Field Test Results of a Potential Acoustic Deterrent to Reduce Bat Mortality from Wind Turbines

Joseph M. Szewczak, Ph.D.
Humboldt State University
Arcata, CA 95521

Edward B. Arnett, Ph.D.
Bat Conservation International
Austin, TX 78716

Screen shot from infrared video recording, Desert Studies Center, Zzyzyx, CA

Summary

Continued documentation of bat mortality at wind energy facilities indicates a potentially serious threat to many bat populations, particularly when extrapolated to the number of proposed installations. Any means of deterring bats from approaching wind turbines may reduce fatalities. We hypothesized that selected regimes of ultrasound could generate a jamming effect or disorienting airspace that could deter bats from entering the dangerous rotor-swept zone of wind turbines. We previously reported preliminary results that such an ultrasound broadcast could deter bats from occupying such a treated airspace. To more thoroughly investigate the deterring effect of ultrasound and determine whether bats could habituate to this acoustic treatment, we monitored foraging activity at 6 different ponds during August and September 2007 in Arizona, California, and Oregon for at least two nights to establish baseline activity levels, and then for 5 to 7 days of continuous treatment with ultrasound broadcast. We measured activity by counting visual passes of bats entering and leaving the recorded view from a Sony TR818 Nightshot video camera with the field of view illuminated with high intensity infrared lamps. The median activity rate/hour when the ultrasound was broadcast was estimated to be between 2.5 and 10.4% of the activity rate when no ultrasound was broadcast ($F_{1,5} = 117.6$, $p = 0.0001$). Our results indicate that ultrasound deterred bats and that they did not habituate or accommodate to continued broadcast of ultrasound for the period of time we studied. Bats may in fact learn to avoid the treated airspace. Bats that experience the ultrasound broadcast upon approaching a treated tower may avoid approaching another tower having similar treatment although such learned behavior has not been quantified. In this way, ultrasound broadcast may potentially serve as acoustic warning beacons as bats could detect their presence from beyond the affected airspace and perhaps the dangerous rotor-swept area. However, the effective range of the ultrasound broadcast from the device we tested did not extend beyond approximately 12–15 m. This may limit the practical application of this approach for directly preventing impacts from turbine rotors, given that modern rotors exceed more than twice this dimension.

Introduction

Because bats have low reproductive rates of one birth per year and many species having just a single offspring, they cannot quickly recover from population declines. This renders them particularly susceptible to mortality events (Kunz 1982, Racey and Entwistle 2000). The growing documentation of bat mortality at wind energy facilities indicates a potentially serious threat to many bat populations (Johnson et al. 2004, 2005, Arnett et al. 2005, 2008, Kunz et al. 2007, Kuvlesky 2007), particularly when extrapolated out to the number of proposed installations (NRC 2007, EIA 2008, Arnett et al. 2008). Trends in bat mortality at wind turbine sites suggest a disproportionate effect upon migrating and tree roosting bats (Kerns 2005, Johnson 2004 2005, Arnett 2008). The preponderance of tree roosting bats found dead at wind turbine sites has raised speculation that the towers may attract bats because they fit the bat's search image of a tall snag silhouetted against the sky (Fig. 1). Recent evaluation of hoary bat (*Lasiurus cinereus*) migration movements supports the notion that bats may seek prominent features for stopover roosts (Cryan and Brown 2007).

Any means of deterring bats from approaching turbines may prevent fatalities. A deterrent may work by either directly diverting approaching bats away, or by a learned aversion from previous exposure, e.g., the aversion training that pre-release California condors receive to avoid utility poles as a means to reduce electrocution after release (Cade et al. 2004).

Figure 1. Comparison of silhouettes of a natural snag with that of a wind turbine.

Few studies have investigated the influence of ultrasound broadcast on bat behavior and activity in the field. Mackey and Barclay (1989) concluded that ultrasound broadcasts reduced bat activity and attributed the reduction to greater difficulty in the bats hearing the echoes of insects and thus reduced feeding efficiency. We previously reported preliminary results that a regime of presumably jamming or disorienting ultrasound could deter bats from occupying such a treated airspace (Szewczak and Arnett 2006). Here we report further results of testing the effectiveness of using ultrasound as a deterrent, and whether bats habituate to the ultrasound or learn to avoid the treated airspace.

Methods

Site Selection

To test the effectiveness of the acoustic deterrent, we sought sites having consistent bat activity, but without the confounding influence of proximity to a roost or limited resource. We selected ponds small enough to concentrate bat activity, but sufficiently large to provide bats with an opportunity to forage over water or drink beyond the treatment effect. For example,

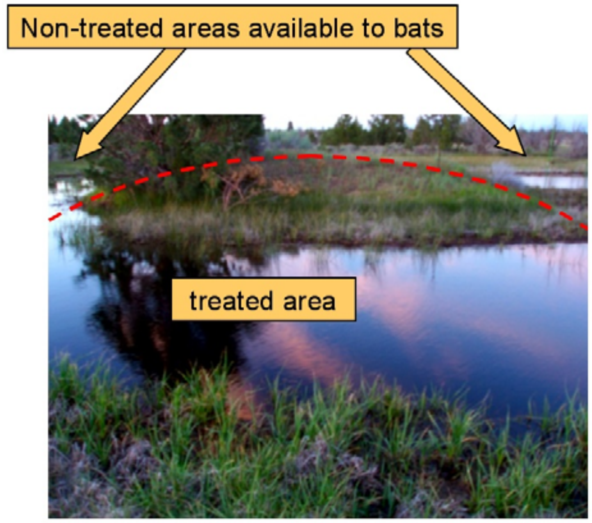

Figure 2. Example of study site showing the availability of ultrasound regime treated airspace and non-treated airspace providing options for bats to access foraging and water resources.

although it might have abundant bat activity, we deemed small resources such as a stock tank inappropriate as bats might have a compulsion to penetrate an uncomfortable airspace to reach a resource with limited availability. We desired to test the response of bats to ultrasound broadcast in a situation where bats could choose whether to occupy the treated airspace without limiting their access to available resources (Fig. 2). Because our previous investigation indicated a 12–15 m effective treatment range of the ultrasonic broadcast, we deemed ponds at least 50 m across to be suitable test sites if a single isolated water resource.

We selected test sites having a calm water surface and having some shoreline free of vegetation and surface debris to provide an unobstructed ultrasound broadcast and camera view, and having a treatment area at least 12 m across to take full advantage of the ultrasound broadcast range. We searched for candidate sites using topographic maps, aerial photographs (Google Earth) and consultation with local biologists and resource managers. Finally logistical considerations of access and security narrowed the final site selections.

Survey Sites

We selected four locations in Arizona, California, and Oregon that met our experimental criteria (Fig. 3; see Appendix 1 for site descriptions). Two of these locations, the Warner Mountains in OR and the Desert Studies Center in CA had more than one suitable site in close proximity that provided convenient logistics to run simultaneous experiments. We performed complete survey protocols at six sites in these four locations.

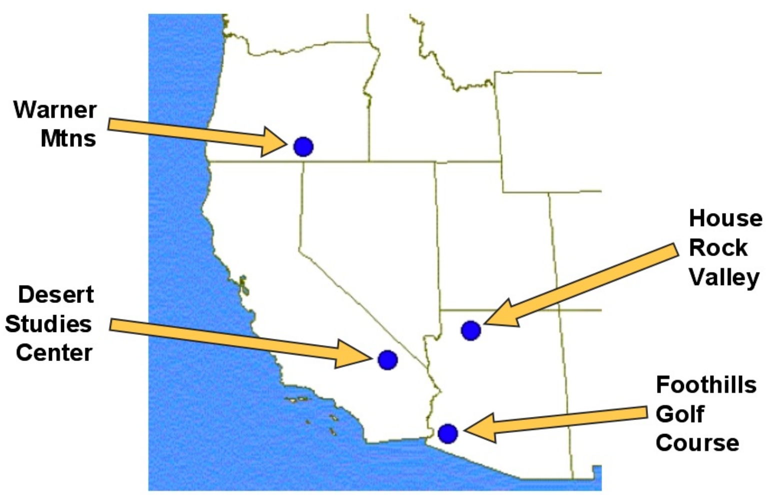

Figure 3. Geographic locations of study sites. Surveys were completed at two locations in the Warner Mountains and at the Desert Studies Center.

Ultrasound Broadcast

We broadcast ultrasound using an AT800 (Binary Acoustic Technologies, Tucson, AZ) portable ultrasonic amplifier and transducer unit capable of emitting high-intensity sound (~120 dB at 1 m; Fig. 4). We programmed the AT800 to broadcast a pre-programmed wideband ultrasonic signal similar to white noise. The deterrent produced a broadband ultrasonic masking signal that covered a frequency band of 20 to 80 KHz and the broadcast was continuous, rather than pulsed, during the field tests. For the first two site trials we only broadcasted from dusk and through the one hour monitoring period, but for the remaining four trials we broadcast throughout the night until the end of the study at each site (up to seven days).

Monitoring

The ultrasound broadcast precluded the use of acoustic bat detectors to monitor bat activity. Instead, we monitored bat activity using Sony Nightshot TR818 camcorders with supplemental infrared illumination by two Wildlife Engineering's Model IRLamp6 infrared lights (Fig 5). To optimize image quality we disabled the SteadyShot® and autofocus functions.

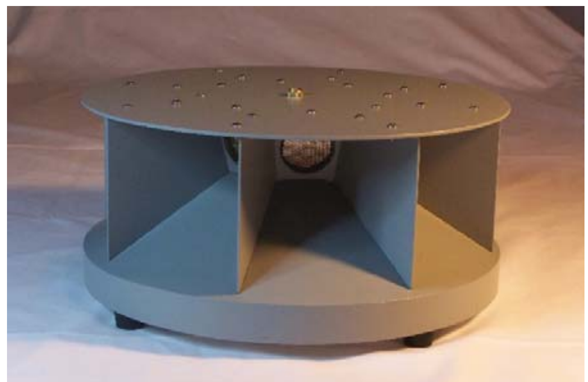

Figure 4. AT800 prototypes ultrasound broadcast unit developed by Binary Acoustic Technology, Tucson, AZ.

We monitored each site for 5 to 7 nights: two nights to establish baseline activity (control), then 3, 4 or 5 nights of treatment. We only monitored on nights having conditions we deemed amenable to bat activity: temperature >10°C, wind < 2.25 m/s (5 mph), and no precipitation. We monitored activity during the first two nights having amenable conditions with no ultrasound emissions. These nights were not always consecutive. On the third night having amenable conditions we began emitting the ultrasound and measured activity on that night as well as the 3rd and subsequent nights (up to 7th) having amenable conditions.

To monitor, we set up the video camera prior to sunset, and began each day at the same time post sunset. Our start time was between one hour and 1.5 hours after sunset, adjusted to include peak bat activity at the site and maintained for that site throughout each trial. We determined sunset for each location using the integrated sunset/sunrise function of a GPS unit. We did not zoom the camera view to enable the widest field of view (Fig. 6), and for each site we aimed the camcorder at a target that enabled replication each night, e.g., vegetation visible in camcorder view direction (Figs. 5 and 7).

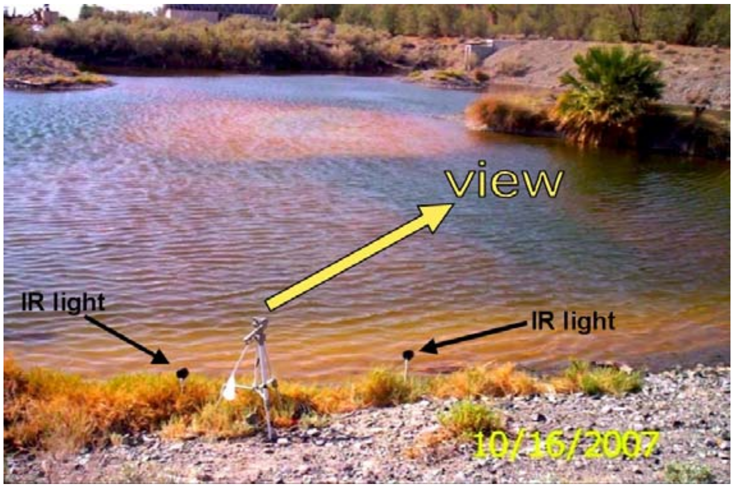

Figure 5. Example of monitoring setup at Zzyzyx west pond showing position of video camcorder tripod (camcorder not shown) relative to the two infrared lights. During treatment experiments, the AT800 ultrasonic broadcast unit would be placed on a support in front of the camcorder position to provide an unobstructed broadcast in the direction of the camcorder view.

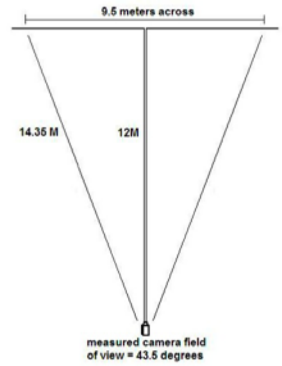

Figure 6. Plan view of camcorder view showing 43.5 degree field of view (no zoom, as used in experiments). The camcorder view provided an approximately 9.5 m wide field at 12 m from the camera, the presumed effective distance of the ultrasound broadcast.

Figure 7. Aerial view of Desert Studies Center (Zzyzyx, CA) showing the two study monitoring sites at the west and north ponds, and graphics indicating camcorder views. (Image captured from Google Earth.)

Analysis

We downloaded the video data on tape from each monitoring session to a laptop using the camera's IEEE 1394 (FireWire®) interface and Sony DVGate software, which encoded the video data as digital files. We briefly reviewed the files from each monitoring session on the laptop computer with QuickTime Pro® multimedia software (Apple, Inc., Cupertino, CA) to ensure successful data acquisition before subsequent monitoring or completion of monitoring at each site.

For each site, we reviewed the same one hour period of each night of monitoring on the laptop computer with QuickTime Pro® software. We quantified bat activity by counting bat passes, which we defined as the occurrence of a bat flying on to and off the screen view. We made no attempt to identify possible repeat passes because we could not identify individuals. We also made no distinction in the quantification of a pass whether the bat remained on screen for a short or long duration. To avoid confusion from other airborne objects such as moths, we only counted bat passed that we could clearly recognize as bats (Fig. 8).

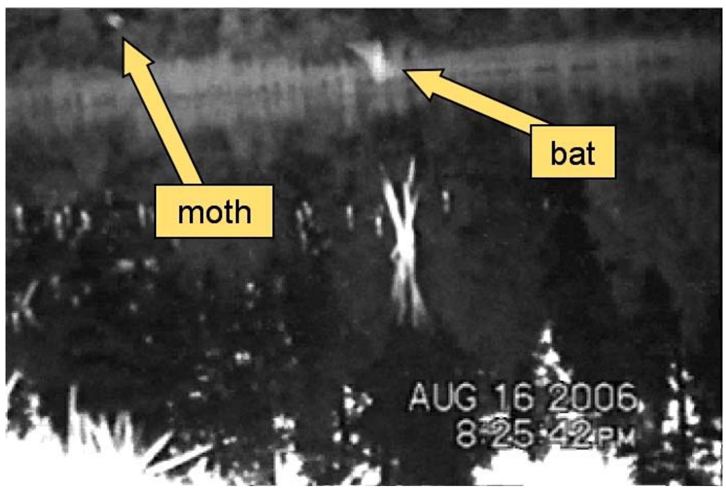

Figure 8. Video capture of a single video frame showing both a moth and a bat. In practice, movement across multiple frames facilitated discerning bats from insects easier than this single image conveys. However, bats farther from the camera could become ambiguous with insect movements. We recognized bats by flight pattern, shape, and wing movements.

We counted passes by visual observation of video playback in five minute intervals beginning the time of start to the nearest time divisible by five (e.g., 20:35), and from then on in five minute increments to complete a one hour count of passes. It was not possible to determine bat species, thus our results represent passes from all species frequenting the ponds during sampling.

Sources of variation in this study include the site, the night within site, and the treatment (ultrasound broadcast or none [control]). We considered the site a blocking factor and the night within the site as the experimental unit to which fixed treatments (ultrasound broadcast or none [control]) were assigned. Due to the potential for the treatment to have residual effect beyond the actual period of its implementation, it was not possible to randomly assign treatment to night. Thus, treatment nights had to follow the control nights. This could potentially have introduced bias if the activity rate at a site was affected simply by our presence and not by the implementation of the treatment. We assumed any such bias was consistent among sites and nights at a site and that the results were not influenced by our presence.

Table 1. Cumulative passes per hour for control nights (blue) and treatment nights (red). Interruptions in the order of days resulted from skipping nights when weather conditions did not meet the criteria to monitor (see text).

days of treatment	Pond 76, Warner Mtns	Pond 77, Warner Mtns	House Rock Valley	Foothills Golf Course	Zzyzyx west pond	Zzyzyx north pond	mean	std error
-4			264		329			
-3								
-2						460		
-1	89	182		308				
0	67	277	276	311	444	448	288	35.6
1	1	13	20	32	73	53		
2								
3	7	15		5	28			
4			21		29	17		
5	8	1	9	10	38	13		
6					31	24		
7						15	21	3.6

The nights within treatments at each site were considered replications of the treatments within the blocks, resulting in a generalized randomized block design. We $\log_e$-transformed the counts of bat passes to stabilize the variance and used analysis of variance (ANOVA) to compare activity during treatment and control nights periods.

Results

The cumulative passes for the one hour period counted for the 12 control nights across all sites ranged from 67 to 460, and the mean number of passes during control nights at the 6 sites was 288.2 (SE = 53.4; Table 1). The cumulative passes for the one hour period counted for the 22 treatment nights ranged from 1 to 73, and the mean number of passes during control nights at the 6 sites was 18.6 (SE = 5.0; (Table 1). The median activity rate/hour when the ultrasound was broadcast was significantly less compared to controls and was estimated to be between 2.5 and 10.4% of the activity rate when no ultrasound was broadcast ($F_{1,5}$ = 117.6, p = 0.0001).

Although we did not quantify it, on control nights without the ultrasound broadcast, shorter breaks between many of the pass events left us with the impression that many of these passes might be the same bats returning into view. Many of the bats observed on the video playback from nights of ultrasound broadcast would enter the field of view and move out of it, leaving longer breaks between passes.

The effect of the ultrasonic treatment on bat activity relative to control activity may be compared across all sites by normalizing activity levels to the mean of the control level at each site. To normalize, we set the mean baseline (control) activity at each site to equal one, and then calculated the treatment activity as a proportion of mean baseline activity. The relative effect of ultrasonic treatment resulted in a similar proportional decline in activity at all sites (Fig. 9).

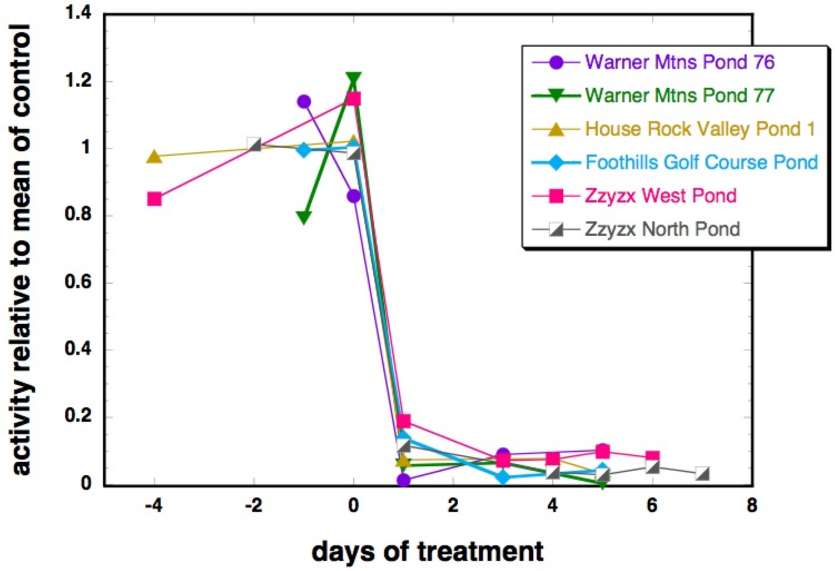

Figure 9. Change in bat pass activity at all sites compared by normalizing all bat passes per hour to values relative to the mean of control levels at each site, i.e., a bat pass count exactly equal to the mean control value would be equal to one.

Discussion and Conclusions

This investigation confirms previous findings that a regime of presumably jamming or disorienting ultrasound can deter bats from occupying such a treated airspace (Spanjer 2006, Szewczak and Arnett 2006). The effect was immediate, with bat activity within the ultrasound treated airspace reduced to 10% of control levels on the first night of treatment. An anecdotal observation during setup for a night of ultrasound broadcast treatment provided a dramatic visual confirmation of the immediate effectiveness of the deterrent. Western pipistrelle bats filled the air above the pond at the Foothill Golf course site, as these bats often do during early dusk at water sources in the southwestern United States. Within one minute of activating the ultrasound broadcast, the pipistrelles scattered out of the treated airspace while continuing to swarm elsewhere on the pond.

The results of this investigation also indicate that bats do not habituate or accommodate to the presence of ultrasound such that over time they learn to disregard and penetrate the treated airspace. On the contrary, over the five to seven days of monitored treatment, the number of bats entering the treated airspace declined. We contend that bats randomly encountered and experienced the treated airspace and elected to avoid it thereafter. Just as bat capture success in mist nets declines on successive nights as bats apparently learn the presence of the nets and thereafter avoid them (Kunz and Kurta 1988), we expect bats that endured a disagreeable encounter with the ultrasound treated airspace similarly learned to avoid it. Over the seven day course of the experimental treatment, bat activity declined to 4% of control levels, less than half of the first night of treatment. In practice, the actual decline of activity at any treated site would likely depend upon the immigration of naïve bats into the area. The bats monitored during this study were all likely residents local to the monitoring sites.

Although the results of this investigation substantiate that ultrasound treated airspace can deter some species of bats, the effectiveness of implementing ultrasonic deterrents as a means to prevent fatal collisions of bats with wind turbine rotors remains uncertain. The rapid attenuation of ultrasound in air limits the effective range that it can be broadcast. The transducers of the AT800 ultrasound broadcast unit essentially loads the airwaves with ultrasound, i.e., ultrasound cannot be broadcast with substantially more amplitude than the device we used. Our observations suggest that a single source of ultrasound broadcast with this amplitude level can affect bats up to a range of about 12–15 m, less than half the length of current wind turbine rotors. Despite the limited airspace of the direct deterrent effect, ultrasonic broadcast may still prove an effective approach for reducing bat mortality from rotor impacts by combined direct and indirect effects.

The limited range of ultrasound broadcast from a wind turbine tower or nacelle might have only a moderate contribution toward reducing impacts of bats randomly flying through the rotor-swept area. However, for bats that may be drawn to and approach turbine towers as potential roosts or gathering sites (Paul Cryan, personal communication), the combination of effective range and learned avoidance response to ultrasound broadcast may have longer term indirect effects in reducing bat mortality at wind turbines. Although the effective volume of airspace affected by the deterrent we used may be limited to a 12–15 m radius, bats could detect the *presence* of such airspace from a greater range. Bats that have previously experienced the jamming or disorienting effect of the ultrasound broadcast upon approaching a treated tower may avoid approaching other treated tower, which they could detect as treated from beyond the affected airspace. In this way, ultrasound broadcast may effectively serve as acoustic beacons to direct bats away from wind turbines.

Acknowledgements

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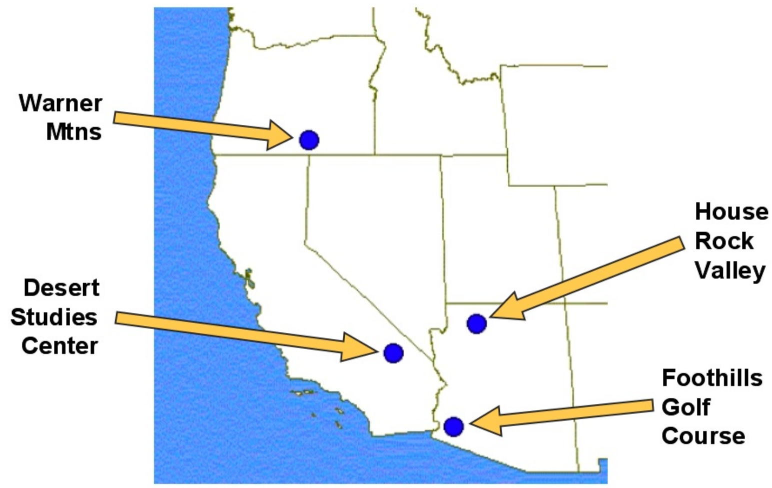
Appendix 1. Descriptions and geographic locations of sites sampled in Arizona, California, and Oregon during this study in 2007. Surveys were completed at two locations in the Warner Mountains and at the Desert Studies Center.



Site 1, Warner Mountains Pond 76, Fremont National Forest, OR. Elevation 1,920 m, UTM 728273 4683618. Stock pond with 3–4 m tall *Salix* around 30% of shore; otherwise short rushes and sedges; surrounding forest >50 m. away Ponderosa pine dominated. Camera set at edge of mud on east side of pond with willow 15 m away going to the in middle of viewfinder (right half of view). Located north on Hwy 140/395 from Lakeview, OR, 9.7 km to Hwy 140 right fork, take 140 east for 19.3 km to intersection of FR 1715 (paved road), go left (north) for 6.1 km, dirt road on left for about 150 m, pond on left (south) of berm.

Site 2, Warner Mountains Pond 77, Fremont National Forest, OR. Elevation 2,103 m, UTM 732461 4689373. Bermed pumper chance on small creek with grasses and a few small willows on all but east side; several mid-age conifers on eastern side. Open grassland to west; Ponderosa pine forest to the north and east. Camera set at southwest corner of pond, at end of berm, 1.5 m northeast from base of conifer. Approximately 11.3 km past North Warner Pond 76: North on Hwy 140/395 from Lakeview 9.7 km to Hwy 140 right fork, take 140 East for 19.3 km to intersection of FR 1715 (paved road) go left (north) for 17.7 km, dirt road on left, ~90 m to pond on left (south) of paved road.

Site 3, House Rock Valley Pond 1, Arizona Strip Bureau of Land Management, AZ. Elevation 1,515 m. UTM 415445 4054685. Bermed stock pond fed by piped-in spring. Devoid of vegetation except 0.2-0.5 m foot tall grasses on west side where water trickles in; 1 m maximum height desert shrub in surrounding area. Camera set at northwest corner of pond. From Fredonia, AZ take Hwy 89A east, 72.4 km to Buffalo Ranch Road, take this south for 8 km to dirt track just after road passes through a wash; pond lies over a hill ~ 150 m east of Buffalo Ranch Road.

Site 4, Foothills Golf Course Pond, Private land holding, 14200 56TH St, Fortuna, AZ. Elevation 119 m. UTM 745027 3613171. Golf course pond. Transition to Sonoran desert at Fortuna Wash; first water for bats arriving from Gila Mountain foothills. Trees around 50%

shoreline; residential to the north (~45 m to fence) and cut grass to east, then residential (~122 m). Camera set at northwest bank of pond. In Fortuna, AZ, take Foothills Road south from I-20 approximately 6.4 km until Air Force gate, make mandatory left before gate onto 56th for approximately 1.6 km to golf course; pond is ~60 m north of office.

Site 5, Zzyzyx West Pond, Desert Studies Center, Mojave Preserve (National Park Service), Zzyzyx, CA. Elevation 284 m. UTM 581486 3889266. Spring-fed pond. Oasis in Mojave Desert. Camera set on north bank of pond. South of Baker, CA, 9.7 km to Zzyzyx exit, follow 6.4 km to Desert Studies Center.

Site 6, Zzyzyx North Pond, Desert Studies Center, Mojave Preserve (National Park Service), Zzyzyx, CA. Elevation 284 m. UTM 581602 3889275. Spring-fed pond. Oasis in Mojave Desert. Camera set on south bank of pond. South of Baker, CA, 9.7 km to Zzyzyx exit, follow 6.4 km to Desert Studies Center.