultrasonic emitters used as deterrents to reduce or eliminate bat presence at development sites hold great promise to mitigate this issue. Results from this study indicate this is possible and will be used to further test and evaluate low-power ultrasound emitters as a means to increase operational flexibility within T&E bat habitats, especially maternity roosts.

HOW TO APPLY RESULTS

This was a pilot project to test the effectiveness of a low-power, commercially-available ultrasound emitter that can deter bats from occupying a targeted habitat. In this case: (1) a foraging habitat and (2) a roosting habitat. This research provides a foundation for further investigation (e.g., experiments at other areas frequented by bats, i.e., travel corridors, and roosting and/or foraging habitats outside the scope of this project). This has the potential to lead to successful mitigation and management efforts where and when impacts on bats may be imminent. The enclosed Matrix, Technology Evaluation for Use in Bat Management can be referenced for regulatory and conservation projects where mitigation for bat presence is needed.

LEARNING AND ENGAGEMENT OPPORTUNITIES

A sample of complementary EPRI research includes the following:

- Environmental Aspects of Renewables Forum: Shaping Future Research on Environmental Aspects of Renewables (3002012539, 2018)
- Compensatory Mitigation for Federally Listed Tree Roosting Bat Species in the U.S. (3002013774, 2018)
- Bat Detection and Shutdown System for Utility-Scale Wind Turbines (3002009038, 2017)
- Petitioned, Candidate, and Proposed Species Distribution and Electric Power Infrastructure: Considerations for Plants with Cooling Water Intake Structures, Hydropower Plants, Wind Energy, and Transmission Lines (3002006249, 2015)

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PROGRAM: P195 Protected and Endangered Species

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ANTPAL	*Antrozous pallidus* (pallid bat)
AWRR	Appleton-Whittell Research Ranch of the Audubon Society
CHOMEX	*Choeronycteris mexicana* (Mexican long-tongued bat)
dB	Decibel; a measure of sound intensity
EPTFUS	*Eptesicus fuscus* (big brown bat)
HF	High frequency
kHz	Kilohertz (1,000 Hertz, or 1,000 cycles per second)
LASBLO	*Lasiurus blossevillii* (western red bat)
LASCIN	*Lasiurus cinereus* (hoary bat)
LASNOC	*Lasionycteris noctivagans* (silver-haired bat)
LASXAN	*Lasiurus xanthinus* (western yellow bat)
LEPYER	*Leptonycteris yerbabuenae* (lesser long-nosed bat)
LF	Low frequency
MYOAUR	*Myotis auriculus* (southwestern myotis)
MYOCAL	*Myotis californicus* (California myotis)
MYOCIL	*Myotis ciliolabrum* (western small-footed myotis)
MYOOCC	*Myotis occultus* (Arizona myotis)
MYOTHY	*Myotis thysanodes* (fringed myotis)
MYOVEL	*Myotis velifer* (cave myotis)
MYOVOL	*Myotis volans* (long-legged myotis)
MYOYUM	*Myotis yumanensis* (Yuma myotis)
NYCspp	*Nyctinomops* species (big free-tailed or pocketed free-tailed bat)
PARHES	*Parastrellus hesperus* (canyon bat; formerly western pipistrelle)
SM4	Song Meter SM4BatFS Ultrasonic Recorder
SPL	Sound pressure level; the logarithmic measure of sound intensity a fixed location
TADBRA	*Tadarida brasiliensis* (Brazilian free-tailed bat)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

PROJECT SUMMARY

We selected two types of study locations to determine the deterrent effect that broadcasted ultrasound from low-power emitters have on bats. One location included foraging areas over remote water resources, and the other study site contained roosting bats in a metal-roofed concrete block garage. We hypothesized that the low-power ultrasound emitters would broadcast enough ultrasound to disrupt bat echolocation and bats would avoid both areas.

The water resource study was conducted from July 3-18, 2018. We chose the Appleton-Whittell Research Ranch of the National Audubon Society in Elgin, Arizona because: (1) it is an arid grassland habitat with limited surface water resources that helps concentrate bats, and (2) previous surveys documented a rich bat fauna that represents species or congeners found across all of North America, including surrogates for *Myotis* species currently listed by the USFWS as threatened or endangered. Five water resources at this location were suitable for the study.

The roost study was conducted from October 13-26, 2018. We chose a concrete block storage structure at the White Oak Conservation in Yulee, Florida that served as a day roost for *Myotis austroriparius* (southeastern myotis). This site was chosen because: (1) the *Myotis* roosting in the building are similar in behavior and habitat utilization to *Myotis septentrionalis* and *M. sodalis*, (the northern long-eared and Indiana myotis respectively), two federally-listed species regulated by seasonal and/or distance restrictions for tree management activities, and (2) the structure provided suitable areas for deploying emitters and time-lapse photography to test and monitor the effects of the emitter trials.

While testing the effectiveness of low-power ultrasound emitters, the technology and equipment used to study emitter effects (i.e., thermal cameras, infrared camcorders, and bat acoustic recording units) were also evaluated for their suitability in future bat monitoring studies. Appendix A summarizes results of our "best use" recommendations for the devices.

BACKGROUND FOR STUDY

The electric power industry faces regulatory and management challenges when addressing the presence of federal-, state- and/or locally-listed bat species on properties slated for development. This challenge becomes increasingly important as additional bat species are listed and will expand the geographic and temporal area where power industry activities could be limited. Currently, there are seasonal and/or proximity restrictions for tree management activities around summer maternity roosts that are occupied by listed bat species. These restrictions can be problematic when construction cannot be completed during the off-season, or when new roosts are found during compliance surveys and summer inventories conducted in an area scheduled for vegetation maintenance. These management issues have led to questions about whether there are safe methods to temporarily deter bats from a roost so that management activities could meet regulatory requirements, reducing or eliminating impacts to bats (defined as "take"). Temporarily deterring bats will create operational flexibility for many management activities. Moreover, deterring bats from occupied tree roosts is not necessarily detrimental since numerous studies have shown that these bats often use multiple roosts and regularly move between them throughout the summer season (Butchkoski and Hassinger 2002, Gumbert et al. 2002, Kurta et al. 2002, Silvis et al. 2014). Thus, if the electric power industry must harvest a tree that threatens public safety, and it is a known bat roost or has characteristics of a bat roost, deterrent technology may be used as a "best management practice" for bat mitigation.

High-powered ultrasound emitters used as bat-deterrents have shown promise in keeping bats from occupying treated airspace in previous studies (Szewczak and Arnett 2007, Szewczak 2011, Arnett et al. 2013, Kinzie 2018). High-power ultrasound emitters have a higher energy demand, but the main constraint is that manufacturing a unit to emit ultrasound over a large effective range makes high-powered ultrasound emitters less affordable (Table 1-1). As such, high-power emitters are less feasible for use in many habitats, or for lengthy periods of time. Low-power ultrasound emitters are readily available and have been used to exclude nuisance bats from both residential structures and for light industrial applications (M. Jensen, Binary Acoustic Technology, personal communication, March 27-April 4, 2019). These emitters can be easily powered with batteries and/or solar panels for short deployments and can be used to target specific locations with limited coverage areas. However, few systematic studies have evaluated them for uses like keeping bats out of areas where impacts on bats may be imminent, such as those subject to planned or ongoing vegetation management activities.

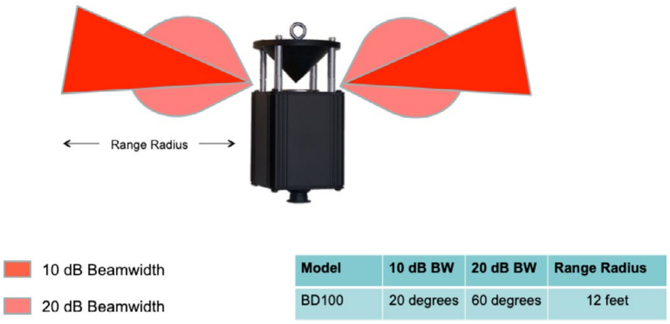
Table 1-1: Comparison of ultrasound emitter models by Binary Acoustic Technology

Model	Power	Field Strength (dB SPL @ 3.2ft)	Effective Range Radius (ft)	Frequency Band (kHz)	Dimensions (in)	Weight (lbs.)	Cost
AT800	High	104	39	20-80	12 x 12 x 7	< 5	$3800
BD-02-WP	High	110	29.5	20-80	48 x 12 x 8	< 5	Custom
SPD16	Ultra High	122	82	20-80	7.5 x 9.5 x 2.5	< 2.5	$2800
BD100	Low	96	12	20-80	6 x 2.6 x 2.6	< 1	$495

This study was a pilot study examining the effectiveness of using a low-power ultrasound emitter to deter bats from foraging or roosting habitats, and was performed similarly to previous studies using high- and ultra-high-powered equipment (Szewczak and Arnett 2007, Arnett et al. 2008, Horn et al. 2008, Arnett et al. 2013, Kinzie 2018). Results from this study will be used to determine the practical application of using low-power ultrasound emitters as a non-invasive technique to exclude bats from potential hazard areas. Results from this study may lead to options useful for conservation and management planning for electric power companies and other land managers.

TECHNICAL SPECIFICATIONS FOR BD100 UNIT

Ultrasound emitters used in this study were low-power, commercially available BD100 units (Binary Acoustic Technology, Tucson, Arizona, USA). These units have a maximum transmit power of 96 dB SPL with a frequency band of 20-80 kHz and an effective range of 12 ft (3.7 m). Two beamwidths are emitted from the units: (1) a cone-shaped 10 dB beam at 20 degrees from the unit and (2) an egg-shaped 20 dB beam at 60 degrees from the unit (Figure 1-1).



Model	10 dB BW	20 dB BW	Range Radius
BD100	20 degrees	60 degrees	12 feet

Figure 1-1: Diagram of broadcast zone of Binary Acoustic Technology BD100 ultrasound emitter, including beamwidth coverage and effective range.

The 10 dB is the main beam with the full effective range. The 20 dB beam is a secondary envelope, or sidelobe of the beam, which has roughly half the effective range but it widens the coverage area (M. Jensen, Binary Acoustic Technology, personal communication, March 27-April 4, 2019). The total power level of 96 dB is reduced (attenuated) over distance according to the frequency and intensity of the sound and due to environmental factors (e.g., relative humidity, temperature, wind, etc.). To calculate the distance of attenuation for an ultrasonic frequency of 50 kHz (the average frequency produced by the emitters), the considerations are*:

1. The total power level specified is the directional power level that the transducer will emit, measured at 3.2 ft (1 m) without the cone: 96 dB SPL @ 3.2 ft (1 m)
2. The cone spreads the energy outward reducing the power level at any point around the cone by –18 dB: Total power level measured at the side is (96 – 18) = 78 dB SPL @ 3.2 ft (1 m)
3. From this 78 dB SPL @ 3.2 ft (1 m), the SPL is reduced as a function of the distance beyond 3.2 ft (1 m)

The formula is:

dB SPL = 78 - 20 × log(distance-m / 3.2 ft [1 m]) - distance-m × humidity-factor

where:

distance-m = desired distance in meters away from the BD100

humidity-factor = a humidity-dependent attenuation (For relative humidity of 10 percent or less this number is about 1.0)

For example:

At a 4.0-meter radius the SPL is:
78– 20×log(4) – 4 = 62 dB

* Source: M. Jensen, Binary Acoustic Technology

Therefore, the greatest intensity of the average ultrasonic frequency (50kHz) emitted at maximum power for the unit (98 dB SPL) is within the first 3.2 ft (1 m).

The BD100 units are designed to impair bats' abilities to successfully echolocate by masking the return echoes from their calls, effectively creating sound that "blurs" target recognition. This makes bats unable to perform precise maneuvers near the airspace affected by the emitters. The units were not designed to broadcast sounds at intensities and frequencies to scare bats, which is an approach that can be ineffective since bats can become accustomed to such sounds (Binary Acoustic Technology website, Accessed 26 May 2018). Instead, the broadband ultrasound generated by the BD100 units merely makes bat echolocation less effective, causing the bat to avoid the broadcast zone for areas with more favorable acoustic conditions (Binary Acoustic Technology website, Accessed 26 May 2018).

UNDERSTANDING BAT ECHOLOCATION: HOW ULTRASOUND EMITTERS AFFECT BATS

Bat echolocation is analogous to submarine sonar: bats produce sound and listen for echoes in order to calculate distance to an object. But echolocation in bats is more specialized because it is done in air and with split-second timing that cannot be replicated even with the most sophisticated human technology.

When a bat echolocates, it produces a loud pulse of high-frequency sound in its larynx then emits that sound usually through its mouth (some species emit echolocation pulses through their noses). The sound creates "pressure" waves on the air, and these waves propagate through the air similar to how waves propagate through water. Through air, the propagation velocity is very high, with the speed of sound in air being approximately 1,129 feet per second (ft/s) [344 meters per second (m/s)]. When the sound wave hits an object, it bounces off as an echo and returns to the bat at the same speed. Bats listen to the echo, and discern minute differences in the return to each ear to precisely locate an object of interest in three-dimensional space (Farrar 1995, Fenton et al. 1995, Simmons and Stein 1980). Bats produce these echolocation pulses at rates of 1-200 times per second, listening to the return echo inbetween each outgoing pulse to properly adjust their flight speed and style relative to objects while navigating and foraging.

The duration of sound that bats use to echolocate is generally between 0.01 second, or 1 millisecond (ms), and 60-ms. And the frequency of sound that bats use to echolocate can be between 5-250 kHz. Humans can hear frequencies between 1-20 kHz. This makes most bat calls out of the range of human hearing, or what we refer to as "ultrasonic." Bats use high frequencies because they need very small wavelengths of sound in order to get echoes from very small targets, such as their insect food. To understand why, consider that any wave will travel at a speed equal to its frequency times its wavelength:

$$v = f \times \lambda$$

where v is the speed of sound, λ is the wavelength, and f is the frequency. And in air, the speed of sound is essentially constant, so this means that there is an inverse relationship between frequency and wavelength: as frequency increases, wavelength must decrease.

In general, a wavelength more than twice the length of a target will not bounce back; it will just pass around an object. However, a sound with a wavelength that is less than twice the length of a target will generate an echo and will bounce back to the bat (Fenton et al. 1998, Fenton 2004, Schnitzler and Kalko 2001, Simmons and Stein 1980). If bats need to receive echoes from very small insects, the sounds they use must have wavelengths that are also very small. Therefore bats need to use very high frequencies (Griffin 1958, Jones 1999).

While echolocating, bats can vary the duration, frequency, intensity, and pulse repetition rate of the sound they make during a sequence of pulses in order to perform precise movements, localize targets, and generate important target detail such as texture (Jones 1999). According to Surlykke and Kalko (2008) and Jakobsen et al. (2013), bats echolocate at intensities between 110-135 dB SPL at 3.9 inches (in) [10 centimeters (cm)], depending on species. The echoes from objects six feet (ft) [3.3 meters (m)] away are nearly 45 dB fainter due to the amplitude of the sound wave decreasing exponentially over distance traveled. As a result, bat calls must be very loud with a high SPL to be effective over any distance since sound attenuates rapidly (Figure 1-2).

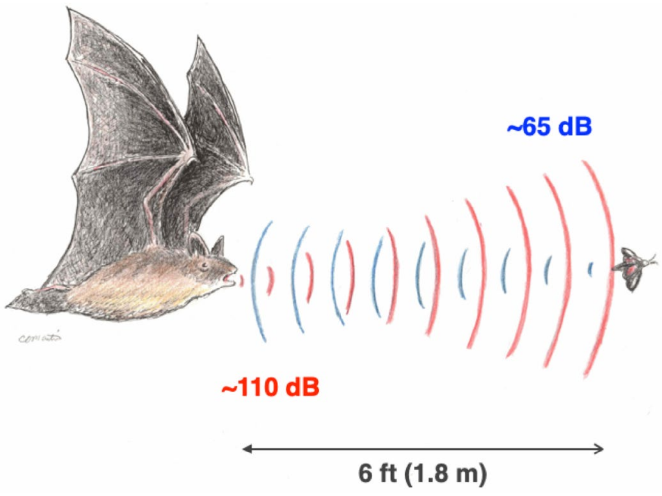


Figure 1-2: Diagram of a bat echolocating a target 6 ft (1.8 m) away with an echo return of 45 dB fainter (blue) than original sound level pressure (red)

As bats approach an object of interest such as an insect, the surface of the water to sip from a pool, or the surface of their roost to perform a pinpoint landing, their echolocation calls become much quieter and much more rapidly produced. At these times, the distance from which they can discern an echo and the time in which to interpret it also becomes much reduced. Anything that interferes with their ability to discern faint echoes from increasingly faint call pulses will disrupt their ability to navigate accurately.

The frequency band for the BD100 ultrasound emitters is 20-80 kHz. This covers the common search phase ultrasound emitted by bats and used for navigation and foraging (Murray et al. 2001, Fenton 2004). Broadcasting ultrasound in this frequency range at a 96 dB SLP @ 3.2 ft (1 m) is expected to over-ride echoes from bat echolocation pulses. This will cause bats to become ineffective while navigating through the broadcast area, thus deterring them from entering the airspace (Binary Acoustic Technology website, Accessed 26 May 2018).

DETERRING BATS

History

In response to human conflict with bats in buildings, the U.S. Fish and Wildlife Service (USFWS) published a public guidance document (USFWS 1982) detailing facts and techniques to eliminate bat problems. This guidance document emphasized non-lethal control methods, including the use of high-frequency sound to repel or disperse bats (USFWS 1982). Hill (1970) used high-frequency dog-training whistles to deter bats at a nuclear power station, which was shown to be effective within 48 hours of continuous operation (USFWS 1982). Other early experiments using ultrasound deterrence had not seen appreciable results; however, research on the effectiveness of high frequency sound to deter bats continued with the USFWS's development of the Bat-I-Cator in 1974, and the testing on bats of ultrasonic devices used for rodent control in 1980 (USFWS 1982, Hurley and Fenton 1980). As research on the properties of bat echolocation advanced, and technology for producing high-frequency sound improved, the potential to assess ultrasound as a bat deterrent was possible (Szewczak and Arnett 2007, Horn et al. 2008, Johnson et al. 2012, Arnett et al. 2013, Kinzie 2018).

Natural Defense

In nature, the use of ultrasound as a "bat deterrent" is evident among certain species of their insect prey. Ultrasonic clicks produced by peacock butterfly (*Inachis io*) have been shown to startle captive long-eared bats (*Plecotus auritus*) and pipistrelle bats (*Pipistrellus pipistrellus*) and ultimately cause the bats to avoid the insect (Mohl and Miller, 1975). The ultrasound is generated through three sound components produced by the peacock butterfly's eyespot display: grating sounds, low-intensity clicks, and high-intensity clicks, each with varying durations and SPLs (Mohl and Miller, 1975). Mohl and Miller observed that the most effective sound component affecting the bats was the high-intensity clicks with a SPL of 100-110 dB at 3-4 in (8-10 cm), where the maximum energy was focused at frequencies between 30-60 kHz. The sounds made by the butterfly are accompanied by a visual display that is designed to deter bird predators, but this was found to have no effect on bats. The bats' reactions were due to just the acoustic component of the display.

Several species of tiger moths (Family *Arctiidae*) have also developed natural ultrasound defenses against bats. Some use high-frequency ultrasound to warn bats that the moth is not palatable, startle predators especially naïve bats, or jam bat echolocation (Ratcliffe and Fullard 2005, Ratcliffe et al., 2008, Corcoron et al. 2009, Conner and Corcoron 2012, ter-Hofstede and Ratcliffe 2016). Different tiger moth species produce different sounds to escape bats (Conner and Corcoron 2012). Dog-bane tiger moth (*Cycnia tenera*) and milkweed tiger moth (*Euchaetes egle*) emit low-duty (i.e., low pulse repetition rates) ultrasonic clicks to coincide with "approach phase" bat echolocation calls. These competing clicks startle bats and prevent an attack (Ratcliffe and Fullard 2005, ter-Hofstede and Ratcliffe 2016). Several studies (Corcoron et al. 2009, Conner and Corcoron 2012) found that members of the genus *Bertholdia* are successful in jamming bat echolocation by emitting ultrasound with a high-duty cycle (increased number of clicks per second produced) and high-degree of frequency modulation (utilizing a broad frequency range) when the bat is located within a short distance of the attack. Corcoron et al. (2009) successfully found that *Bertholdia trigona* were able to successfully jam big brown bat (*Eptesicus fuscus*) echolocation calls and avoid capture. Clicks emitted by B. trigona were also noted to have a high-duty cycle which was equally effective at jamming bat echolocation. Other tiger moth species used in similar studies of prey-predator interactions emitted a low-duty cycle click that was more likely to startle or warn bats (Corcoron et al. 2009), though eventually bats would become acclimatized to the sound, after which they could successfully adapt and feed upon the moths. These studies support the technology used in the BD100 to create disruptive, "jamming" air-space rather than to "startle" bats with sound.

Using Ultrasound Emitters to Deter Bats

Studies on the use of sound to deter bats from hazardous airspace were prompted by high bat mortality events at wind turbines. (Szewczak and Arnett 2007, Arnett et al. 2008, Horn et al. 2008, Arnett et al. 2013, Kinzie 2018). Researchers hypothesized that ultrasound broadcasts within the rotor-swept zone of turbines would create the same disruptive "jamming" airspace that moths were known to produce. If so, bats would avoid these structures and fatalities at wind facilities would decrease (Szewczak and Arnett 2007, Arnett et al. 2008, Horn et al. 2008, Arnett et al. 2013, Kinzie 2018). In order to successfully test this hypothesis, equipment needed to be developed that was capable of broadcasting ultrasound to influence bats in the rotor-swept zone of a single turbine, which could exceed 5,000 square meters (m2). The result were high-powered, ultrasonic emitters similar to the AT800, BD-02-WP, and SPD16 available from Binary Acoustic Technology (Table 1-1.)

These high-power ultrasound emitters were first tested and proven effective at deterring bats from airspace where bats had been observed using water resources (Szewczak ad Arnett 2007, Johnson et al. 2012), and at bridges proposed for maintenance or replacement (Szewczak 2011). When installed in sufficient quantity at wind turbines (8 individual deterrent devices per turbine), results showed that broadcasting ultrasound frequencies in the rotor swept zone decreased the number of bat fatalities at turbine treatment sites compared to control sites where no deterrents were installed (Arnett et al. 2013, Kinzie 2018). Additionally, broadcasting ultrasound frequencies has deterred bats attempting to roost and forage within a flight cage (Spanjer 2006, Kinzie 2018). Unfortunately, due to their high energy needs, the high-power ultrasound emitters used in these trials are not feasible to deploy on a long-term basis or outside situations with dedicated power availability. Therefore, our study examined the effect of using a low-power ultrasound emitter to deter bats under similar situations: (1) discourage bat use of airspace near a favorable habitat, and (2) prevent bats from roosting in unwanted areas targeted with ultrasound broadcast.

2 ARIZONA WATER RESOURCE STUDY

INTRODUCTION

We tested the effectiveness of low-powered ultrasound emitters to deter bats as they approach to forage or drink at water resources. The study location in Arizona presented a unique opportunity to test the emitters in a place that had both: (1) a natural concentration of bats, and (2) documented species diversity. We hypothesized that ultrasound broadcasted in the airspace over water resources would decrease bats' abilities to use their echolocation, and they would avoid frequenting the areas.

Broadcasted ultrasound from *high-powered ultrasonic emitters* has proven to interfere with the ability of bats to precisely echolocate (Spanjer 2006, Szewczak and Arnett 2007, Arnett et al. 2013, Kinzie 2018). As a result, bats avoid entering the broadcast area. However, high-powered emitters are designed for treating large areas with ultrasound and require a dedicated power source typical of developments with existing major infrastructure. This study set out to determine if battery-powered *low-powered emitters* would achieve similar results at a more localized level. We used *thermal and night-vision video* observations to view bat activity and quantify the number of "bat sips" and "bat fly-bys" at each survey site. We also used *ultrasonic microphones and bat detectors* to record the number of "echolocation call sequences" as a measure of overall bat activity pre-, post-, and during treatment with ultrasonic emitters. Specifically, we set out to determine if emitters deployed at isolated water resources deter bats approaching the water and/or cause them to pass by without drinking. **At this site, we designed our study to answer four main questions:**

Question 1: Will the ultrasound broadcast have a deterrent effect on bat activity at treatment sites when compared to baseline data from the sites that was collected pre- or post-treatment?

Question 2: Will the ultrasound broadcast at treatment sites increase bat activity at nearby sites that remain untreated with broadcasted ultrasound?

Question 3: How long will it take for bat activity to rebound once treatment ceases, or will bats continue to avoid areas where they have encountered ultrasonic deterrents?

Question 4: Does the ultrasound broadcast have more effect on bats that predominantly use high-frequency echolocation calls than those that use low-frequency call types?

Bats must listen to increasingly faint, and increasingly broad bandwidth ultrasonic echoes, and interpret them with millisecond-precision to accomplish complex echolocation tasks such as approaching and sipping at the surface of the water or while foraging on aquatic insects (Spanjer 2006, Kinzie 2018). Therefore, any decline in bat activity during deterrent trials would indicate that the low-powered ultrasound emitter negatively affected the bats' abilities to utilize the resource. Because the deterrent is expected to have a jamming or blurring effect on bat echolocation, bats may be able to approach the water resource, but will eventually turn away without taking a sip, or bats will relocate to a site with a quieter airspace.

By simultaneously monitoring the airspace above and around all five survey sites at this location, we were prepared to detect any change in relative bat activity levels when emitter trials were started and stopped at certain sites while others were left un-treated. Sites were within 140-445 ft (43-136 m) of each other and up to 1.1 miles (2 km) distant. All were within the average nightly foraging range and commuting distances for the area bat species. A synthesis of decades of bat studies has addressed forest bat foraging range and commuting distances and found that across species, these values range between 247 - 7410 acres (10 - 3,000 hectares) and 0.31 - 15 miles (0.5 - 24 km) respectively (Lacki, et al. 2007).

Few previous studies have attempted to quantify bat activity post-treatment with ultrasonic broadcasts to determine any lingering deterrent effect on bats. By conducting pre-treatment monitoring with video and acoustic detectors, and post-treatment monitoring with acoustic-detectors alone, we were able to collect these data and determine continued deterrent effect, if any, on the population of bats affected by this study.

North American bat species are separated into two main acoustic guilds, based on the "characteristic frequency" or Fc (i.e., characteristic frequency represents the frequency with the lowest slope in an echolocation call pulse, generally this is also the frequency with the most energy or intensity), of their echolocation calls: (1) High-frequency bats that use echolocation calls which are predominantly >/= 35 kHz, and (2) Low-frequency bats that use echolocation calls which are predominantly </= 35 kHz. The emitters in this study broadcast ultrasound with a broadband frequency range of between 20 – 80 kHz. Previous studies using high-powered deterrents showed a slight difference in effect on these two guilds of species (Kinzie 2018). By recording bat echolocation with acoustic detectors, we were able to identify and analyze activity from high- and low-frequency bat species to determine any differences in effect from the deterrents between the two guilds.

STUDY LOCATION

Similar to field tests performed by Szewczak and Arnett (2007), we chose the Arizona study location because it was comprised of a species diversity reflective of North America as a whole. Due to the arid environment at this location, our survey sites at remote water resources were a significant attractant to bats of all species (Taylor and Tuttle 2007, Korine et al. 2016). Bats drink on the wing at pooled water resources and many of these water resources create vegetative communities that provide increased insect diversity and abundance. This provides not only drinking but also foraging opportunities for bats (Tuttle et al. 2006, Taylor and Tuttle 2007). In a combined capture and acoustic survey at this site conducted during the summer of 2017, bat activity from 14 different bat species was confirmed at these water resources (Tyburec, 2017). Testing low-power ultrasound emitters at locations with rich and concentrated bat diversity such as at AWRR will provide data on the effectiveness of low-powered emitters on numerous bat species that will have continent-wide application.

In 2018 the permanent water resources with known bat activity at AWRR were revisited to determine their suitability for treatment with ultrasound emitters. Five water resources were selected; three within the vicinity of AWRR Headquarters (Sites 1-3), and two sites about one mile (1.6 km) southeast of Headquarters known as McDaniel tanks (Sites 4, 5) (Figure 2-1). All water resources continued to provide an unobstructed "swoop zone," allowing bats of all flight types to perform the necessary "touch and go" landing required to successfully drink on the wing.

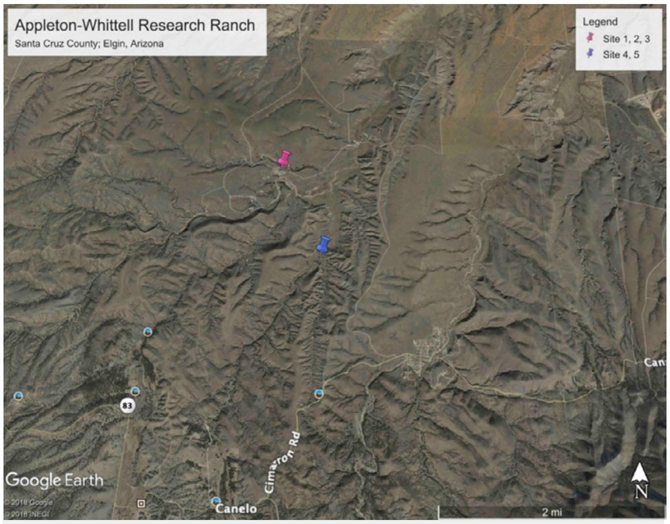


Figure 2-1: Project Location. Appleton-Whittell Research Ranch of the National Audubon Society, Elgin, Arizona, USA; 31.590860° N; -110.507247° W

The Headquarters sites included two concrete water troughs (Sites 1 and 2) and a constructed pond (Site 3). The dimensions of the concrete troughs were approximately 14 ft x 4 ft x 18 in (4.3 m x 1.2 m x 46 cm) with an open water surface of approximately 10 ft x 2 ft (3 m x 0.6 m) (Appendix B, Photo B-1, and B-2). Site 1 was located approximately 140 ft (43 m) northeast of Site 2 (Figure 2-2). Site 3 exhibited natural characteristics, including ground-level topography, fringe vegetation, and sediment substrate (Appendix B, Photo B-3, and B-4). The size of Site 3 was approximately 10 ft x 10 ft (3 m x 3 m). Site 3 was approximately 445 ft (136 m) southeast of Site 2 (Figure 2-2).

Figure 2-2: Distance between sites at Research Ranch Headquarters

A barn located adjacent to Site 2 was an active bat roost. Several species of bats used the barn as both a day roost and night roost. A single-chamber bat house installed on the west side of the barn, within 15 ft (4.6 m) of the concrete water trough at the site, was also an active day roost.

The McDaniel tanks (Sites 4 and 5) were constructed ponds approximately 1.1 mi (2 km) southeast of the Headquarters sites. The ponds were created in 2017 and exhibited natural characteristics, including ground-level topography, fringe vegetation, and sediment substrate, and contained submerged or partially submerged organic debris such as branches and logs (Figure 2-3; Appendix B, Photo B-5). Sites 4 and 5 were approximately 25 ft (8 m) apart and approximately 75 ft (23 m) and 35 ft (11 m) in diameter, respectively.

Figure 2-3: Location of McDaniel Tanks, Site 4, and Site 5. These ponds were not yet constructed at the time of this aerial photograph.

METHODS

Equipment Deployment and Data Collection

Methods for ultrasound emitter field tests at these five water resource sites were similar to methods detailed in the document *Field Test Results of a Potential Acoustic Deterrent to Reduce Bat Mortality from Wind Turbines* (Szewczak and Arnett 2007). However, unlike the high-power ultrasound emitters used in the study by Szewczak and Arnett, this study used low-power, commercially available BD100 units (Binary Acoustic Technology, Tucson, Arizona, USA). These units transmitted continuous broadband ultrasound at 20-80 kHz, with a maximum transmit power of 96 dB SPL, and an effective range of 12 ft (3.7 m).

Three quantifiable metrics were used at each survey site in this study: (1) "bat fly-bys" over the water resource, (2) "bat sips" from the surface of the water, and (3) "echolocation call passes" at the survey site. Szewczak and Arnett (2007) quantified only "bat fly-bys." A "sip" was defined as any obvious sip a bat took at the surface of the water. This usually created a ripple in the water. However, "close proximity" of the bat to the surface of the water was also defined as a "sip" since not all sips created an obvious ripple. Ripples were easily masked by a shadow. And, depending on weather conditions, ripples occurred in the water prior to the bats' presence. To be consistent during each video review, a distance value for "close proximity" to the surface of the water was determined prior to video review at each site. Every "sip" a bat took at the surface of the water was counted (Appendix B, Photos B-6 and B-7). A bat "fly-by" was defined as activity by a bat away from the surface of the water and not defined as a "sip." Each time a bat entered then left the viewing area was counted as a "fly-by" if it was not determined to be a "sip" (Appendix B, Photos B-8 to B-11).

By adding the "sips" metric, we were able to quantify the effect of ultrasonic broadcast on bats when they had to perform up-close maneuvers. This was especially important given the limited broadcast range produced by the low-power emitters used during the survey. Additionally, we employed ultrasonic bat detectors to collect "echolocation call passes" within the airspace surrounding the survey sites. This represented a larger area than could be viewed with the video monitoring equipment. If general bat activity in this larger area is also reduced during the deterrent trials, it could indicate that non-naïve bats (i.e., bats that have encountered the "jamming" or "blurring" effects of the low-powered deterrent on previous nights), would avoid the area prior to actually encountering the broadcast at distances that would actually disrupt their echolocation abilities.

Bat activity was monitored at Site 1 and Site 2 using THOR-HD thermal imager (American Technology Network Corporation, San Francisco, California, USA). Site 3, 4, and 5 were monitored using an AX700 NightShot infrared camcorder (Sony Corporation, Minato, Tokyo, Japan) with auxiliary infrared lights. Thermal imagers were recalibrated periodically each night due to changing environmental conditions. As a result, multiple video files were generated per night per site. Infrared camcorders generated one video file per night. A typical survey night with video and ultrasound emitter deployment occurred between 19:30 and 23:30 (Appendix C).

Sites were also monitored with a Song Meter SM4BAT-FS (SM4) bat detector with a cabled SMM-U1 omnidirectional ultrasonic microphone (Wildlife Acoustics, Maynard, Massachusetts, USA). Microphones were positioned atop a 12-18 foot (3.7-5.5 m) mast to collect recordings at typical bat-flight heights and eliminate any interfering echo from the pooled water surfaces. Masts were located within 6-10 ft (1.8-3 m) of the water source at each site. We programmed bat detector "triggers" appropriate for high-frequency sounds typical of bat echolocation call pulses. This effectively ignored other high-frequency triggers (i.e., from insects, anthropogenic nose, and the ultrasound emitters themselves). Bat detectors automatically turned on 20 minutes (min) after sunset and recorded until 20 min before sunrise each night. (Appendix C). Bat detectors recorded for 15-18 consecutive nights, collecting echolocation call passes from a volume of at least 500 m3 (17,650 ft3). This value is the minimum volume of detection based on the frequency and intensity of the bat echolocation call types. Species that use lower frequencies and/or higher intensities will be picked up at greater distances from the detector, up to 60 m (200 ft).

Baseline monitoring, before deploying deterrents, began on 3 July 2018. Deterrent trials began on 6 July 2018, and post-treatment monitoring began on 12 July 2018. Each site included between 2-3 consecutive baseline monitoring nights, 4-7 consecutive nights of deterrent trials, and 4-8 consecutive nights of post-treatment monitoring. Baseline monitoring was done with video cameras and bat detectors at each site. Deterrent trials were conducted for periods of 1:45-4:30 hours each night, with start times between 19:00h-20:30h and end times between 20:30h-23:45h at the different sites depending on logistics, weather, and equipment function. A portable, hand-held ultrasonic detector with near-real-time audio/video (e.g., echolocation call spectrograph display) output was used to ensure ultrasound emitters were functioning (SonobatLIVE [Arcata, CA] on a Microsoft SurfacePRO [Redmond, WA] with a Pettersson M500 USB microphone [Uppssla, SWEDEN]). Ultrasonic emitters were paired with video-monitoring and bat detectors during each trial. Post-treatment monitoring was done with video equipment and bat detectors, or bat detectors alone. Appendix C provides a site-by-site detail of monitoring equipment deployed, and the deterrent trials conducted. General notes for trials and monitoring at each site are detailed below.

Site 1: An ultrasound emitter was deployed and operated at Site 1 from July 6-14 for a minimum of 1:40h and a maximum of 4:21h, with most of the nights surveyed for approximately 3:40h, depending on logistics, weather, and equipment function. The ultrasound emitter was attached to a pole and positioned approximately 32 in (81 cm) above the water's surface. Bat activity was recorded using a thermal imager and ultrasonic SM4 bat detector. From July 15-18, the ultrasound emitter was removed from Site 1, and post-treatment data was collected.

Site 2: baseline data collection at Site 2, no ultrasound emitter was deployed because the site was adjacent to an active bat day-roost. However, Site 2 was monitored with video and ultrasonic bat detectors to collect "non-treatment site" data. This was used to compare relative bat activity while ultrasound emitters were operating nearby at Sites 1 and 3. A bat detector was deployed at this site for the entire survey period. A thermal imager was deployed to document bat activity from July 6-14. A bat detector alone continued to record bat activity from July 15-18, concurrent with post-treatment bat activity collected with bat detectors at Sites 1 and 3.

Site 3: An ultrasound emitter was deployed and operated at Site 3 from July 6-11 for a minimum of 3:00h and a maximum of 4:12h, with most of the nights surveyed for approximately 3:50h. The ultrasound emitter was attached to a pole and positioned approximately 60 in above the water's surface on July 6; however, the unit was lowered to 32 in (81 cm) above the water's surface on July 7 to match the height of the emitter deployed at Site 1. Bat activity was documented using an infrared camcorder. From July 12-18, the ultrasound emitter was removed from Site 3, and post-treatment data was collected.

Site 4: At Site 4, four emitters were deployed from 12-15 July for a minimum of 0:43h and a maximum of 3:38h, with most nights surveyed for approximately 3:30h. Emitters were deployed approximately 33 in (84 cm), 32 in (81 cm), 34.5 in (87.6 cm), and 29.5 in (74.9 cm) above the surface of the water. Since the effective range of an ultrasound emitter was 12 ft (3.7 m), the four emitters were deployed at distances of 24.7 ft (7.53m), 20 ft (6.1 m), 23 ft (7 m), and 25.3 ft (7.71 m) from each other to maximize horizontal coverage of the water resource. During each treatment night, an infrared video camcorder documented bat activity at the same time ultrasound emitters operated.

Site 5: Three ultrasound emitters were deployed and operated from July 5-11. The minimum time equipment operated was 0:43h and the maximum was 3:38h, with most of the nights surveyed for approximately 3:30h, depending on logistics, weather, and equipment function. The height of each of the three ultrasound emitters above the surface of the water was 38 in (97 cm), 30 in (76 cm), and 59 in (150 cm). Due to tree limbs in the water, one ultrasound emitter was placed at 59 in (150 cm) to rise above the debris. Since the effective range of the ultrasound emitter was 12 ft (3.7 m), the emitters were deployed at 21 ft (6.4 m), 16 ft (4.9 m), and 19.5 ft (5.94 m) from each other to maximize horizontal coverage of the water resource (Appendix B, Photo B-12). During each treatment night, an infrared video camcorder documented bat activity at the same time ultrasound emitters operated. All three ultrasound emitters at Site 5 were removed on July 12, and post-treatment bat activity was recorded using an infrared video camcorder through July 15 (Table 2-1).

Sites 4 and 5 Combined: To determine if bat sips and flybys at non-treatment sites increase while adjacent sites are treated, no ultrasound emitters were deployed at Site 4 while emitters were operating at Site 5. During this time period, Site 4 was monitored with an infrared camcorder to collect data at a site with no treatment while ultrasound emitters were operating at Site 5 (Table 2-3). Once ultrasound emitters were removed from Site 5 on July 12, four ultrasound emitters were then deployed and operated at Site 4 beginning on July 13. This was done to determine if the bat activity would shift from Site 4 to Site 5 after the ultrasound emitters were removed at Site 5. Treatment continued at Site 4 until July 15. An infrared video camcorder continued to document bat activity at Sites 4 and 5.

An SM4 bat detector was deployed between Sites 4 and 5 on July 3-5. The unit was moved to the south end of Site 4 (i.e., non-treatment site) from July 6-11, primarily to record bat echolocation calls at one pond at a time instead of recording calls from both ponds combined. With the exception of July 5, the bat detector was not recording adjacent to the operating ultrasound emitters like the equipment setup at the Headquarters sites (Sites 1-3). During treatment with the ultrasound emitters at Site 4 from July 12-15, the bat detector was moved to the south end of Site 5 (i.e., non-treatment site). The bat detector was returned to its original location between Sites 4 and 5 at about 23:00 on July 15 after all other equipment was removed from the site. Post-treatment bat activity was collected using only a bat detector from 23:00h on 15 July through dawn on 19 July.

Weather Data

Weather data were collected from an on-site AWRR weather station where data were reported online by https://www.wunderground.com. Since weather conditions may affect bat activity, only nights with favorable weather were analyzed. Favorable weather conditions were considered to be temperatures equal to or above 59 degrees Fahrenheit ([°F], 15 degrees Celsius [°C]), wind speeds no greater than 9 miles per hour [mph] (14.5 kilometer per hour [kph]) for more than 30 min, and precipitation for less than 30 min between 19:30 and 23:30 for the video monitoring and 19:30-05:00 for the bat acoustic monitoring survey. These thresholds describing favorable weather conditions were based on extrapolating similar metrics for Indiana, Northern long-eared myotis, and Florida bonneted bat survey guidelines. (USFWS 2019).

Table 2-1: Summary of baseline data collection, treatment, and post-treatment at all five water resource sites, including dimensions of water resource, number of ultrasound emitters deployed, and height of each deployment

Site No.	Dimension ft (m)	Ultrasound Emitters	Ultrasound Emitter Height, in (cm)	Baseline Data Collection	Treatment Data Collection	Post-treatment Data Collection
1	10 x 2 (3 x 0.6)	One	32 (81)	July 3-5	July 6-14	July 15-18
2	10 x 2 (3 x 0.6)	No treatment	No treatment	July 3-5	No treatment	No treatment
3	10 x 10 (3 x 3)	One	32 (81)	July 4-5	July 6-11	July 12-18
4	75 (23) diameter	Four	33/32/34.5/29.5 (84/81/87.6/74.9)	July 3-4	July 12-15	July 16-18
5	35 (11) diameter	Three	38/30/59 (97/76/150)	July 3-4	July 5-11	July 12-18

Data Analysis

Video files from all thermal imagers and infrared camcorders were downloaded and then processed through Final Cut Pro software (Apple Corporation, Cupertino, California, USA) to include time and date stamp. Video files recorded at all five sites from July 3-11 were reviewed using video viewing software such as QuickTime Player 7 (Apple Corporation, Cupertino, California, USA) or VLC Media Player (VideoLAN Organization). Video files included for data assessment spanned the pre-treatment and treatment survey dates from July 3-11 at all five survey sites. Due to unfavorable weather conditions and inconsistent equipment relocation, video files from July 12-15 were not included in the data analysis.

The viewing area was defined as the entire field of view captured by the video equipment. This entire area was included to decrease subjectivity by each reviewer when determining bat proximity to the water resource in three-dimensional space represented on a two-dimensional screen. For the video review, bat activity was divided into two categories: (1) "sips," and (2) "fly-bys" at the water resource.

Song Meter SM4BAT bat detectors were used to: (1) quantify relative bat activity at each site pre-treatment, during treatment, and post-treatment, (2) document any decrease in activity at sites during treatments and compare to relative bat activity without treatment, (3) determine if or how quickly it will take bats to return to the treatment sites post-treatment, (4) document species occurrence at each site, and (5) document any difference in the deterrent effect on species that predominantly use high-frequency echolocation calls vs. low-frequency echolocation calls.

Data from bat detectors at each site were downloaded and post-processed using the SonoBat DataWizard to insert the site meta-data and date/time-stamps for each triggered event (i.e., bat echolocation call pass). The SonoBat4 viewer was used to manually identify each recording to quantify each bat pass and classify it to species or species-guild when possible. Recordings with bat echolocation call passes from multiple individuals and/or species were identified and accounted for as separate passes so the relative bat-pass metric could be accurately assessed at each monitoring site. Bat passes from echolocating bats at each site were then used as comparisons to bat activity identified in the video recording analysis.

Bat acoustic files were "batched" using SonoBat 4.3 Full-Spectrum Analysis Software (SonoBat, Arcata, California, USA). The batch-process allowed every bat pass at every site from every date/time-index to be quantified, so relative numbers of files collected pre-treatment, during treatment, and post-treatment could be counted to determine the effects of the ultrasound emitters on relative bat activity at each site, each night during the survey period.

Statistics

Video Files

Observations of successful water "sips" and bat "fly-bys" were summed at each of the treatment sites from July 3-11 (Sites 1, 3, and 5), each night, with and without treatment with an ultrasound emitter. Summed activity was divided by the duration of observation to obtain "sips" and "fly-bys" per hour rates. The resulting metrics were collected at the water resources for the first nine nights of video review, July 3-11. Only the data collected for three or more hours at each site were included in the statistical analysis. Times prior to 19:50h were excluded due to no bat activity. Analysis of Variance (ANOVA) was used to compare bat activity between treatment and non-treatment nights using R software for statistical computing (R Foundation for Statistical Computing, Vienna, Australia). Response of "sip rate" to treatment and response of "fly-by rate" to treatment were analyzed using ANOVA. These analyses included ANOVA with treatment as a fixed effect within sites (with site as a random effect) using Type III Sums of Squares (for unbalanced design) and ANOVA with treatment as a fixed effect within sites (with site as a random effect and treatment effects scored within sites) using REML in the R package. The REML test helped strengthen the results of the ANOVA analyses. The REML test was added since it handles random effects well and is more robust on unbalanced designs. The two sites exclusively without treatment from July 3-11, Site 2, and Site 4, were not included in statistical analyses for the video data because results showed neither was independent of the treatment sites. Nonetheless, these data are graphically represented. Finally, video data collected on July 9 were excluded from all analyses due to unfavorable weather conditions.

Bat Acoustic Files

ANOVA was used to compare total acoustic bat activity as measured by total number of "bat echolocation call passes" per site and per night throughout the pre-treatment, treatment, and post-treatment periods, using R software for statistical computing. ANOVA was also used to compare the effect the ultrasound emitters had on bats with predominantly high-frequency (>35 kHz) versus low-frequency (<35 kHz) echolocation call types during treatment and non-treatment nights. Due to the presence of high-frequency ultrasound interference at one treatment site (Site 3) and, due to the absence of a bat detector at another treatment site (Site 5), Site 1 was the only treatment site with bat acoustic data useable for statistical analysis. The analysis examined the change in acoustic activity on nights when ultrasound emitters were operating versus nights when they were not. The data were separated into an early period during which time the ultrasound emitters were operating, and a late period when ultrasound emitters were never operating. The early period was defined as 19:00-23:59, and the late period was 00:00-04:59. For this analysis, treatment Site 1 was compared to non-treatment Site 2. Analysis was restricted to July 3-17 so that the same amount of data was used for each site. No bat detector data were collected at Site 2 on July 18 due to the memory card reaching maximum capacity on July 17. Bat acoustic data collected on July 9, 12, and 13 were excluded from all analyses due to unfavorable weather conditions.

RESULTS

Video Monitoring

For the first nine survey nights July 3-11, 2018, 95 hours of video files were reviewed from the three treatment sites (1, 3, and 5) and 61 hours from the two non-treatment sites (2 and 4). Video night data reviewed on July 9 from all sites were eliminated from analysis due to unfavorable weather, and video files from July 12-15 were not reviewed due to unfavorable weather conditions and inconsistent equipment relocation.

Mean "sips per hour" decreased by 95.3 percent at Site 1, 74 percent at Site 3, and 88.6 percent at Site 5 while ultrasound emitter(s) were operational compared to the baseline data collected prior to operation (Table 2-2). In addition, there was a significant decrease in the total number of "bat sips per hour" at each individual site at all treatment sites (Figures 2-4 to 2-7; f1,2 = 41.9, p = 0.023). ANOVA tests using REML in the R package had a similar result, supporting Type III Sums of Squares analysis. These results indicate that ultrasound emitters *are* effective at inhibiting bat sips at the surface of the water.

Table 2-2: Mean (SE) sips per hour by site and treatment

Site	Baseline	Treatment	Percent Reduction
1	31.6 (3.2)	1.5 (0.5)	95.3
3	112.5 (13.7)	29.2 (5)	74
5	137.8 (13.5)	15.7 (1.1)	88.6

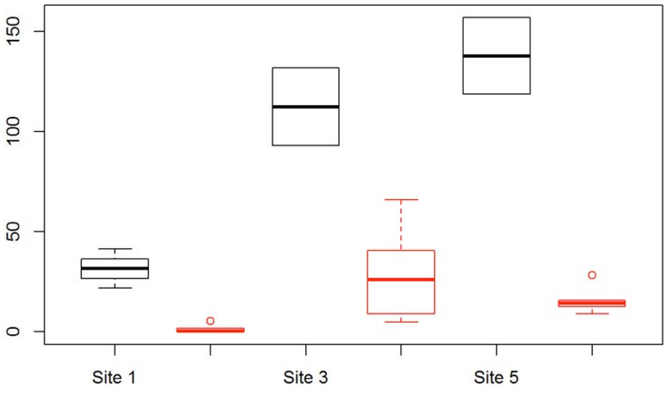


Figure 2-4: Boxplot: Raw sips per hour. Treatment nights in red.

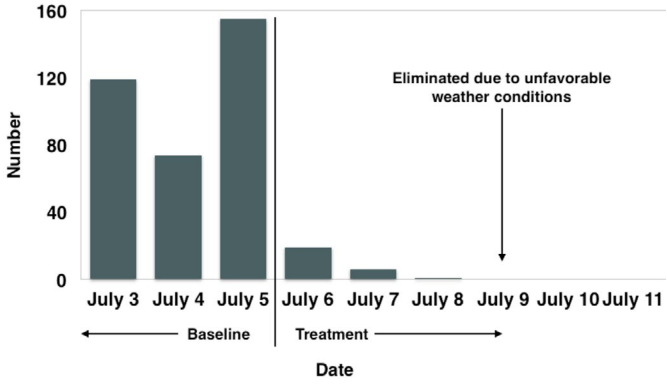


Figure 2-5: Site 1 video review, sips per night, July 3-11, 2018. Baseline data were collected prior to operation of the ultrasound emitter and treatment data were collected during the operation of the ultrasound emitter.

At the AWRR Headquarters sites (Sites 1-3), while bat activity, measured by total number of sips, decreased at treatment Site 1 and Site 3, the total number of sips increased at Site 2 where no ultrasound emitter was operating (Figure 2-8). Similarly, total number of sips at treatment Site 5 decreased during ultrasound emitter operation while the total number of sips at Site 4 increased during the same time frame (Figure 2-9). An exception to this was on July 3 at Site 4. Bat activity during baseline data collection on July 3 at Site 4 was comparable to bat activity while ultrasound emitters were operating at Site 5.

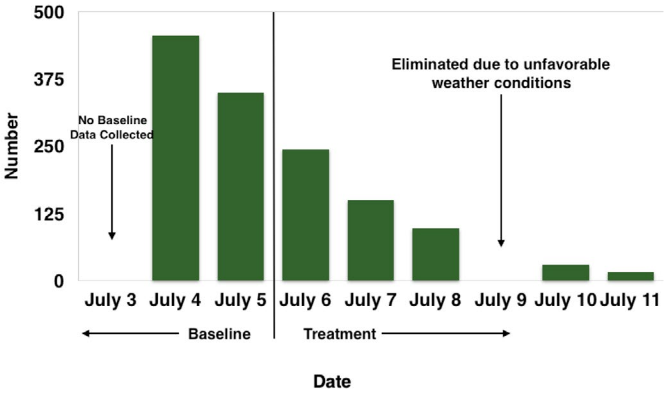


Figure 2-6: Site 3 video review, sips per night, July 3-11, 2018. Baseline data were collected prior to operation of the ultrasound emitter, and treatment data were collected during the operation of the ultrasound emitter.

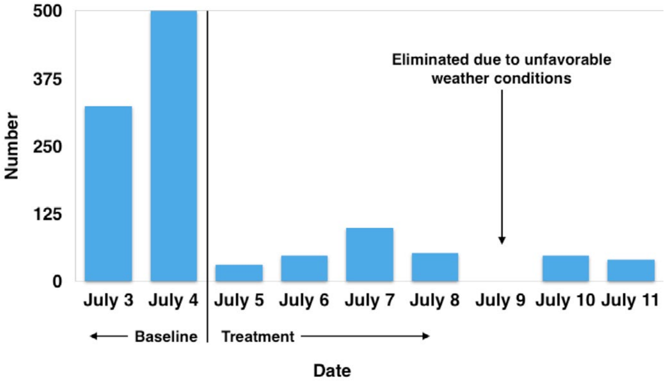


Figure 2-7: Site 5 video review, sips per night, July 3-11, 2018. Baseline data were collected prior to operation of the ultrasound emitter, and treatment data were collected during the operation of the ultrasound emitter.

Mean bat "fly-bys per hour" varied among treatment sites with the greatest reduction in bat fly-bys observed at Site 5 (78.4 percent) during the operation of ultrasound emitter(s) compared to the baseline data collected prior to operation. Mean fly-bys per hour decreased by 2.6 percent at Site 1 and 10.9 percent at Site 3 (Table 2-3). Bat activity summed at each individual site measured by the "total number of fly-bys" decreased at all treatment sites (Figure 2-10 to 2-13). However, ANOVA tests did not show a statistically significant fly-by rate with treatment (f1,2 = 2.06, p = 0.287). ANOVA tests using REML in the R package had a similar result, supporting Type III Sums of Squares analysis. These results suggest that ultrasound emitters are not effective at inhibiting bat fly-bys within the area encompassed by the video viewing area.

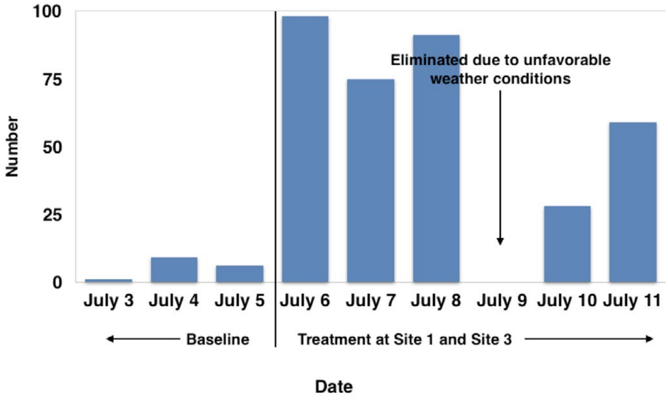


Figure 2-8: Site 2 (no treatment) video review, sips per night, July 3-11, 2018. Baseline data were collected prior to operation of the ultrasound emitters at Site 1 and 3. Data collection continued at Site 2 while ultrasound emitters were operating at Site 1 and 3.

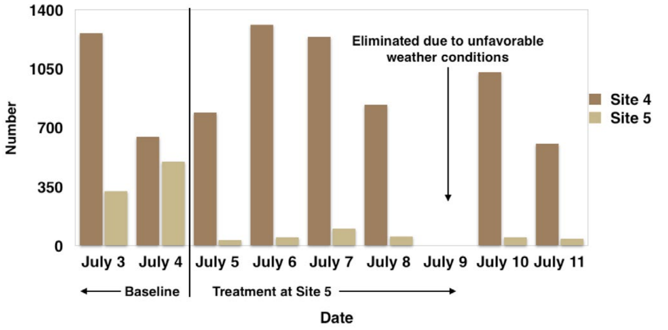


Figure 2-9: Site 4 (no treatment) and Site 5 (treatment) video review comparison, sips per night, July 3-11, 2018. Baseline data were collected at both Site 4 and 5 prior to operation of the ultrasound emitters at Site 5. Data collection continued at Site 4 while ultrasound emitters were operating at Site 5.

Bat Echolocation Monitoring

Ultrasound Emitter Trials

Number of echolocation call passes per hour, per night

Using data collected from bat detectors, Site 1 showed the most convincing correlation between treatment and depressed bat activity, when compared to baseline data. During pre-midnight, baseline data collection between 19:00-23:00h on July 3-5, the bat detector recorded an average of 12 to 30 bat passes per hour. During this same time period on July 6-12 when emitters were operational, bat activity averaged between 0-10 bat passes per hour. Additionally, bat passes per hour increased each night after treatment ceased between 23:00-23:30h. Once ultrasound emitters were permanently removed on the night of July 15, pre-midnight bat activity increased to an average of 25-60 bat passes per hour (Figure 2-14).

Table 2-3: Mean (SE) fly-bys per hour by site and treatment

Site	Baseline	Treatment	Percent Reduction
1	15.1 (1.6)	14.7 (2.2)	2.6
3	44 (1.3)	39.2 (3.9)	10.9
5	83.4 (27.4)	18 (1.9)	78.4

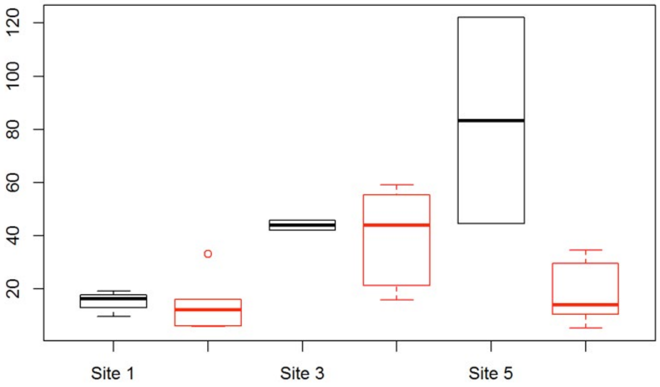


Figure 2-10: Boxplot: Raw fly-bys per hour. Treatment nights in red.

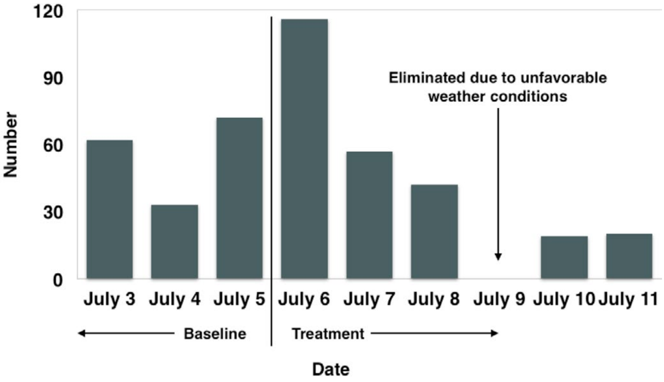


Figure 2-11: Site 1 video review, fly-bys per night, July 3-11, 2018. Baseline data were collected prior to operation of the ultrasound emitter, and treatment data were collected during the operation of the ultrasound emitter.

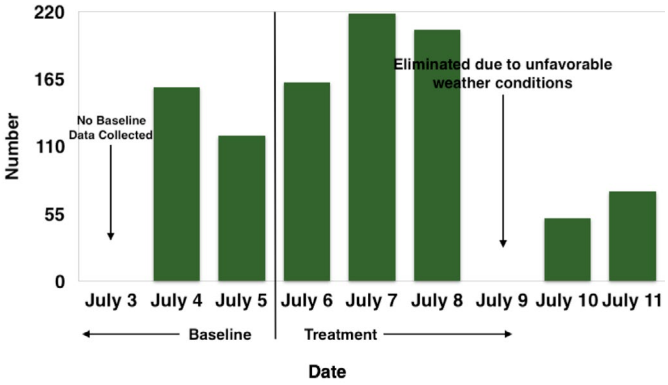


Figure 2-12: Site 3 video review, fly-bys per night, July 3-11, 2018. Baseline data were collected prior to operation of the ultrasound emitter, and treatment data were collected during the operation of the ultrasound emitter.

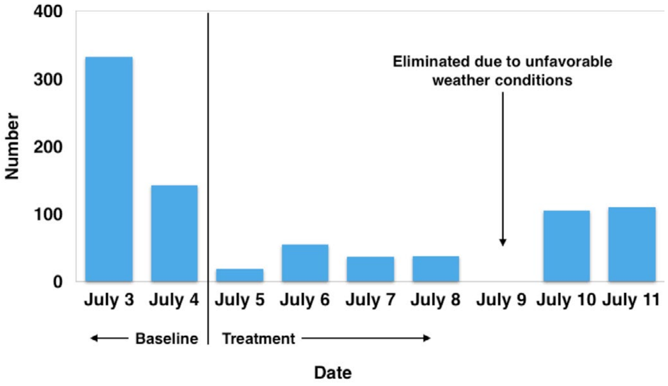


Figure 2-13: Site 5 video review, fly-bys per night, July 3-11, 2018. Baseline data were collected prior to operation of the ultrasound emitter, and treatment data were collected during the operation of the ultrasound emitter.

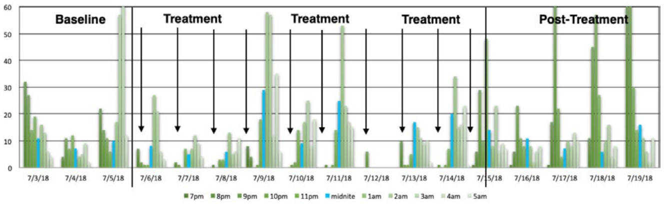


Figure 2-14: Site 1 acoustic call data, bat passes per hour per night.
Treatment occurred between 19:30 and 23:30.
Unfavorable weather conditions were reported by AWRR weather station on July 5, 9, and 12; unfavorable weather was observed on July 13.

At Sites 4 and 5, bat passes per hour show that the ultrasound emitter did not have an effect on bat activity at the adjacent pond where no treatment occurred. This result suggests that the effective range of the ultrasound emitters did not extend to the adjacent site, approximately 25-50 ft away. With the exception of July 5, the bat detector recorded bat passes at the pond where no ultrasound emitter was present. On July 5, the bat detector recorded bat passes from both Sites 4 and 5 (treatment and no treatment) combined. Pre-midnight bat activity on July 5 was depressed, as compared to the baseline data collected on July 3-4 (Figure 2-15).

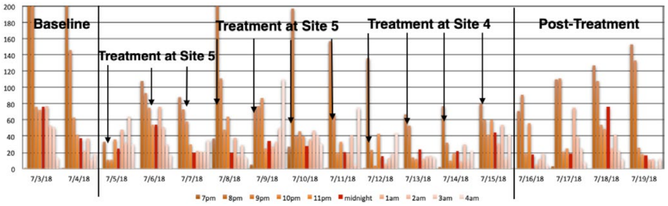


Figure 2-15: Acoustic call data, bat passes per hour per night at Site 4 and Site 5
On July 5, bat passes were recorded between Site 4 (no treatment) and Site 5 (treatment). From July 6-15, bat passes were recorded at opposite site of treatment. Unfavorable weather conditions were reported by AWRR weather station on July 5, 9, and 12; unfavorable weather was observed in the field on July 13.

Pre-midnight bat passes decreased at Site 3 during treatment compared to the baseline data. Bat echolocation call passes went from a high of 100 per hour when the ultrasound emitter was non-operational to less than 20 per hour when it was operational. However, when ultrasound emitters were permanently removed after the survey night of July 11, there was no re-bounding of bat activity to numbers matching bat passes during baseline data collection, as observed at Site 1 (Figure 2-16). Further analysis of the recordings at this site noted the presence of high-frequency interference (Figure 2-17). This interference was unlike that which was recorded from the ultrasound emitters (Figure 2-18). Additional research would be needed to determine if this high-frequency interference may have been responsible for bat activity not re-bounding to numbers matching bat passes during baseline data collection.

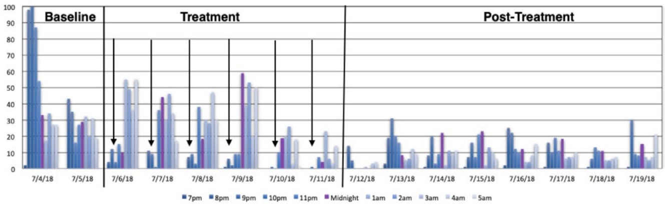


Figure 2-16: Site 3 acoustic call data, bat passes per hour per night
Treatment occurred between 19:30 and 23:30.
Unfavorable weather conditions were reported by AWRR weather station on July 5, 9, and 12; unfavorable weather was observed in the field on July 13. Post-treatment bat activity did not re-bound to numbers matching bat passes during baseline data collection.

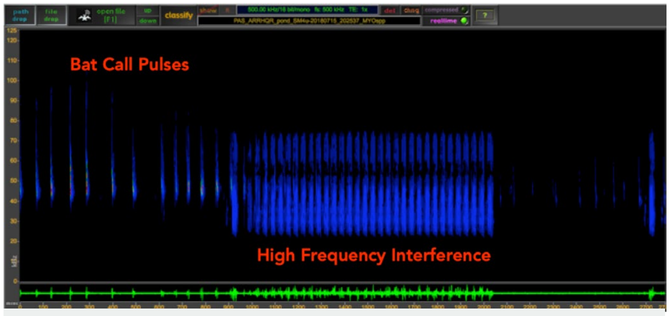


Figure 2-17: Acoustic recording of bat call pulses and high-frequency interference at Site 3. There was no re-bounding of bat activity to numbers matching bat passes during baseline data collection, possibly due to the unexpected high-frequency interference.

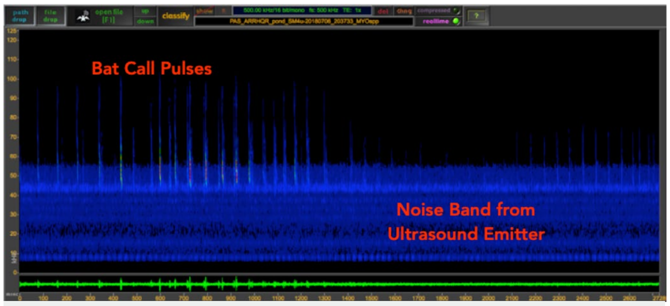


Figure 2-18: Effect of ultrasound emitter on the soundscape surrounding the unit.

Site 2 showed the greatest variability in bat activity each night from a low of 400 bat passes per hour to a high of 1600 bat passes per hour. Activity at Site 2 more than doubled during treatment nights at Sites 1 and 3 on July 9, 10, and 11 compared to baseline data collection and pre-midnight activity. The bat detector's memory card at Site 2 reached maximum capacity around 21:30 on the night of July 18; therefore, continuous data collection occurred from July 3-17.

ANOVA Tests

Mean total echolocation call passes per night for time of night (i.e., "early" or "late") and date decreased at treatment Site 1 by 91.5 percent during the operation of ultrasound emitter(s) compared to the baseline data collected prior to operation (Table 2-6). During the same time at the non-treatment Site 2, bat activity increased by 67 percent compared to baseline data. When ultrasound emitters were not operating (i.e., "late"), acoustic bat activity rebounded to 95 percent of the activity during baseline data collection. When emitters were removed permanently, acoustic bat activity rebounded 133 percent of the activity during baseline data collection (Table 2-4).

Table 2-4: Mean (SE) total acoustic bat passes per night by treatment, analysis of date and time of night.

Site	Baseline	Pre-Treatment	Treatment	Post-Treatment
1	Early	47.3 (8.5)*	4 (0.3)*	63 (11.3)*
	Late	81.3 (25)*	76.8 (4.2)*	47.7 (4.2)*
2	Early	250 (9.2)	300.8 (13.9)	429 (31.4)
	Late	223 (34.2)	453.5 (17.5)	469.3 (36)

**Statistically significant effect*

ANOVA tests showed a statistically significant effect of date and time of night for total acoustic bat passes at treatment Site 1 ($f_{1,2} = 7.57$, $p = 0.004$), suggesting that ultrasound emitters affected bat activity at Site 1 (Figure 2-19). No statistically significant effect of date and time of night for total acoustic bat passes was found at Site 2 ($f_{1,2} = 0.275$, $p = 0.763$), suggesting that there was no significant change in bat activity at Site 2 from July 3-17 (Figure 2-20).

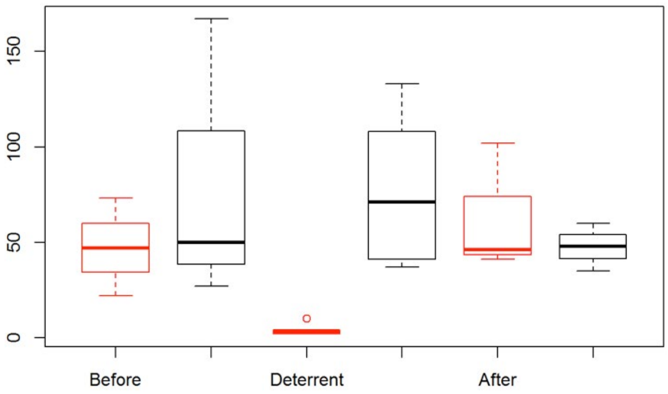


Figure 2-19: Boxplot: Raw total acoustic bat passes per night at Site 1. Detections from early hours (19:00-23:59) are in red.

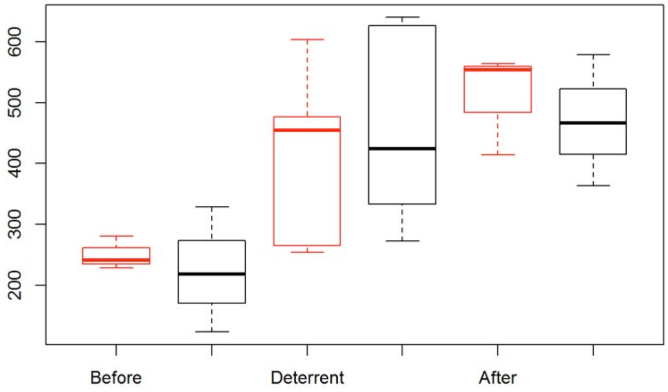


Figure 2-20: Boxplot: Raw total acoustic bat passes per night at Site 2. Detections from early hours (19:00-23:59) are in red.

Table 2-5: Bat species richness per site as determined by analysis of bat echolocation calls. Species that emit high frequency (HF) and low frequency (LF) call types are identified.

Common Name	Scientific Name	Alpha Code	Call Type	Bat Passes per Site (Percent)			
				Site 1	Site 3	Site 2	Site 4&5
Arizona myotis	*Myotis occultus*	MYOOCC	HF	0	< 1	< 1	0
Big brown bat	*Eptesicus fuscus*	EPTFUS	LF	42	40	87	62
Big/Pocketed free-tailed bat	*Nyctinomops spp**	NYCspp	LF	< 1	< 1	< 1	< 1
Brazilian free-tailed bat	*Tadarida brasiliensis*	TADBRA	LF	22	7	3	11
California myotis	*Myotis californicus*	MYOCAL	HF	18	32	2	10
Canyon bat	*Parastrellus hesperus*	PARSUB	HF	< 1	0	< 1	0
Cave myotis	*Myotis velifer*	MYOVEL	HF	2	4	3	4
Fringed myotis	*Myotis thysanodes*	MYOTHY	LF	7	10	1	4
Hoary bat	*Lasiurus cinereus*	LASCIN	LF	1	< 1	1	< 1
Lesser long-nosed bat	*Leptonycteris yerbabuenae*	LEPYER	HF	1	1	< 1	0
Long-legged myotis	*Myotis volans*	MYOVOL	HF	0	0	0	1
Mexican long-tongued bat	*Choeronycteris mexicana*	CHOMEX	HF	0	< 1	< 1	0
Pallid bat	*Antrozous pallidus*	ANTPAL	LF	2	< 1	1	< 1
Silver-haired bat	*Lasionycteris noctivagans*	LASNOC	LF	2	1	1	2
Southwestern myotis	*Myotis auriculus*	MYOAUR	HF	1	2	< 1	3
Western red bat	*Lasiurus blossevillii*	LASBLO	HF	< 1	1	< 1	2
Western small-footed myotis	*Myotis ciliolabrum*	MYOCIL	HF	0	1	< 1	< 1
Western yellow bat	*Lasiurus xanthinus*	LASXAN	LF	1	1	< 1	< 1
Yuma myotis	*Myotis yumanensis*	MYOYUM	HF	1	0	0	< 1

** these two species are acoustically ambiguous*

Species Richness

The bat detectors collected over 20,000 recordings. All recordings were manually vetted to species or species-guild. Part of the vetting process identified recordings that contained multiple bat passes from different individuals and/or species. This provided more accurate results for relative activity levels during treatment and non-treatment periods. After accounting for multiple bats in a recording, a total of 27,951 individual bat passes were identified from the collected recordings. Echolocation calls from 15 species were recorded at Site 1; 17 species at Site 3; and 19 species at Site 2. At Sites 4 and 5 combined, echolocation calls from 16 bat species were recorded. A total of 19 and potentially 20 species were identified among all sites (Table 2-5). Of these, 11 species emit "high-frequency" echolocation calls (greater than about 35 kHz), and 8 emit low-frequency calls (less than about 35 kHz). A few species were present at sites in percentages of less than one percent, but because the entire collection of recordings was manually vetted, presence for these species was confidently confirmed. (In the case of Site 2 where over 10,000 bat passes were collected, species represented at proportions of < 1% still made up close to 100 bat passes at the site.) Overall, more than 17,000 recordings were confidently identified to species. The remaining recordings were assigned to either a high- or low-frequency species guild based on the value of the average "characteristic frequency" of the echolocation call. The entire collection of recordings was post-processed using SonoBat v4.3 call analysis software to obtain file-level metrics for each bat pass, and to assign bat passes to each site and night allowing for additional analysis at the site-level.

Table 2-6: Mean (SE) high-frequency acoustic detections per night by treatment, time of night, and date

Site	Time	Pre-Treatment	Treatment	Post-Treatment
1	Early	15.4 (2.4)*	4 (0.3)*	11 (2.7)
	Late	33.3 (5.4)*	22.2 (1.1)*	11 (0.3)
2	Early	92.3 (2.3)	117.3 (2.8)	81.7 (10.7)
	Late	62.3 (9.6)	111.7 (3.8)	59 (3.3)

**Statistically significant effect*

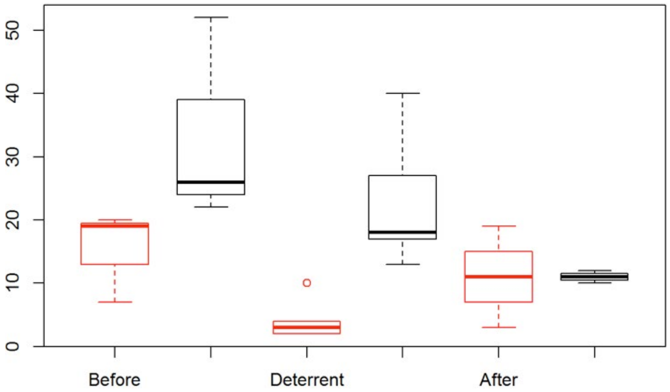


Figure 2-21: Boxplot: Raw high-frequency acoustic bat passes per night at Site 1. Detections from early hours (19:00-23:59) are in red.

Effect of Ultrasound Emitters on High- vs. Low-Frequency Bat Species

Mean high-frequency echolocation call passes per night for date and time of night decreased at treatment Site 1 by 74 percent during the operation of ultrasound emitter(s) compared to the baseline data collected prior to operation (Table 2-6). During the same time at Site 2 (no-treatment site), acoustic bat activity increased by 27 percent compared to the baseline data. When ultrasound emitters were not operating (i.e., after about 2300h), acoustic bat activity for high-frequency detections rebounded to 67 percent of the activity during baseline data collection. When emitters were removed permanently, acoustic bat activity for high-frequency detections did not rebound to the same activity during baseline data collection (Table 2-6).

A statistically significant effect of date and time of night for high-frequency acoustic bat passes occurred at treatment Site 1 ($f_{1,2}$ = 3.55, p = 0.05), suggesting that ultrasound emitters affected high-frequency bat activity at Site 1 (Figure 2-21).

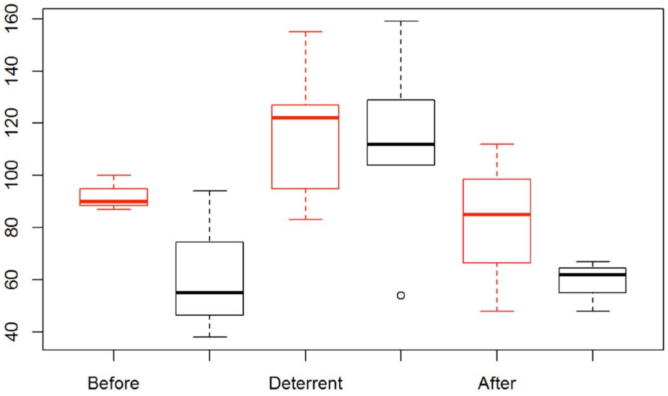


Figure 2-22: Boxplot: Raw high-frequency acoustic bat passes per night at Site 2. Detections from early hours (19:00-23:59) are in red.

No significant effect of date and time of night for high-frequency acoustic bat passes occurred at Site 2 ($f_{1,2}$ = 0.610, p = 0.554), suggesting that there was no significant change in high-frequency acoustic bat activity in absence of an ultrasound emitter at this site from July 3-17 (Figure 2-22).

Mean low-frequency acoustic bat passes per night for date and time of night decreased at treatment Site 1 by 100 percent during the operation of ultrasound emitter(s) compared to the baseline data collected prior to operation (Table 2-7). During the same time at no-treatment Site 2, acoustic bat activity for low-frequency detections increased by 91 percent compared to the baseline data. When ultrasound emitters were not operating (i.e., after about 2300h), acoustic bat activity for low-frequency detections rebounded to 114 percent of the activity during baseline data collection. When emitters were removed permanently, acoustic bat activity for low-frequency detections rebounded to 163 percent of the activity during baseline data collection (Table 2-7).

Table 2-7: Mean (SE) low-frequency acoustic bat passes per night by treatment, time of night, and date

Site	Baseline	Pre-Treatment	Treatment	Post-Treatment
1	Early	32 (6.4)*	0 (0)*	52 (9.2)*
	Late	48 (19.6)*	54.7 (3.9)*	36.7 (4)*
2	Early	157.7 (11.2)	300.8 (13.9)	429 (31.4)
	Late	160.7 (24.8)	341.8 (18.5)	410.3 (32.9)

**Statistically significant effect*

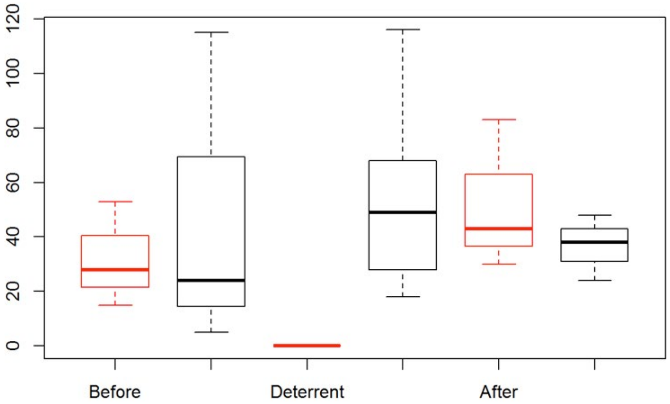


Figure 2-23: Boxplot: Raw low-frequency acoustic bat passes per night at Site 1. Detections from early hours (19:00-23:59) are in red.

A statistically significant effect of date and time of night for low-frequency acoustic bat passes occurred at treatment Site 1 (Figure 2-23; $f_{1,2} = 9.34$, $p = 0.002$), suggesting that low-frequency bat echolocation may be affected by the ultrasound emitter to a greater extent than high-frequency bat echolocation. ANOVA tests did not show a statistically significant effect of date and time of night for low-frequency acoustic bat passes at the no-treatment Site 2 ($f_{1,2} = 0.104$, $p = 0.902$). This suggests that there was no significant change in low-frequency acoustic bat activity at Site 2 from July 3-17 (Figure 2-24).

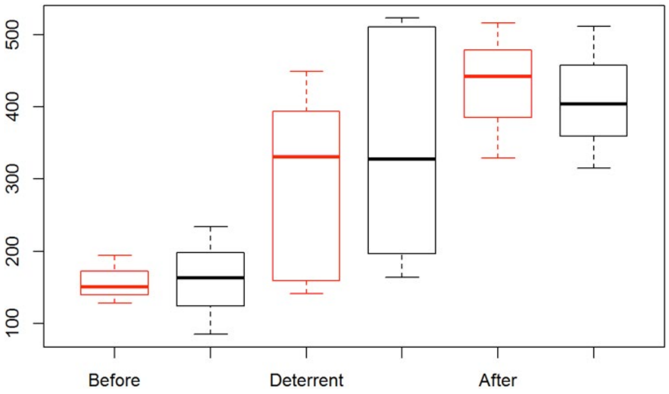


Figure 2-24: Boxplot: Raw low-frequency acoustic bat passes per night at Site 2. Detections from early hours (19:00-23:59) are in red.

Weather Data

Nights with unfavorable weather during both video and bat acoustic call monitoring between 19:30 and 5:00 from July 3-15 was reported by the AWRR weather station on July 5, 9, and 12 and included precipitation and/or high winds (i.e., wind speeds greater than or equal to 9 mph [14.5 kph]). High winds were reported on July 5 between 19:26-20:02, at 02:32, at 03:25, and between 04:37-04:53 (Figure 2-25). Rain was reported on July 9 from 19:43-21:46 and on July 12 from 21:03-24:51. Rain was reported again on July 12 from 02:02-02:56 (Figure 2-26). Although no unfavorable weather was reported by the AWRR weather station during the survey time period on July 13, rain was observed onsite from approximately 16:30-20:30, which caused a delay for the video and ultrasound emitter start time for that night. During post-treatment bat echolocation call monitoring from July 15-19, no unfavorable weather was reported by the AWRR weather station. Temperatures on each survey night from July 3-19 were above 59 °F (15 °C) as reported by the AWRR weather station (Figure 2-27).

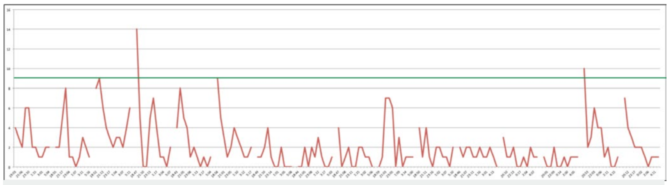


Figure 2-25: Wind speed (mph) during each survey night, 19:00-05:00, July 3-18, 2018
Green line marks maximum wind speed threshold for an acceptable survey, no greater than 9 mph for more than 30 min.

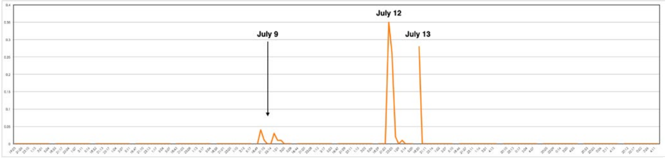


Figure 2-26: Precipitation (in) during each survey night, 19:00-05:00, July 3-18, 2018
Threshold for an acceptable survey is no more than 30 min precipitation during the survey night.

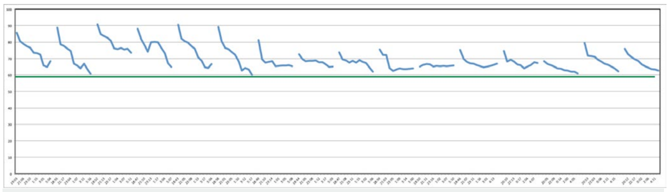


Figure 2-27: Temperature (°F) during each survey night, 19:00-05:00, July 3-18, 2018
Green line marks minimum temperature threshold for an acceptable survey, 59 °F.

DISCUSSION AND CONCLUSION

Results from the Arizona Water Resource Study show that deploying low-powered, ultrasonic emitters *will deter* bats from affected airspace as was evident in the significant difference in the total number of successful "sips" during treatment compared to no treatment. Therefore, the effect of ultrasound emitters during this navigational activity supports our hypothesis.

Although mean "bat fly-bys per hour" from the video data showed a 78.4 percent reduction at Site 5, the total bat "fly-by" data from the video files did not show a significant effect. Number of successful "fly-bys" did not show a strong downward trend as did the sips, which likely resulted from the limitation of the approximate 12-ft (3.7-m) effective range of the ultrasound emitters. Therefore, the broadcast areas not effectively covered due to the design and placement of the emitters, and due to the large video viewing area that may have captured bats passing by with no interest in the water resource regardless of the emitters. Given this, we have made recommendations to improve study design for future research (Appendix D).

The debris in the water at Site 5 may have contributed to the reduction in bat passes at this site. Adding the ultrasound broadcast to this site that already had navigational challenges may have resulted in one too many obstacles for bats to circumvent, especially since there was a larger, obstacle-free pool (Site 4) adjacent to Site 5 to use.

In addition, the video data results did show that the effect of the ultrasound emitters increases over time. The downward trend in bat activity in the form of "sips" and "fly-bys" is of special note. Operating the ultrasound emitters over a longer period of time may have yielded stronger results for both the "sips per hour" and "bat fly-bys per hour" metrics (Appendix D). This is likely due to non-naïve bats encountering the deterrent long before its effects can disrupt their echolocation. These non-naïve bats, having encountered the broadcast airspace on prior nights likely choose to forage elsewhere when presented with the same acoustic interference.

Also of special note are the visual observations made from the video assessment. Bats' behavior captured in the video recordings did show events in which a bat would approach the broadcast area and then appear to veer off in a direction away from the emitters (Photo C-8). This observation would count as a "fly-by," even though the bat's behavior appeared to change in the vicinity of the operating ultrasound emitters. This result was most evident at Site 1, where the entire surface of the water was within 5 ft (1.5 m) of the ultrasound emitter and within its most effective range. The video data also showed bats that would take sips at locations away from the emitters, as was evident at Site 3 where the edge of the 10-ft (3-m) diameter pond was nearing the 12-ft (3.7-m) effective range of the ultrasound emitters. As illustrated earlier, the strength of the ultrasound emitted from the unit quickly attenuates beyond the first 3.2 ft (1 m) from the device. Previous studies also described change in bat behavior in the presence of ultrasound emitters (Kinzie 2018).

Relative bat echolocation call passes decreased during treatment at Sites 1 and 3 from July 3-11, supporting video data results during the same time period. In absence of the ultrasound emitter, bat activity immediately rebounded at treatment Site 1. At Site 3, there was no re-bounding of bat activity to numbers matching bat passes during baseline data collection as observed at Site 1. The high-frequency ultrasound interference observed in the bat acoustic files at Site 3 may have influenced the post-treatment results at that site. In addition to the video equipment, bat detector, and ultrasound emitter used for this study, two cameras were installed at the site by Audubon staff or volunteers at Site 3. One was a motion-activated trail-camera that triggered on movement within the frame. This camera was present on the bank of the pond during the entire survey, July 3-18. The other was a time-lapse camera deployed on July 12 that regularly triggered throughout the day and night to track the summer monsoon development (S. Wilcox personal communication, December 13, 2018). Both or either cameras may have produced a high-frequency noise as part of their focusing/range-finding mechanics ("Autofocus," accessed February 17, 2019). Therefore, this high-frequency noise may have functioned similarly to the ultrasound emitters and effectively depressed bat activity at the site. Neither a trail-camera nor time-lapse camera was present at Site 1.

The video observations and the bat echolocation call data both demonstrated that not all bats avoided the broadcast area. The manufacturer had stated that the unit transmits the majority of the ultrasound above the unit and less below the unit (M. Jensen personal communication, July 7, 2018). Variable approaches by bats above or below the emitter may allow them to successfully sip at the surface of the water despite the active ultrasound broadcast. Additionally, due to the arid environment of the study area, water is a significant draw to all wildlife. Although an alternate, nearby water source was available to the bats where no ultrasound emitter was operating, bats may have decided to enter the broadcast zone anyway, perhaps using other sensory cues for navigation in addition to, or instead of, echolocation.

Previous studies testing ultrasound emitters on wind turbines also reported that the ultrasound broadcast did not prevent all bats from approaching the rotor-sweep zone (Arnett et al. 2013, Kinzie 2018), likely due to distance and area covered by the broadcast (Arnett et al. 2013). As illustrated previously, ultrasound attenuates rapidly in air, and the extent of attenuation is influenced by myriad environmental factors, including temperature, pressure, humidity, and wind. Therefore, the inherently variable echolocation repertories of bats, behavior of ultrasonic sound in air, and/or environmental conditions may have influenced the effect of the ultrasound broadcast and may explain why not all bats avoided the broadcast area during our study.

In summary, this study provided answers to the following four questions:

Question 1: Will the ultrasound broadcast emitter have an effect on bat behavior at treatment sites compared to baseline data before the ultrasound treatment?

Yes - Bat activity is negatively affected by ultrasound broadcast as determined by (1) the total number of sips at treatment sites compared to non-treatment sites, (2) observations of bat behavior in the video recordings, (3) total echolocation call passes at treatment sites compared to non-treatment sites, and (4) total echolocation call passes during time of night and date. Although not all bats avoided the broadcast zone, the data suggested that the ultrasound emitters decreased bats' abilities to echolocate, especially when approaching the surface of the water. Both the number of sips and echolocation call passes provide the strongest evidence for this conclusion. Total number of bat fly-bys collected from the video recordings do not show a decrease in bat activity and may not be the best metric to use to test the effect of emitters on bat activity.

Question 2: Will the ultrasound broadcast at treatment sites increase bat activity at nearby sites that remain untreated with broadcasted ultrasound?

Yes - The video data was useful to understanding whether bats preferred areas where no ultrasound was broadcasted. Bat activity increased at non-treatment sites, Site 2 and 4, while ultrasound emitters operated at nearby sites. However, ANOVA tests could not be used for this assessment since bat activity at non-treatment Site 4 was very different than bat activity at non-treatment Site 2 during baseline data collection.

Question 3: How long will it take for bat activity to rebound once treatment ceases, or will bats continue to avoid areas where they have encountered ultrasonic deterrents?

Uncertain- Data analyzed from the bat detectors indicated that once ultrasound emitters were not operating later in the night and when they were removed permanently at Site 1, bat activity rebounded. Acoustic bat passes from Site 3 could not be used for this analysis due to the unexpected high-frequency interference noted at this site possibly impacting the results. However, at Site 3, the total number of bat acoustic files recorded reflected that bat activity rebounded late each night from July 6-11, after the ultrasound emitter trial ended for the night.

Question 4: Does the ultrasound broadcast have more effect on bats that predominantly use high-frequency echolocation calls than those that use low-frequency call types?

Yes - Results showed that bat species that echolocate using high-frequency ultrasound (>35 kHz) and species that echolocate using low-frequency ultrasound (<35 kHz) are both affected, but a greater effect was indicated for bat species that emit low-frequency ultrasound. ANOVA tests on echolocation call data at Site 1 confirmed this result.

3 FLORIDA ROOST STUDY

INTRODUCTION

A structure used for maintenance and storage on the campus of White Oak Conservation, Yulee, Florida was known to serve as a bat roost. Several characteristics of this roost made it favorable to test the effectiveness of low-power ultrasound emitters:

- A large number of bats were roosting within this structure. Therefore, any effect from the ultrasound emitters would be noticeable
- The building and, consequently, the roost space was large making it favorable for visual observation, equipment monitoring, and alternate roost areas if treatment is concentrated in sections
- The bats roosting within the structure included a Myotis species [southeastern myotis (*Myotis austroriparius*)], which is the same genus as the federally-listed species regulated by seasonal and/or distance restrictions for tree management activities.

The bats roosted mainly on the east wall of the building at the time of this study. Instead of deploying the ultrasound emitters against the wall, the units were deployed in the airspace in front of the wall to identify the effective range of the broadcast that would affect bats as they approached and prepared to roost. The precise range-finding operations bats use while echolocating to roost are similar to those used while foraging and drinking that were investigated during the Arizona Water Resource Study. The intention of the methodology at the Florida roost was not to exclude the bats from the structure but to encourage the bats to navigate to another area of the roost.

Our hypothesis was that broadcasted ultrasound in the airspace around a roost “jams” or “blurs” bats ability to echolocate, and bats will avoid roosting in the areas treated by the emitters. Broadcasted ultrasound may interfere with the ability of bats to precisely echolocate (Spanjer 2006, Szewczak and Arnett 2007, Arnett et al. 2013, Kinzie 2018) and bats may choose to avoid entering the broadcasted area while returning to roost at dawn. Three questions were investigated at this site:

Question 1: Will the ultrasound broadcast affect bat roosting behavior within the treatment area compared to baseline data before the ultrasound treatment?

Question 2: Will bats return to roost within the broadcast zone once treatment ceases?

Question 3: Will bats from the genus Myotis roost in the broadcast zone?

We observed the amount of area covered by the roosting bats pre-treatment, during treatment, and post-treatment to determine whether or not the ultrasound emitters affected where the bats choose to roost upon returning to the structure at dawn. The two bat species roosting in the structure were the southeastern myotis (*Myotis austroriparius*) and Brazilian free-tailed bat (*Tadarida brasiliensis*). Each has some heterogeneous areas within the roost where both species can be found. Given that roosting areas were numerous at this site, that bats were observed to roost in discreet locations, such as between boards and other objects, as well as stacked on top of each other, within-roost site fidelity was not known. Therefore, the treatment area was not compared to the no-treatment area as it was in the Arizona Water Resource Study because determining if the bats moved from the treatment area to the no-treatment area was not quantifiable without marking individual bats, a methodology that was not within the scope of this pilot study.

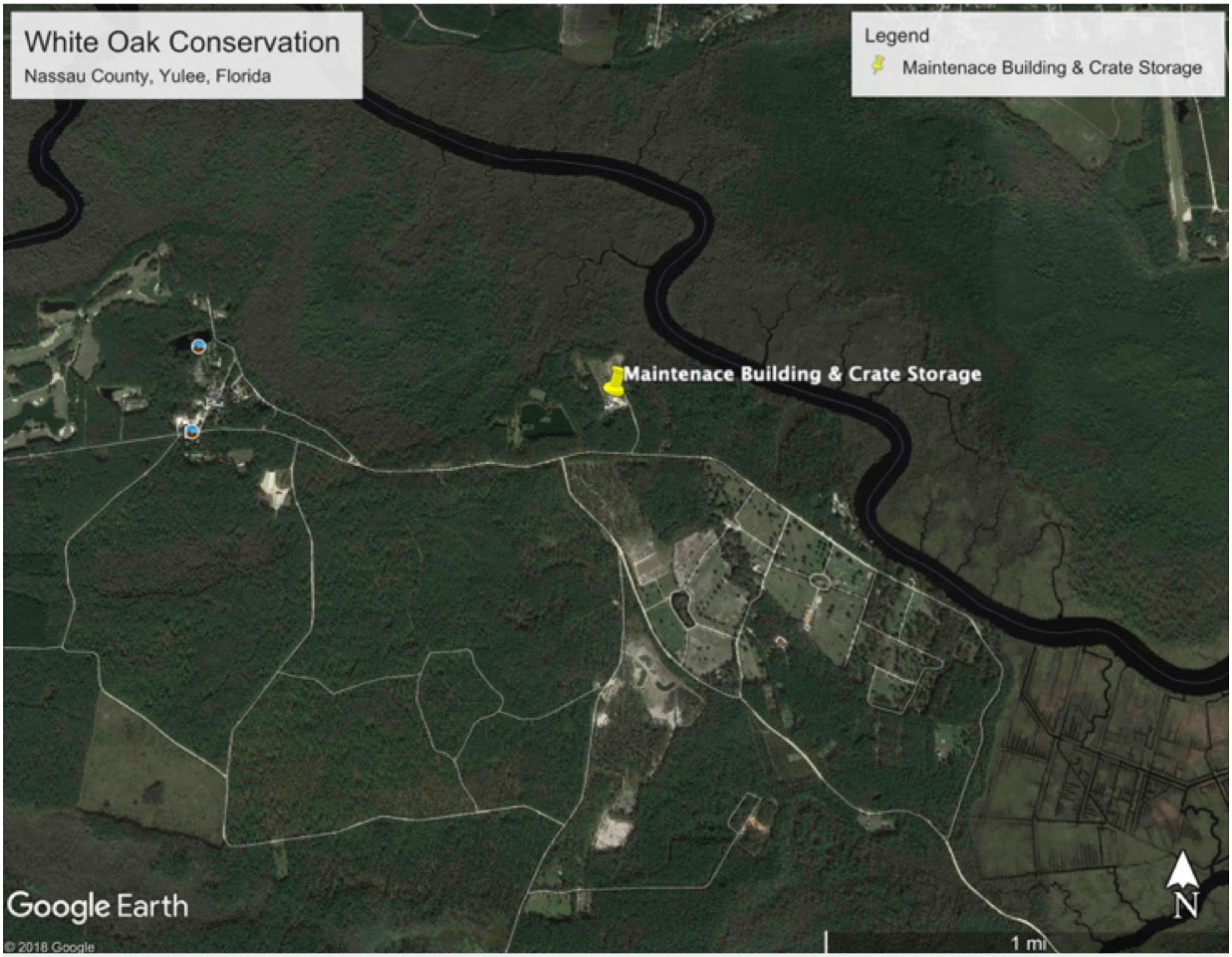


Figure 3-1: Project Location White Oak Conservation, Yulee, Florida, USA 30.755767° N; -81.745042° W

STUDY AREA

White Oak Conservation is an exotic animal conservation facility with diverse habitat features including forest interior, streams, lakes, and ponds (Figure 3-1). A ten-mile (16-km) stretch of St. Mary's River bisects the property. The property also includes numerous buildings and structures. The research site was a concrete block maintenance building attached to an open-sided, concrete, roofed crate storage area (Figure 3-2) (Appendix E, Photo E-1). The building consisted of a large colony of southeastern myotis (*Myotis austroriparius*) and Brazilian free-tailed bat (*Tadarida brasiliensis*) (Appendix E, Photo E-2). The combined colony is likely limited by available roost space and numbers peak at approximately 4,000 individuals.

Figure 3-2: Bat roost site within the garage area of the maintenance building. This area is used for storage.

METHODS

The Institutional Animal Care and Use Committee (IACUC) of the Southeast Zoo Alliance for Reproduction and Conservation, affiliated with White Oak Conservation Foundation, evaluated and approved the methods for the Florida Roost Study.

Equipment Deployment and Data Collection

The garage area roost site was a section approximately 48 ft x 34 ft (14.6 m x 10.4 m) of a larger 130 ft x 34 ft (39.6 m x 10.4 m) maintenance building used for storage. The section of the maintenance building that did not include the roost was an open pavilion used primarily for crate storage. Since space was plentiful at this roost and the bats roosted in multiple areas of the building, treatment at this site with ultrasound emitters was designed to move bats from one area of the building to another. Complete and permanent exclusion of the bats from the roost was not intended. BD100 ultrasound emitters (as used in the Arizona Water Resource Study) were also used for the Florida Roost Study, with a maximum transmit power of 96 dB SPL at 20-80 kHz and an effective range of 12 ft (3.7 m).

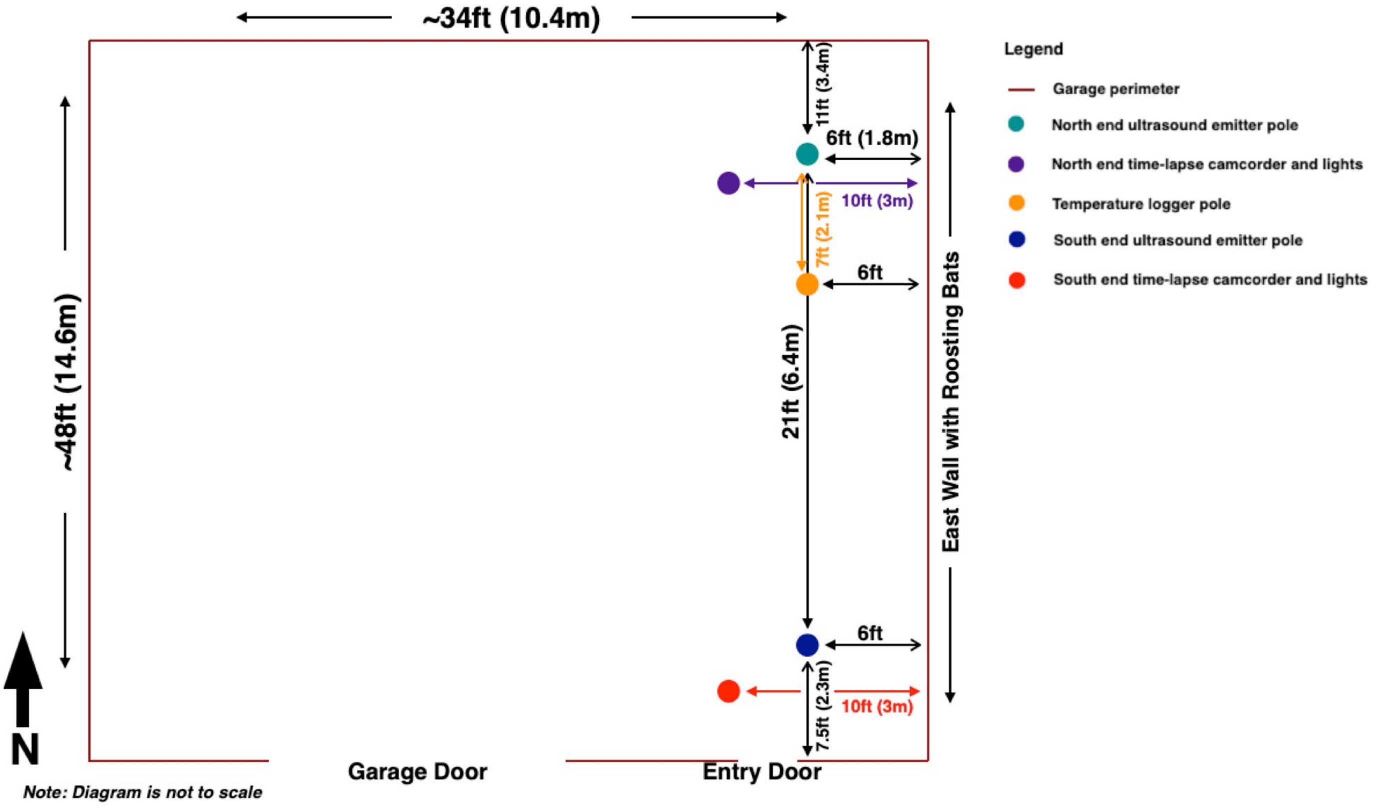


Figure 3-3: Equipment deployment inside garage area/roost site. The roost site is a concrete block building with a metal roof used as infrequently accessed storage space.

We deployed equipment beginning on October 9, 2018. A telescoping pole was fitted with two ultrasound emitters and secured in place on the south end of the east wall where bats were roosting at the time of the study (Appendix E, Photo E-3). One ultrasound emitter was attached approximately 6 ft (1.8 m) above the floor; the other ultrasound emitter was attached approximately 4 ft (1.2 m) from the peak of the roof. The pole was deployed on the south end at approximately 6 ft (1.8 m) from the east wall and 7.5 ft (2.3 m) from the south wall. This configuration was intended to cover a large vertical and horizontal area of the wall and remain within the specifications of the effective range for the BD100 unit. A NightShot infrared camcorder (Sony Corporation, Minato, Tokyo, Japan) was set to a time-lapse photography mode and deployed inside the roost approximately 10 ft (3 m) from the east wall on the south end and approximately 6 ft (1.8 m) above the floor (Figure 3-3). Auxiliary infrared lights were deployed to increase illumination. The camcorder was positioned at about a 45-degree angle towards the bats on the east wall. The camcorder was programmed to take a photograph of the roosting bats every minute for approximately 12 hrs beginning at 14:00 on October 9 to collect pre-treatment data. Ultrasound emitters were not operating during this time.

We deployed a NightShot infrared camcorder set to the time-lapse photography mode approximately 10 ft (3 m) from the east wall and approximately 6 ft (1.8m) above the floor (Figure 3-3) at the north end of the roost. Auxiliary infrared lights were deployed to increase illumination. The camcorder was pointed diagonally at about a 45-degree angle towards the peak of the roof to photograph roosting bats in the upper section and peak of the east wall where bats were located. The camera was programmed to take a photograph every minute for approximately 16 hrs beginning at 23:10 on October 9 to collect pre-treatment data (Table 3-1). An ultrasound emitter pole was not deployed at the north end of the roost at this time.

We resumed equipment deployment at the north end of the roost on October 10. A telescoping pole was fitted with two ultrasound emitters 21 ft (6.4 m) north of the south end pole, approximately 6 ft (1.8 m) from the east wall, and 11 ft (3.4 m) from the north wall (Figure 3-3; Appendix E, Photo E-4, and E-5).

Table 3-1: Equipment operation for treatment and no treatment monitoring October 9 and October 13-26, 2018.

Date	Area	Time-lapse Camcorder		Ultrasound Emitters (No.)	Ultrasound Emitter On-Off	Data Collection
		Start Time (hrs)	End Time (hrs)			
9-Oct-18	North End	23:10	15:48	0	–	Pre-treatment
9-Oct-18	South End	14:00	13:59	2	Off	Pre-treatment
13-Oct-18	North End	18:53	11:31	2	–	Pre-treatment
13-Oct-18	South End	18:50	11:28	2	–	Pre-treatment
14-Oct-18	North End	17:55	10:33	2	–	Pre-treatment
14-Oct-18	South End	17:51	10:29	2	–	Pre-treatment
15-Oct-18	North End	18:19	10:59	2	21:15-7:12	Treatment
15-Oct-18	South End	18:17	10:55	2	Off	No treatment
16-Oct-18	North End	18:19	10:58	2	19:30-7:20	Treatment
16-Oct-18	South End	18:18	10:57	2	Off	No treatment
17-Oct-18	North End	18:18	10:57	2	20:03-7:17	Treatment
17-Oct-18	South End	18:12	10:54	2	Off	No treatment
18-Oct-18	North End	18:16	9:36	2	Dusk-Dawn	Treatment
18-Oct-18	South End	18:14	9:37	2	Off	No treatment
19-Oct-18	North End	18:17	9:46	2	Dusk-Dawn	Treatment
19-Oct-18	South End	18:16	9:46	2	Off	No treatment
20-Oct-18	North End	18:17	9:46	2	Dusk-Dawn	Treatment
20-Oct-18	South End	18:07	21:10*	2	Off	No treatment
21-Oct-18	North End	18:08	10:46	2	Off	No treatment
21-Oct-18	South End	18:07	10:45	2	Off	No treatment
22-Oct-18	North End	18:41	10:06	2	Dusk-Dawn	Treatment
22-Oct-18	South End	18:40	10:06	2	Off	No treatment
23-Oct-18	North End	18:08	10:46	2	Off	No treatment
23-Oct-18	South End	18:08	10:46	2	Dusk-Dawn	Treatment
24-Oct-18	North End	18:05	10:46	2	Off	No treatment
24-Oct-18	South End	18:01	10:41	2	Dusk-Dawn	Treatment
25-Oct-18	North End	18:08	10:46	2	Off	No treatment
25-Oct-18	South End	18:05	10:43	2	Off	No treatment
26-Oct-18	North End	18:06	10:03	2	Off	No treatment
26-Oct-18	South End	18:04	10:03	2	Dusk-Dawn	Treatment

**Time-lapse camcorder ceased functioning*

After equipment deployment was completed on October 10, no additional data were collected from either of the time-lapse camcorders at the south or north end of the roost, and no ultrasound emitters were operating so that roosting bats can acclimate to the new objects and allow for an undisturbed time period after the disturbance from equipment deployment. Additional pre-treatment data collection was to occur on October 13 and 14. However, due to equipment issues, no acceptable surveys were conducted on these nights.

Treatment at the north end occurred from October 15-17. Ultrasound emitters were manually turned on between 19:30 and 21:15 depending on when bats left the roost and manually turned off at about 07:15 the following morning. The south end ultrasound emitters remained off. Time-lapse camcorders at both the north and south end were manually turned on prior to bats leaving the roost between 18:00 and 19:00 and were programmed to take a photograph every minute for 15 hrs.

Light sensor equipment was used at the north end from October 18-20 and on October 22 to turn on the ultrasound emitters at dusk and off at dawn. Time-lapse camcorders at both the north and south end continued to be turned on manually between 18:00 and 19:00 and take a photograph every minute prior to bats leaving the roost then continue for approximately 15 hrs. Ultrasound emitters remained off on October 21 due to unfavorable weather.

Beginning on October 23, treatment ceased at the north end, and ultrasound emitters began operating at the south end using the light sensor equipment to turn them on at dusk and off at dawn. Time-lapse camcorders at both the north and south end continued to be turned on manually between 18:00 and 19:00 and take a photograph every minute prior to bats leaving the roost then continue for approximately 15 hrs. Treatment and time-lapse photography at the south end also occurred on October 24 and 26 using the same methods. Ultrasound emitters did not operate on October 25 due to unfavorable weather.

Data Analysis

Photographs from both the north and south end were downloaded to a computer after each 15-hour segment. A photograph was reviewed from the north end each hour during no treatment on October 9 to identify when the bats began to return to the roost. A time was determined after the bats returned at dawn but before the time-lapse camcorder shut off to assess the effectiveness of the ultrasound emitter on the returning bat population at the north end.

We determined that a sample of photographs taken at 09:00 at the beginning of treatment, middle, and end of treatment would be a suitable time to show if the treatment affected roosting behavior. A north end photograph of the east wall without bats was projected onto a screen and overlain with a photograph of roosting bats from October 15, 20, 22. For each photograph at 09:00, the number of concrete blocks on the east wall covered with half or more bats were counted and compared to previous nights to estimate cluster size after the bats returned at dawn. Concrete blocks were approximately 16 in x 8 in (41 cm x 20 cm). Photographs were compared to October 9, the night with no treatment at either the north or south end.

Photographs were reviewed in the same way from October 23 and 26 at the north end while ultrasound emitters were operating at the south end. South end photographs from October 22 (pre-treatment) and October 23, 26 (treatment) were assessed in the same way. All photographs were compared to October 9, the night with no treatment at either the north or south end.

Weather Data

Drop 3 environmental data loggers (Kestrel,® Minneapolis, Minnesota, USA) were deployed to record temperature. Since weather conditions may affect bat roosting behavior, ultrasound emitters operated only during nights with favorable weather. Favorable weather conditions were considered to be temperatures equal to or above 59 °F (15 °C), wind speeds no greater than 9 mi/hr (14.5 km/hr) for more than 30 min, and precipitation for less than 30 min from dusk to dawn each survey night.

A data logger was deployed outside the roost site on October 10 to document ambient weather conditions. Three data loggers were affixed to a telescoping pole at three different heights to collect environmental data inside the roost throughout the study (Appendix E, Photo E-5). The data loggers were positioned near the roost peak, at mid-level, and approximately 6 ft (1.8 m) above the roost floor. The data logger pole was deployed approximately 7 ft (2.1 m) south of the north end ultrasound emitter pole (Figure 3-3). Additional weather information was observed in the field. Only the data collected from the logger outside the roost was analyzed. The data collected from the loggers within the roost were available only if needed.

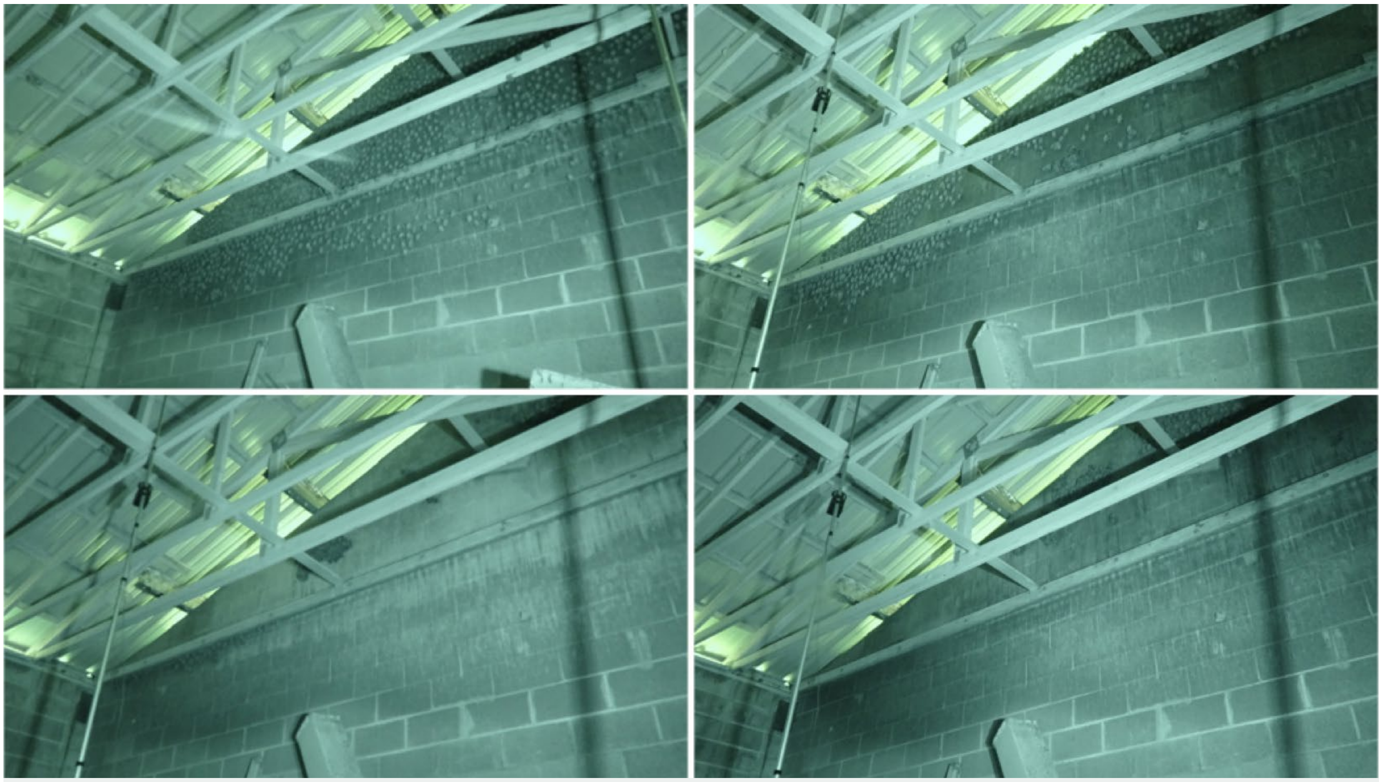


Figure 3-4: Bats roosting at 09:00 on east wall at north end of roost
From top, left to right: October 9 (no treatment), October 15 (treatment from 21:15-07:12), October 20 and October 22 (treatment from dusk to dawn).

RESULTS

Time-lapse camcorders at the north and south end took approximately 30,000 photographs on October 9 and from October 13-26, 2018. Bats began to return to the roost between 06:00 and 07:00. Photographs taken at 09:00 were used for the visual assessment. Due to equipment issues, photographs from October 13 and 14 were not included in the assessment. Data assessment began with the night of October 15. Also, due to unfavorable weather, ultrasound emitters were not operating on October 21 and 25; therefore, photographs from these survey dates were not included in the assessment.

Using photographs taken at 09:00 on October 15, 20, and 22, we observed that the cluster of bats at the north end treatment decreased at the roost (Figure 3-4). Bats occupied 53 concrete blocks on the east wall on the night with no treatment, October 9. On October 15, the number of concrete blocks with roosting bats decreased to 20. Bats occupied six concrete blocks on October 20 and five concrete blocks on October 22 (Table 3-2). However, weather conditions had changed on October 21 and could have affected the number of roosting bats on October 22. At 19:00, prior to bat emergence, temperatures had decreased from an average of 78°F (26°C) from October 15-20 to 60°F (16°C) on October 21. Beginning on October 22, temperatures between 19:00 and 09:00 were below 70°F (21°C) for the remainder of the survey.

Table 3-2: Area covered by bats during no treatment (October 9, 2018) and treatment (October 15-26, 2018) at the north end of roost

Date	Time	Concrete Blocks (No.)	Data Collection
October 9	09:00	53	Pre-treatment
October 15	09:00	20	Treatment
October 20	09:00	6	Treatment
October 22	09:00	5	Treatment
October 23	09:00	5	Post-treatment
October 26	09:00	10	Post-treatment

Figure 3-5: Bats roosting at 09:00 on east wall at north end of roost post-treatment.
From top, left to right: October 9 (no treatment), October 23 and October 26 (post-treatment).

Post-treatment observations at the north end were made from photographs taken at 09:00 on October 23 and 26. We observed that the cluster of bats at the north end treatment area increased post-treatment at the roost. Bats occupied five concrete blocks on the east wall at the north end on October 23 and ten concrete blocks on October 26 (Table 3-2). Although bats appeared to begin to return to the north end, no post-treatment determination can be made about the observation due to the low number of bats that returned and the potential influence of the unfavorable weather conditions beginning on October 21 (Figure 3-5).

Figure 3-6: Bats roosting at 09:00 on east wall at south end of roost during treatment.
From top, left to right: October 22 (pre-treatment), October 23 and October 26 (treatment from dusk to dawn).

Using photographs taken at 09:00 on October 23 and 26, we observed that the size of the cluster of bats at the south end treatment decreased at the roost. However, when compared to pre-treatment on October 22, the size of the bat cluster increased on the first night of treatment (Figure 3-6). Bats occupied 28 concrete blocks on the south end pre-treatment, October 22. On the first night of treatment, October 23, the number of concrete blocks with roosting bats increased to 35, then by October 26, the number decreased to 29 (Table 3-3).

Table 3-3: Area covered by bats during no treatment (October 22, 2018) and treatment (October 23-26, 2018) at the south end of roost

Date	Time	Concrete Blocks (No.)	Data Collection
October 22	09:00	28	Pre-Treatment
October 23	09:00	35	Treatment
October 26	09:00	29	Treatment

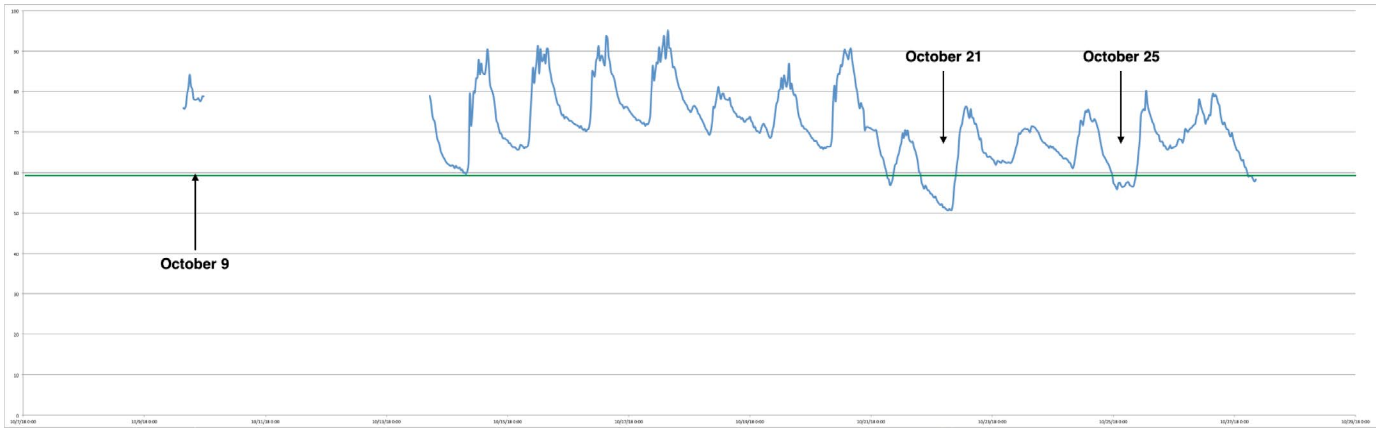


Figure 3-7: Ambient temperature (°F) from 15:30 to 23:30, October 9, 2018 and from 17:00 October 13 to 08:30 October 26, 2018. Green line marks minimum temperature threshold, 59 °F. Baseline data were collected at north and south end of roost on October 9. Treatment (ultrasound emitters operating) at the north end occurred from October 15-22 and from October 23-26 at the south end. Unfavorable weather occurred on October 21 and 25.

Weather conditions beginning on October 21 changed compared to previous nights (Figure 3-7). In addition to the temperature drop detailed earlier, isolated storms were also present on and after October 21, as observed in the field. As a result of these weather changes, it is not known if the ultrasound emitters were responsible for the decrease in roosting bats at the roost on the south end from October 23-26 or if the weather change caused them to move to another roost.

DISCUSSION AND CONCLUSION

From the time-lapse photography at the north end treatment area, we determined that the size of the bat cluster on the east wall of the roost decreased from October 15 to October 22 compared to pre-treatment observations on October 9. However, the results are inconclusive as to whether the ultrasound broadcast was responsible for the decrease. Bats appeared to begin to return to the north end post-treatment; however, no post-treatment determination can be made about the observations due to the small increase in cluster size and potential influence of unfavorable weather conditions beginning on October 21.

When treatment was shifted to the south end, the bat cluster increased on the first night then began to decrease. However, the unfavorable weather conditions beginning on October 21 again may have influenced the cluster size. Previous studies have shown that bats are known to relocate during this time of year, and movement may be initiated after passage of storm fronts (Arnett et al. 2008, Zeyzus and Larkin 2009). A conclusion cannot be made after October 21 on whether the decrease at the south end was a result of bats relocating due to potential triggers such as time-of-year and storm front passage and, similarly, the increase at the north end potentially being a result of bats relocating from elsewhere. If bats were relocating to this roost site from elsewhere after October 21, this may be an explanation for why the cluster size at the south end increased on the first night of treatment.

Additionally, on October 21, when ambient temperatures plummeted during the survey night, we observed that bat clusters included bats stacked on top of each other, up to four bats deep in some areas, perhaps to increase body temperature. Bats stacked on top of each other would have decreased the cluster size at the south end treatment area using the methods detailed in the assessment for this study. Nonetheless, bats stacking on top of each other may have also been a strategy to avoid the broadcast zone of the ultrasound emitters.

Results from this study indicated that not all bats within the effective range of the ultrasound emitters moved from the north or south end during treatment. The reasons may be the same as noted for the Arizona Water Resource Study. These reasons may include differences in echolocation characteristics among bat species, attributes of sound waves in air, potential for bats to use different types of calls under difference circumstances, and bats acclimating to the broadcast ultrasound, and/or the environmental conditions, which may have influenced the effect of the ultrasound broadcast.

Positioning the ultrasound emitters closer to the east wall and attaching additional ultrasound emitters on the pole may have had a more noticeable effect. Additionally, at the north end treatment area, roof beams were present that may have shielded the bats from the ultrasound broadcast due to the design of the units and ultrasound frequencies traveling mostly in a straight line (Figure 1-2). Szewczak (2011) noted similar concerns during a deterrent study where bridge beams may have blocked ultrasound broadcast. Other recommendations to improve study design for future research are detailed in Appendix D.

Results from a previous study reported that Brazilian free-tailed bats responded negatively to ultrasound emitters in a flight room (Kinzie 2018). Brazilian free-tailed bats are one of two species occupying the roost in this study and emit low-frequency ultrasound (characteristic frequency of about 25 kHz). The Arizona Water Resource Study also showed that there was a greater significant effect of the ultrasound emitters on the presence of low-frequency bat species (<35 kHz) versus high-frequency bat species (>35 kHz) at Site 1. The other species occupying the roost in this study was the southeastern myotis, which emit high-frequency ultrasound (characteristic frequency of about 45 kHz). The decrease in cluster size of these bats during treatment at the north end and the results of the high frequency versus low-frequency acoustic bat passes at Site 1 in the Arizona Water Resource Study suggest that the ultrasound broadcast affected both of these species. In this study, the effect of the ultrasound emitters would be hindering the ability of both species to navigate to roost within the broadcast zone.

In summary, this study has attempted to answer three questions:

Question 1: Will the ultrasound broadcast affect bat roosting behavior within the treatment area compared to baseline data before the ultrasound treatment?

Uncertain - The north end treatment area showed a decrease in bat cluster size on the east wall of the roost compared to pre-treatment observations. However, the results are inconclusive as to whether the ultrasound broadcast was responsible for the decrease.

Question 2: Will bats return to roost within the broadcast zone once treatment ceases?

Uncertain - Bats appeared to begin to return to the north end post-treatment; however, no post-treatment determination can be made about the observations due to the small increase in cluster size and potential influence of unfavorable weather conditions during post-treatment data collection.

Question 3: Will bats from the genus *Myotis* roost in the broadcast zone?

Uncertain - Since bat species were observed to integrate at this roost and bat cluster size decreased during treatment at both the north end and south end, this suggests that bats from the genus *Myotis* may not roost within the broadcast area of ultrasound emitters. However, the overall results were inconclusive because of weather variables.

4 SUMMARY AND IMPLICATIONS FOR FUTURE RESEARCH

Accomplishments of this study and recommendations for future research are summarized below and represented in Appendix D.

ARIZONA WATER RESOURCE STUDY

1. ***Determine the effect, if any, of low-power ultrasound emitters on the number of bat sips at the water surface, number of bat fly-bys near the water, and number of echolocation call passes in the vicinity of the treated water resource.***

   We used thermal imagers, infrared camcorders, and/or acoustic recording equipment (i.e., "bat detectors") to collect data at three treatment sites and two non-treatment sites. At each of the three treatment sites, number of bat sips, fly-bys, and echolocation call passes were determined from video and bat detector audio files. The results of the study indicated that the low-power ultrasound emitters had a significant effect for bat sips at the surface of the water at all three treatment sites and for echolocation call passes at Site 1. The results also suggested that there was a decrease in the number of bat fly-bys summed from each individual site; however, when performing a statistical analysis on the three treatment sites combined, no significant effect resulted.

2. ***Determine if number of bat sips at the surface of the water, number of bat fly-bys at the water resource, and number of echolocation call passes at the water resource increase at no-treatment sites while ultrasound emitters are operating at adjacent treatment sites.***

   We used the same equipment to collect data at two no-treatment sites. Although a combined statistical analysis was not feasible for this assessment since bat activity at no-treatment Site 4 was very different than bat activity at no-treatment Site 2 during baseline data collection, number of sips, fly-bys, and acoustic bat passes at each individual site showed an increase in bat activity at the no-treatment sites while ultrasound emitters were operating at adjacent treatment sites.

3. ***Determine if number of bat sips at the surface of the water, number of bat fly-bys at the water resource, and number of echolocation call passes at the water resource rebounded once ultrasound emitters were non-operational each night and/or removed permanently at the end of the treatment phase of the study.***

   Data obtained from bat detectors at Site 1 were useful for this assessment. Analysis showed a statistical effect of time and date when treatment ended for the night as well as a more persistent effect at the end of the treatment phase of the study. Post-treatment data obtained once the ultrasound emitters were removed at the conclusion of the study at treatment Site 3 were influenced by unknown high-frequency interference not associated with the study and could not be used in the statistical analysis. However, using the number of acoustic bat passes after ultrasound emitters were turned off each night at Site 3 did show a subsequent rebound in bat activity. Bat detector relocation at Site 4 and Site 5 resulted in inconsistent data collection and could not be used in the statistical analysis.

4. ***Determine if the ultrasound broadcast affected some bat species and not others.***

   Acoustic bat pass data collected at Site 1 was used for this statistical analysis. Total echolocation call passes at Site 1 using time of night and date were separated into high-frequency bat calls (>35 kHz) and low-frequency bat calls (<35 kHz) during treatment, then compared to baseline data. Results indicated a statistical effect for both high and low-frequency calls; however, the statistical effect was greater for the low-frequency calls.

FLORIDA ROOST STUDY

1. ***Determine the effect, if any, of low-power ultrasound emitters on bat cluster size within the treatment area along a wall of roosting bats within a structure compared to baseline data (no treatment) within the same area.***

   Infrared camcorders set to the time-lapse photography mode were used to collect data on bat roosting behavior within two areas of a building roost, the north end and south end of the east wall. Each of the two areas was treated on different dates. The first area, the north end of the building, was treated over an eight-night period. From superimposing photographs of the east wall with roosting bats over a photograph of the east wall without roosting bats at the beginning, middle, and end of treatment, cluster size was estimated by counting the number of concrete blocks occupied by the bats at 09:00 after the dawn return to the roost. The size of the bat cluster on the east wall of the roost had decreased from October 15 to October 22 compared to pre-treatment observations on October 9. However, the results are inconclusive as to whether the ultrasound broadcast was responsible for the decrease. When treatment was switched to the south end on October 23, results were inconclusive due to weather changes that occurred on and after October 21.

2. ***Determine if bats will return to roost within the broadcast zone once treatment ceases.***

   Using the same methods as used for determining the effect of treatment, bats appeared to begin to return to the north end once treatment was switched to the south end. However, no post-treatment determination can be made about the observations due to the small increase in cluster size and potential influence of unfavorable weather conditions beginning on October 21. No post-treatment data were collected at the south end.

3. ***Determine if bats from the genus Myotis will roost in the broadcast zone.***

   Two bat species were observed roosting in the structure, southeastern myotis (*Myotis austroriparius*) and Brazilian free-tailed bat (*Tadarida brasiliensis*). The two bat species roosting in the structure have some, but not complete, homogeneous areas within the roost where both species can be found. The absence of bats within the broadcast zone would suggest that bats present within the roost from the genus *Myotis* did not navigate to the roosting area within the broadcast zone. Since it was observed that bat cluster size decreased within the broadcast zone at the north end during treatment, this would suggest that the ultrasound emitters were hindering the ability of both species to navigate to roost within the broadcast zone. However, the results are inconclusive as to whether the ultrasound broadcast was responsible for the decrease.

Results from this study demonstrate that deploying low-powered, ultrasonic emitters will affect bat behavior within the broadcast zone, and this technology shows promise as an effective means to discourage bats from an area proposed for disturbance. The most convincing effect occurred in the Arizona Water Resource Study when bats were sipping at the surface of the water. The Arizona study also showed a rebound in bat activity when ultrasound emitters were not operating or were removed permanently, and results from this study also indicated an effect on both high and low-frequency ultrasound emitted by different bat species. These results prepare the direction for future research on testing other applications for low-power ultrasound emitters to determine if the same or similar effect would occur in different habitat areas such as at tree roosts. However, future research should consider details provided in Appendix A regarding effectiveness of methods used in this study.

Future research would elucidate the practical application of using low-power ultrasound emitters as a safe technique to keep bats away from potential hazard areas, such as areas for planned or on-going vegetation management activities. However, future research should consider using artificial roosts instead of natural tree roosts due to the ability to control variables at artificial structures. Additionally, due to regulatory and management challenges for land managers with regard to provisions for federally-listed bat species, future research using known roosts for federally-listed species would assist in determining the effectiveness, if any, of low-power ultrasound emitters on encouraging listed species to choose one of its previously established alternate roost sites (Butchkoski and Hassinger 2002, Gumbert et al. 2002, Kurta et al. 2002, Silvis et al. 2014) during vegetation management activities, creating operational flexibility for these activities.

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A TECHNOLOGY EVALUATION FOR USE IN BAT MONITORING

Technological equipment used during this study was evaluated for its suitability for this and other types of bat monitoring studies. The best use of these devices is detailed in Table A-1.

Table A-1 | Technology Evaluation for Use in Bat Monitoring

Device	How it Works	Strengths and Weaknesses	Monitoring Use Suitability (Low, Moderate, High)			
			Emergence Counts - Caves	Emergence Counts - Maternity Roost	Vegetation Monitoring	Species Identification
Thor-HD Thermal Imager (American Technology Network Corporation)	Objects that emit heat are emitting energy. The camera reads the infrared signals coming in and translates them into an image that we can easily see. The best part about this technology is that there is no need for sunlight or artificial light to form an image.	**Strengths:** • Range of detection is greater than infrared camcorder • High sensitivity • No extra illuminating equipment needed • Targets are easy to see and count • Timestamp imprinted on video • Good quality video recording • Best used for short-term, attended recording • Camera is waterproof • Good for long distance viewing and over water	**HIGH** Targets in motion are readily visible and can be counted manually or in certain circumstances computer aided counting may be used Because the camera can be positioned near the point of emergence interest, targets are large and easily recognizable	**HIGH** Targets in motion are readily visible and can be counted manually or in certain circumstances computer aided counting may be used Because the camera can be positioned near the point of emergence interest, targets are large and easily recognizable	**MODERATE** High sensitivity and range of detection is fitting for observing temperature variations within vegetation of varying distances from equipment Presence/absence of temperature differences would be determined and equipment would be used at appropriate times of day; therefore, weaknesses would not hinder use	**LOW** Accuracy for identifying species depends on local species richness, quality of recording, and observer's experience. Image is monochrome and color information is not possible.
		Weaknesses: • Environmental conditions affect video quality, not effective if there is no temperature contrast between target and background • Small video image and narrow field of view compared to Infrared Camcorder • Significant amount of storage memory needed for videos • Labor intensive • In field: cannot operate long-term without periodically resetting due to environmental changes and large file sizes • Recording review: length of time needed for review is greater than length of recording • Requires manual review unless software is available for automatic detection				

Table A-1 | Technology Evaluation for Use in Bat Monitoring

Device	**How it Works**	**Strengths and Weaknesses**	**Monitoring Use Suitability (Low, Moderate, High)**			
			Emergence Counts - Caves	**Emergence Counts - Maternity Roost**	**Vegetation Monitoring**	**Species Identification**
Infrared Camcorder Sony FDR-AX700 (Sony Corporation)	Certain Sony video cameras contain a "NightShot" feature, which enables the camera to be sensitive to 850 nm wavelength infrared light. In total darkness, this light must be supplied for the camera to image.	**Strengths:** • High quality HD video recording; best with extra illumination • Built in recorder • Generally less expensive than thermal camera solutions • Wide field of view • Can also use time-lapse photography mode for long-term monitoring	**HIGH** Targets in motion are readily visible and can be counted manually or in certain circumstances computer aided counting may be used Because the camera can be positioned near the point of emergence interest, targets are large and easily recognizable	**HIGH** Targets in motion are readily visible and can be counted manually or in certain circumstances computer aided counting might be used Because the camera can be positioned near the point of emergence interest, targets are large and easily recognizable View is generally wider than thermal cameras and therefore easier to select an optimal monitoring position	**LOW** Infrared feature not needed if used between dawn and dusk Unlikely to be able to distinguish objects in vegetation unless objects are leaving from/returning to vegetation	**LOW** Accuracy for identifying species depends on local species richness, quality of recording, and observer's experience Image has a monochrome colorcast and so colors cannot be determined.
		Weaknesses: • Time consuming post-processing required to display time stamp on recorded video • Illuminator IR lamp equipment, batteries, and stands needed for best results and setup properly after dark to achieve even illumination • IR lamp light rapidly falls off; multiple lamps are required to light large subjects • Significant amount of storage memory needed for videos • Labor intensive recording review: length of time needed for review may be greater than length of recording • Requires manual review unless software is available for automatic detection • Camera and lights are not waterproof				

Table A-1 | Technology Evaluation for Use in Bat Monitoring

Device	How it Works	Strengths and Weaknesses	Monitoring Use Suitability (Low, Moderate, High)			
			Emergence Counts - Caves	Emergence Counts - Maternity Roost	Vegetation Monitoring	Species Identification
SM4BAT Acoustic Recording Unit (Wildlife Acoustics)	An acoustic survey for bats involves recording their high-frequency echolocation calls with a specially designed high-frequency sensitive microphone on a "bat detector," capable of digitizing these recordings and saving them as audio *.WAV files. Analysis of echolocation calls involves converting the digitized sound into illustrations (i.e., "spectrographs") representing how the frequencies and intensities of the sounds change over time, and then qualitatively and quantitatively analyzing the content of the spectrographs. Acoustic surveys are based on the premise that different species will produce unique call-types much like birds and other vocal animals. Therefore, by collecting a recording from a bat, researchers can determine species by measuring these frequency-time and intensity-time parameters.	**Strengths:** • An acoustic survey for bats involves recording their high-frequency echolocation calls with a specially designed high-frequency sensitive microphone on a "bat detector," capable of digitizing these recordings and saving them as audio *.WAV files. • Analysis of echolocation calls involves converting the digitized sound into illustrations (i.e., "spectrographs") representing how the frequencies and intensities of the sounds change over time, and then qualitatively and quantitatively analyzing the content of the spectrographs. • Acoustic surveys are based on the premise that different species will produce unique call-types much like birds and other vocal animals. Therefore, by collecting a recording from a bat, researchers can determine species by measuring these frequency-time and intensity-time parameters.	**HIGH** For presence or absence information, microphones can be positioned in such a way so that only bats entering a cave may be recorded..Species information may not be available under these circumstances due to recording conditions	**HIGH** For presence or absence information. Specific location of emergence may not be able to be determined. Species information may not be available under these circumstances due to recording conditions	**NOT APPLICABLE**	**LOW-HIGH** Species ID relies upon the ability to record fully rendered, high-quality echolocation call sequences. How closely a bat passes a microphone, how long the bat stays within the optimum volume of detection of the microphone, or how loud a bat will echolocate is impossible to control. Many echolocation call recordings will not be of high enough quality or contain enough content to be confidently identified to species or species-guild. Nevertheless, during a long-term deployment, enough recordings are collected and many of them will be of sufficient quality for analysis and ultimate identification to species.
		Weaknesses: • Impossible to determine age, sex or reproductive condition of the bats • Biased towards recording bats that produce the loudest echolocation calls and the lowest frequency echolocation calls, since these are detectable over longer distances • Different species will converge on similar sound types, making bat echolocation call sequences far less species-specific, resulting in bias towards easy-to-identify species that produce distinct and unique echolocation call types				

Table A-1 | Technology Evaluation for Use in Bat Monitoring

Device	How it Works	Strengths and Weaknesses	Monitoring Use Suitability (Low, Moderate, High)			
			Emergence Counts - Caves	Emergence Counts - Maternity Roost	Vegetation Monitoring	Species Identification
Bat Counter (Apodemus)	Dual layers of infrared beams are arranged around a rectangular or square frame. Objects passing through the frame break beams and the sequence of the break is recorded with a timestamp to determine which direction the object was travelling.	**Strengths:** • Unattended very long term event counts can be recorded as long as power and memory allow • Can be synced with a high speed camera system to capture images of triggered events	**HIGH** Large entrances/ exits may require multiple devices or constricting passages to encourage bats to fly through the frame	**HIGH** Large entrances/ exits may require multiple devices or constricting passages to encourage bats to fly through the frame Suitable for known entrances/ exit points of a maternity roost	**NOT APPLICABLE**	**LOW** Counter only tallies beam breaks unless camera system captures clear images. Species ID then relies on species richness of the local area
		Weaknesses: • Relatively small frame sizes are ideal for small, concentrated exit points but large entrances may require multiple counter devices or temporarily restricting the entrance size • While sensors are along two sides of the frame, debris, snow, or ice may settle over sensors rendering them useless in certain situations				

B PHOTOGRAPHS - ARIZONA WATER RESOURCE STUDY

Photo B-1
Site 1 with thermal imager (foreground) and pole with bat detector microphone (background)

Photo B-2
Site 2 with thermal imager and pole with bat detector microphone

Photo B-3
Site 3 with infrared camcorder and external infrared lights (foreground) and pole for bat detector microphone (background); AWRR trail camera (background)

Photo B-4
Site 3 infrared video, ultrasound emitter on right edge of pool; AWRR trail camera visible behind ultrasound emitter

Photo B-5
Site 4 (left) including pole with bat detector microphone and Site 5 (right) with three ultrasound emitters deployed in water

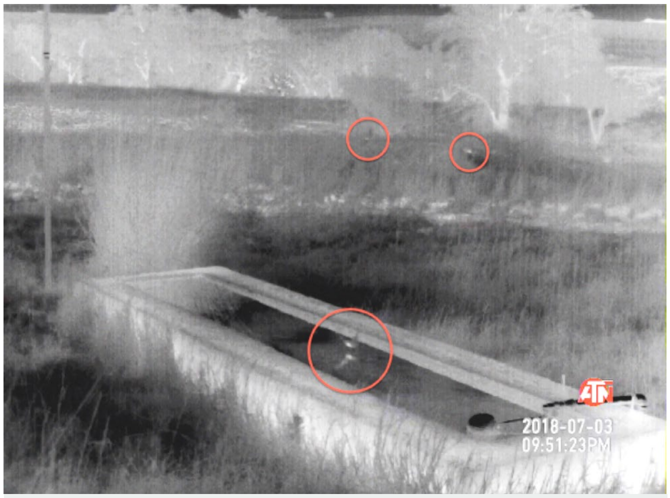

Photo B-6
Site 1 thermal imagery, baseline data collection; two bat fly-bys and one bat sip circled in red

Photo B-7
Site 2 thermal imagery, no treatment; bat sip circled in red

Photo B-8
Site 1 thermal imagery, treatment data collection; ultrasound emitter circled in blue, bat fly-by circled in red; bat appeared to approach water for a sip then turned away

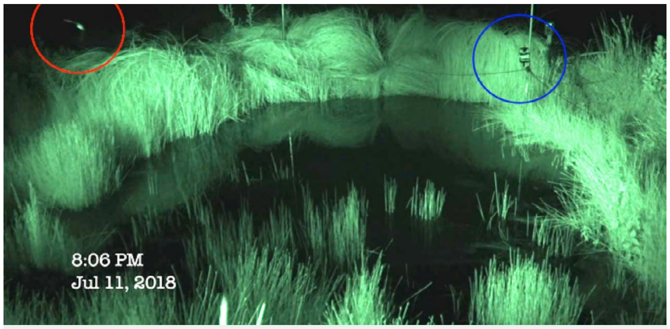

Photo B-9
Site 3 infrared video, treatment data collection; ultrasound emitter circled in blue, bat fly-by circled in red

Photo B-10
Site 4 infrared video, no treatment; bat fly-by circled in red

Photo B-11
Site 5 infrared video, treatment data collection; ultrasound emitters circled in blue, bat fly-by circled in red

Photo B-12
Site 5 infrared video, treatment data collection; ultrasound emitters circled in blue

C EQUIPMENT DEPLOYMENT

Table C-1 details equipment deployment at all five survey sites for the Arizona Water Resource Study. Bat activity was monitored using thermal imagers or infrared camcorders with auxiliary infrared lights. Acoustic recording unit (i.e., bat detector) with an omnidirectional microphone was deployed and operated each night during pre-treatment, treatment, and post-treatment. One to four ultrasound emitters were deployed at treatment sites.

Table C-1 | Equipment Deployment July 3-18 2018

Date	Site No.	Bat Detector (No. Present)	Bat Detector		Total Detector HRS	Thermal Imager (No. Present)	Infrared Camcorder (No. Present)	Ultrasound Emitter (No. Present)	Video Recorder and Ultrasound Emitter		Total Video Hours	Notes
			Start Time (hrs)	End Time (hrs)					Start Time (hrs)	End Time (hrs)		
3-Jul-18	1	1	19:51	5:01	9:09	1	0	0	19:37	23:40	4:03	Baseline data collected
4-Jul-18	1	1	19:51	5:01	9:09	1	0	0	19:24	23:16	3:52	Baseline data collected
5-Jul-18	1	1	19:51	5:02	9:10	1	0	0	19:18	23:35	4:17	Baseline data collected
6-Jul-18	1	1	19:51	5:02	9:10	1	0	1	19:13	23:21	4:08	Treatment
7-Jul-18	1	1	19:50	5:03	9:12	1	0	1	19:09	23:30	4:21	Treatment
8-Jul-18	1	1	19:50	5:03	9:12	1	0	1	19:22	23:21	3:59	Treatment
9-Jul-18	1	1	19:50	5:04	9:13	1	0	1	19:59	23:00	3:01	Treatment
10-Jul-18	1	1	19:50	5:05	9:14	1	0	1	19:30	23:08	3:38	Treatment
11-Jul-18	1	1	19:49	5:06	9:16	1	0	1	19:29	23:23	3:54	Treatment
12-Jul-18	1	1	19:49	5:05	9:15	1	0	1	19:35	21:15	1:40	Treatment; Ended early due to unfavorable weather
13-Jul-18	1	1	19:49	5:06	9:16	1	0	1	20:33	23:26	2:53	Treatment; Late start due to concerns with weather
14-Jul-18	1	1	19:49	5:07	9:17	1	0	1	19:33	23:23	3:50	Treatment
15-Jul-18	1	1	19:48	5:07	9:18	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit; Removed thermal camera and ultrasound emitter permanently
16-Jul-18	1	1	19:48	5:09	9:20	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
17-Jul-18	1	1	19:47	5:08	9:20	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
18-Jul-18	1	1	19:47	5:09	9:21	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit

Table C-1 | Equipment Deployment July 3-18 2018

Date	Site No.	Bat Detector (No. Present)	Bat Detector		Total Detector HRS	Thermal Imager (No. Present)	Infrared Camcorder (No. Present)	Ultrasound Emitter (No. Present)	Video Recorder and Ultrasound Emitter		Total Video Hours	Notes
			Start Time (hrs)	End Time (hrs)					Start Time (hrs)	End Time (hrs)		
19-Jul-18	1	1	19:46	5:09	9:22	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
3-Jul-18	2	1	19:51	5:01	9:09	1	0	0	19:38	22:40	3:02	Baseline data collected
4-Jul-18	2	1	19:51	5:01	9:09	1	0	0	19:32	23:12	3:40	Baseline data collected
5-Jul-18	2	1	19:51	5:02	9:10	1	0	0	19:19	23:34	4:15	Baseline data collected
6-Jul-18	2	1	19:51	5:03	9:11	1	0	0	20:52	23:33	2:41	No treatment
7-Jul-18	2	1	19:50	5:03	9:12	1	0	0	19:08	23:32	4:24	No treatment
8-Jul-18	2	1	19:50	5:03	9:12	1	0	0	19:23	23:28	4:05	No treatment
9-Jul-18	2	1	19:50	5:05	9:14	1	0	0	19:57	22:59	3:02	No treatment
10-Jul-18	2	1	19:50	5:05	9:14	1	0	0	19:29	23:08	3:39	No treatment
11-Jul-18	2	1	19:49	5:06	9:16	1	0	0	19:28	23:23	3:55	No treatment
12-Jul-18	2	1	19:49	5:05	9:15	1	0	0	19:37	21:17	1:40	No treatment; Ended early due to unfavorable weather
13-Jul-18	2	1	19:49	5:06	9:16	1	0	0	20:30	23:29	2:59	No treatment; Late start due to concerns with weather
14-Jul-18	2	1	19:49	5:06	9:16	1	0	0	19:35	23:25	3:50	No treatment
15-Jul-18	2	1	19:48	5:07	9:18	0	0	0	–	–	0:00	No treatment; Data collected using only acoustic recording unit; Removed thermal camera permenantly
16-Jul-18	2	1	19:48	5:08	9:19	0	0	0	–	–	0:00	No treatment; Data collected using only acoustic recording unit
17-Jul-18	2	1	19:47	5:08	9:20	0	0	0	–	–	0:00	No treatment; Data collected using only acoustic recording unit
18-Jul-18	2	1	19:47	21:23	1:35	0	0	0	–	–	0:00	No treatment; Data collected using only acoustic recording unit
19-Jul-18	2	1	0:00	0:00	0:00	0	0	0	–	–	0:00	No treatment; Data collected using only acoustic recording unit
3-Jul-18	3	–	–	–		–	–	–	–	–	0:00	No equipment deployed
4-Jul-18	3	1	19:51	5:01	9:09	0	1	0	19:43	23:11	3:28	Baseline data collected
5-Jul-18	3	1	19:51	5:02	9:10	0	1	0	19:15	23:33	4:18	Baseline data collected

Table C-1 | Equipment Deployment July 3-18 2018

Date	Site No.	Bat Detector (No. Present)	Bat Detector		Total Detector HRS	Thermal Imager (No. Present)	Infrared Camcorder (No. Present)	Ultrasound Emitter (No. Present)	Video Recorder and Ultrasound Emitter		Total Video Hours	Notes
			Start Time (hrs)	End Time (hrs)					Start Time (hrs)	End Time (hrs)		
6-Jul-18	3	1	19:51	5:02	9:10	0	1	1	19:17	23:30	4:13	Treatment
7-Jul-18	3	1	19:50	5:03	9:12	0	1	1	19:29	23:42	4:13	Treatment; Lowered deterrent from 1.5m (60in) above water to 0.8m (32in) above water
8-Jul-18	3	1	19:50	5:03	9:12	0	1	1	19:29	23:27	3:58	Treatment
9-Jul-18	3	1	19:50	5:04	9:13	0	1	1	20:06	23:05	2:59	Treatment
10-Jul-18	3	1	19:50	5:05	9:14	0	1	1	19:33	23:01	3:28	Treatment
11-Jul-18	3	1	19:49	5:05	9:15	0	1	1	19:31	23:28	3:57	Treatment
12-Jul-18	3	1	19:49	5:05	9:15	0	1	0	19:35	21:14	1:39	Post-treatment data collected; Removed ultrasound emitter permenantly, only IR camera remained; Ended early due to unfavorable weather
13-Jul-18	3	1	19:49	5:06	9:16	0	1	0	20:39	23:00	2:21	Post-treatment data collected; Late start due to concerns with weather
14-Jul-18	3	1	19:49	5:07	9:17	0	1	0	19:30	23:22	3:52	Post-treatment data collected
15-Jul-18	3	1	19:48	5:07	9:18	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit; Removed infrared camera permenantly
16-Jul-18	3	1	19:48	5:08	9:19	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
17-Jul-18	3	1	19:47	5:08	9:20	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
18-Jul-18	3	1	19:47	5:09	9:21	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
19-Jul-18	3	1	19:46	5:10	9:23	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
3-Jul-18	4	1*	19:51	5:01	9:09	0	1	0	19:51	22:35	2:44	Baseline data collected; *Acoustic recording unit deployed between Site 4 and Site 5
4-Jul-18	4	1*	19:51	5:01	9:09	0	1	0	19:29	23:36	4:07	Baseline data collected; IR light problems from 20:17hrs to 20:48hrs; *Acoustic recording unit deployed between Site 4 and Site 5

Table C-1 | Equipment Deployment July 3-18 2018

Date	Site No.	Bat Detector (No. Present)	Bat Detector		Total Detector HRS	Thermal Imager (No. Present)	Infrared Camcorder (No. Present)	Ultrasound Emitter (No. Present)	Video Recorder and Ultrasound Emitter		Total Video Hours	Notes
			Start Time (hrs)	End Time (hrs)					Start Time (hrs)	End Time (hrs)		
5-Jul-18	4	1*	19:51	5:02	9:10	0	1	0	19:32	23:13	3:41	No treatment; *Acoustic recording unit deployed between Site 4 and Site 5
6-Jul-18	4	1*^	19:51	20:25	0:33	0	1	0	19:38	23:03	3:25	No treatment; *^Acoustic recording unit deployed between Site 4 and Site 5 at about 20:25hrs
7-Jul-18	4	1	19:50	5:03	9:12	0	1	0	19:45	23:18	3:33	No treatment
8-Jul-18	4	1	19:50	5:04	9:13	0	1	0	19:42	23:12	3:30	No treatment
9-Jul-18	4	1	19:50	5:04	9:13	0	1	0	19:55	20:35	0:40	No treatment; Ended early due to rain
10-Jul-18	4	1	19:50	5:04	9:13	0	1	0	19:57	23:28	3:31	No treatment
11-Jul-18	4	1	19:49	5:05	9:15	0	1	0	19:38	23:01	3:23	No treatment
12-Jul-18	4	0	–	–	–	0	1	4	19:29	21:42	2:13	Treatment; Switched ultrasound emitters from McDaniels 2 (north pond) to McDaniels 1 (south pond); Moved acoustic recording unit to McDaniels 2 (north pond); Ended early due to unfavorable weather
13-Jul-18	4	0	–	–	–	0	1	4	19:38	23:00	3:22	Treatment
14-Jul-18	4	0	–	–	–	0	1	4	19:29	23:02	3:33	Treatment
15-Jul-18	4	0^	–	–	–	0	1	4	19:42	23:08	3:26	Treatment; ^Acoustic recording unit deployed between Site 4 and Site 5 at 23:08
16-Jul-18	4	1*	19:48	5:08	9:19	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit; Removed infrared camera and ultrasound emitters permenantly
17-Jul-18	4	1*	19:47	5:08	9:20	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
18-Jul-18	4	1*	19:47	5:09	9:21	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
19-Jul-18	4	1*	19:46	5:09	9:22	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit
3-Jul-18	5	1*	19:51	5:01	9:09	0	1	0	19:57	22:40	2:43	Baseline data collected; *Acoustic recording unit deployed between Site 4 and Site 5 (same unit as described under Site 4)
4-Jul-18	5	1*	19:51	5:01	9:09	0	1	0	19:22	23:33	4:11	Baseline data collected; *Acoustic recording unit deployed between Site 4 and Site 5 (same unit as described under Site 4)

Table C-1 | Equipment Deployment July 3-18 2018

Date	Site No.	Bat Detector (No. Present)	Bat Detector		Total Detector HRS	Thermal Imager (No. Present)	Infrared Camcorder (No. Present)	Ultrasound Emitter (No. Present)	Video Recorder and Ultrasound Emitter		Total Video Hours	Notes
			Start Time (hrs)	End Time (hrs)					Start Time (hrs)	End Time (hrs)		
5-Jul-18	5	1*	19:51	5:02	9:10	0	1	3	19:34	23:12	3:38	Treatment; *Acoustic recording unit deployed between Site 4 and Site 5 (same unit as described under Site 4)
6-Jul-18	5	0	20:26	5:02	8:36	0	1	3	19:38	23:02	3:24	Treatment; *Acoustic recording unit moved from between Site 4 and Site 5 to over Site 4 at about 20:25hrs
7-Jul-18	5	0	–	–	–	0	1	3	19:43	23:21	3:38	Treatment
8-Jul-18	5	0	–	–	–	0	1	3	19:40	23:08	3:28	Treatment
9-Jul-18	5	0	–	–	–	0	1	3	19:54	20:37	0:43	Treatment; Ended early due to rain
10-Jul-18	5	0	–	–	–	0	1	3	19:54	23:27	3:33	Treatment
11-Jul-18	5	0	–	–	–	0	1	3	19:36	23:03	3:27	Treatment
12-Jul-18	5	1	19:49	5:05	9:15	0	1	0	19:29	21:41	2:12	Post-treatment data collected; Switched ultrasound emitters from McDaniels 2 (north pond) to McDaniels 1 (south pond); moved acoustic recording unit to McDaniels 2 (small pond); Ended early due to unfavorable weather
13-Jul-18	5	1	19:49	5:06	9:16	0	1	0	19:34	23:00	3:26	Post-treatment data collected
14-Jul-18	5	1	19:49	5:06	9:16	0	1	0	19:27	23:05	3:38	Post-treatment data collected
15-Jul-18	5	1^	19:48	5:07	9:18	0	1	0	19:37	23:08	3:31	Post-treatment data collected beginning after deterrent removal at 23:08; ^Acoustic recording unit deployed between Site 4 and Site 5 at 23:08
16-Jul-18	5	1*	19:48	5:08	9:19	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit; Removed infrared camera and ultrasound emitters permenantly; *Acoustic recording unit deployed between Site 4 and Site 5
17-Jul-18	5	1*	19:47	5:08	9:20	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit; *Acoustic recording unit deployed between Site 4 and Site 5
18-Jul-18	5	1*	19:47	5:09	9:21	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit; *Acoustic recording unit deployed between Site 4 and Site 5
19-Jul-18	5	1*	19:46	5:09	9:22	0	0	0	–	–	0:00	Post-treatment data collected using only acoustic recording unit; *Acoustic recording unit deployed between Site 4 and Site 6

D METHODS EVALUATION

Primary methods used during the Arizona Water Resource Study and Florida Roost Study were evaluated for their effectiveness. It is important to address strengths and areas for improvement of the study approach to help guide future research. Favorable outcomes of the study approach were highlighted, or areas for improvements were recommended in Table D-1.

Table D-1 | Methods Evaluation | Arizona Water Resource Study

What we tried	Why we tried it	Lessons Learned	Future Improvements
Treated water resources of varying types and sizes with ultrasound emitters	Previous bat capture studies indicated known bat use and diversity at these water resources; Geographical area ideal to attract bats to water	Treatment not consistent among all sites due to varying types and sizes of water resources used	Deploy artificial water resources such as plastic watering troughs of same dimensions in same geographical area; Treat with same number of ultrasound emitters; Deploy ultrasound emitters at exact same height and location
Viewing area was defined as the entire field of view captured by the video equipment	Decreased subjectivity by each reviewer when determining bat proximity to the water resource in three-dimensional space represented on a two-dimensional screen	Large video viewing area may have captured bats passing by with no interest in the water resource regardless of the emitters; therefore, inflating number of bat passes	Deploy artificial water resources such as plastic watering troughs of same dimensions to enable video viewing area to be same among all sites; Deploy a three-dimensional camera array to determine bat proximity to water resource
Established two non-treatment sites within the vicinity of treatment sites	To determine if non-treatment sites increased in bat activity while treatment occurred at an adjacent site or at sites within same vicinity	Non-treatment sites were effected by treatment sites; therefore, could not use non-treatment sites as a control since they were not independent of treatment sites	Include both non-treatment sites and a control site
No control was used during the study	No suitable sites were available independent of treatment sites to use as a control	A control would have strengthened experiment	Deploy artificial water resources such as plastic watering troughs of same dimensions; Establish one as a control in a location where treatment would not have an effect
Study time of year was close to Arizona monsoon season	Outcome of planning and scheduling	Weather limited length of consistent data collection	Implement study in May or June within same geographical area
Deployed two different types of video equipment to record bat activity	Enabled a comparison to determine best equipment to use for future studies	Video quality varied among equipment and among sites	Use one type of video camera for all sites
Deployed infrared video camcorders to record bat activity	Evaluated effectiveness of this technology for this purpose; Equipment produces good image quality	Infrared video camcorders require external lights for best image quality; external lights are limited in projected distance; shadows may be present, limiting viewing area	For this type of study, deploy thermal imagers instead of infrared camcorders with external infrared lights since thermal imagers provided most consistent image quality
Deployed thermal imagers to record bat activity	Evaluated effectiveness of this technology for this purpose; Equipment produces good image quality	Thermal imagers used needed to be reset periodically due to changing environmental conditions and to prevent file corruption	This equipment was adequate for this type of study since thermal imagers provided most consistent image quality

Table D-1 | Methods Evaluation | Arizona Water Resource Study

What we tried	Why we tried it	Lessons Learned	Future Improvements
One of five sites did not have a bat acoustic detector deployed during entire survey period	Due to the close proximity of two sites (Site 4 and 5), a bat acoustic detector was used to determine if treatment at one site effected bat activity at adjacent site; Distance of potential treatment overlap and effect could be determined	Bat activity during treatment at one site was not obtained via bat acoustic detector	Obtain more bat acoustic detectors and deploy one at each site
With the exception of one ultrasound emitter at Site 5, all ultrasound emitters were deployed at the same or close-to-same height	To be consistent among all sites; One ultrasound emitter at Site 5 was higher than others to rise above debris in water	Not all bats were discouraged from airspace within treatment areas perhaps due to design of emitters and 12-ft (3.7-m) effective range	Deploying more than one ultrasound emitter vertically may be more effective in discouraging bat use of airspace over a wider range due to design of emitters
Passes per hour were used as a metric for analysis	Determining "passes per hour" paralleled a previous study by Szewczak and Arnett (2007); Determining the number of bat passes made while ultrasound emitters are operating, including bat flybys without stopping to drink or forage and the absence of bat passes compared to when ultrasound emitters were not operating, may be able to identify the limit of effectiveness of the ultrasound emitters at these unobstructed water areas; Additionally, a decrease in bat passes while ultrasound emitters are operating may support our hypothesis that broadcasting ultrasound at a water resource will discourage bats from entering treated airspace due to the broadcast having a "jamming" effect of bats' natural use of ultrasound	Using "passes per hour" as a metric did not help support our hypothesis; however, it did identify limits to the manufacturer's specification of a 12-ft (3.7m) effective range and identified broadcast areas not effectively covered due to the design of the emitters (e.g., area below the unit); Additionally, the large video viewing area at some of the sites may have captured bats passing by with no interest in the water resource regardless of the emitters and would have been counted as a pass.	
	Use "passes per hour" as a metric in the future; however, limit the video viewer area and deploy more than one ultrasound emitters vertically to cover areas where the broadcast is insufficient due to the design of the emitters		
Sips per hour were used as a metric for analysis	Bats likely require unhindered ultrasound transmission and reception to accomplish complex echolocation tasks such as sipping at the surface of the water; therefore, a decrease in bat sips while ultrasound emitters are operating may support our hypothesis that broadcasting ultrasound at a water resource will discourage bats from entering treated airspace due to the broadcast having a "jamming" effect of bats' natural use of ultrasound	Using "sips per hour" as a metric helped support our hypothesis	Use "sips per hour" as a metric in the future

Table D-1 | Methods Evaluation | Florida Roost Study

What we tried	Why we tried it	Lessons Learned	Future Improvements
Deployed two ultrasound emitters on a telescoping pole, one 6ft (1.8m) off the floor, one 4ft (1.2m) from the peak, to broadcast ultrasound horizontally and vertically within roost	Due to large area covered by roosting bats, deploying ultrasound emitters in this array increased coverage of the broadcast	Since the majority of the bats roosted 6ft from the floor to the peak, this array covered the majority of the roosting area	This array covered the majority of the roosting area; however, moving the ultrasound emitters closer together and adding a third emitter to the pole may increase effectiveness since the greatest intensity of the ultrasound is within 3.2ft (1m) of the unit
Pole with ultrasound emitters affixed was 6ft (1.8m) from wall where bats roosted	The manufacturer's specification of a 12-ft (3.7-m) effective range was divided in half to increase effectiveness of the ultrasound emitters	Ultrasound emitters were possibly too far away from wall where bats roosted, especially since beams were present that could block ultrasound and since ultrasound intensity drops further away from unit	Moving ultrasound emitters closer to the area where bats roosted may increase effectiveness since the greatest intensity of the ultrasound is within 3.2ft (1m) of the unit
Study time of year was too close to autumn weather changes	Outcome of planning and scheduling	Weather conditions after the 10th night of the survey was erratic and, therefore, treatment after this night could not be attributed to the decrease in bat cluster size	Implement study in August within same geographical area
Cluster size after the dawn return, measured by number of concrete blocks covered with bats from photo-documentation, was used to determine effectiveness of ultrasound emitters	It was necessary to determine if bats avoided roosting within the broadcast zone upon the dawn return and, since the broadcast zone covered an area of the concrete blocks where the bats roosted prior to the evening emergence, presence or absence of bats on the concrete blocks provided a good gage of avoidance or no avoidance of the broadcast zone; Dimensions of concrete blocks are consistent throughout the roost; Number of bats present could not be used because bats were observed roosting on top of each other and it could not be determined if the bats did this to avoid the broadcast zone or due to some other reason (e.g., thermoregulation)	In this particular roost environment, determining cluster size using area covered was a good gage of avoidance or no avoidance of the broadcast zone	Determining cluster size after the dawn return, measured by number of concrete blocks covered with bats from photo-documentation (i.e., area covered by bats), was a good gage to determine effectiveness of ultrasound emitters in this particular roost environment; Using computer-generated polygons to measure area covered would also be effective
Time-lapse photography was used to monitor presence or absence of bats on roost wall	Since the roost was monitored throughout the night, time-lapse photography was an effective monitoring tool to use over long periods of time; Data organization and review post-survey was not labor intensive	Time-lapse photography is an effectiveness tool for long-term monitoring and file management is not labor intensive	Time-lapse photography can be used for future monitoring of roosts of this type

E PHOTOGRAPHS-FLORIDA ROOST STUDY

Photo E-1
Maintenance building and crate storage; Garage (far end) used for storage and was location of roosting bats

Photo E-2
Bats roosting on east wall at south end of roost; Bottom half (darker pelage): southeastern myotis (Myotis austroriparius); Top half (lighter pelage): Brazilian free-tailed bat (Tadarida brasiliensis)

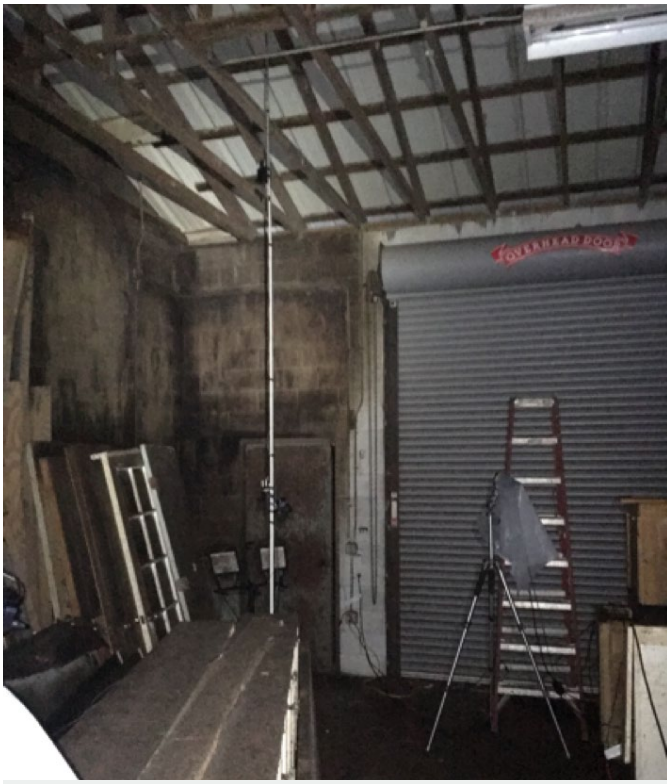

Photo E-3
South end ultrasound emitter pole and infrared time-lapse camcorder

Photo E-5
North end ultrasound emitter pole (background), data logger pole (middle), south end ultrasound emitter pole (foreground)

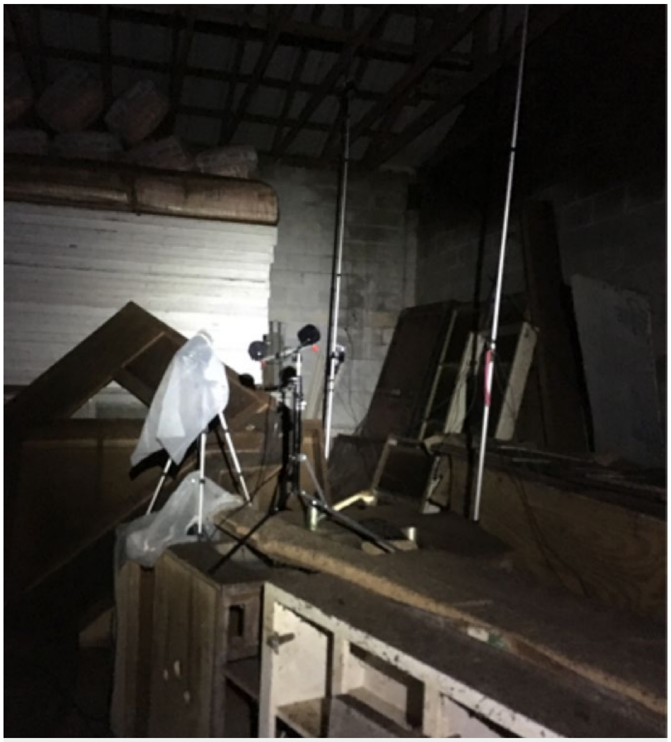

Photo E-4
North end infrared time-lapse camcorder with external infrared lights, ultrasound emitter pole (background), and data logger pole (foreground)

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