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Mobile acoustic transects detect more bat activity than stationary acoustic point counts in a semi-arid and agricultural landscape

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ABSTRACT

Arid environments are characterized by resource pulses that cause spatio-temporal variability in species abundance, which can make population assessments difficult. Mobile acoustic methods may improve survey success by maximizing geographic extent, characterizing landscape distribution patterns, and improving encounter rates. Bats exemplify survey challenges in arid environments as they are highly mobile and aggregate around spatio-temporal resource hotspots. We compared bat detection success of stationary acoustic methods to that of mobile acoustic transects. In a semi-arid landscape, we recorded bat echolocation calls and compared three different sampling methods along the same 24 km route: a driven transect; a set of five, permanent ten-minute point counts; and a set of point counts at nightly randomized locations. The effect of method on the number of bat passes was analyzed using a bootstrapped generalized linear mixed effect model. The mean number of passes for the mobile method was 2.14 (CI: 1.45–2.99) and 0.98 (CI: 0.77–1.21) for the pooled stationary methods. We suggest that driven transects more effectively measure bat activity in arid and open landscapes. Testing of novel survey methods in arid environments is vital to conservation success as climate change increases the extent of these biomes and the variability of resource pulses.

1. Introduction

Arid environments are characterized by highly stochastic precipitation patterns (Morton et al., 2011). Consequently, the availability of food and water resources for arid-dwelling species varies both in space and time, but organisms exploit spatio-temporal increases in resources (resource pulses) numerically, by altering abundances, or functionally through behavioral changes (Abrams and Ginzburg, 2000). Numerical responses can involve baseline increases in population or an aggregation response in which organisms temporarily cluster around resource hotspots (Zach and Falls, 1979). Species that are mobile and employ an aggregation response can thus be challenging to survey or monitor as abundance density will be variable across the landscape. Methods that maximize geographic extent may increase overall species encounter rates, better characterize distributional patterns and landscape usage at large scales, and result in more accurate species abundance assessments.

Mobile methods are effective in characterizing landscape-level trends in populations and distributions because they can maximize geographic coverage. Mobile methods are frequently used in arid environments (Caro, 2011) were species densities can rapidly change in response to shifts in resource availability. Traditionally, mobile surveys involve visually documenting wildlife or indirect signs of wildlife such as nests or scat. Visual mobile methods have successful been used to detect and monitor changes in bird (Sauer et al., 2013) and large mammal populations (Caro, 2011). Conway and Simon (2003) showed that mobile methods detected more burrowing owls per hour when compared to stationary methods, which is beneficial when rapid population assessments are necessary for conservation actions. The advent of bioacoustic detectors has expanded the use of mobile methods from large or easily seen organisms to those that are cryptic, too small, or too fast to identify visually while in a moving vehicle. Mobile acoustic methods have been used to successful assess species distributions and population changes in insects (Jeliazkov et al., 2016), birds (Dawson and Efford, 2009), and bats (Britzke et al., 2011; Roche et al., 2011; Jones et al., 2013); taxa that emit sounds that are easily detected by acoustic technology. Recent advances in bioacoustic technology have expanded mobile acoustic methods to new species (e.g., cryptic

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mesopredators –Comazzi et al., 2016), community level biodiversity (Sueur et al., 2008), and ecosystem health (Tucker et al., 2014). Arid and open environments are ideal habitats for acoustic monitoring as there is little vegetative clutter to attenuate sound and species density is often low, reducing overlap in emitted bioacoustic signals. The combination of mobile methods and acoustic technology has the potential to be a fundamental tool for those designing biodiversity surveys and monitoring plans in arid environments.

Bats are one of the most diverse and successful mammal taxa in arid regions. For example, insectivorous bats are the most diverse group of mammals in the deserts of Israel with 33 species (Korine and Pinshow, 2004) and almost a quarter (59) of all bat species in South America are found in the dryland savannas of the continent (Sandoval and Barquez, 2013). Bats in arid landscapes provide important ecosystem services as agents of pest suppression, pollination, and seed dispersal and are an ideal bioindicator group for the health and stability of ecosystems (Jones et al., 2009). Despite taxonomic dominance and their importance in arid regions, bats are severely understudied in arid regions with almost nothing known about abundances and distributional patterns (Korine et al., 2016). This is in large part because bats exemplify the challenge of species monitoring in arid environments as they are highly mobile and known to exploit and aggregate around spatio-temporal resource hotspots (Razgour et al., 2011; Müller et al., 2012). For example, bats in arid regions frequently converge at water sources, but sampling only at these areas results in biased understanding of how bats use the landscape. Geluso and Geluso (2012) hypothesized that variation in capture rates from 1971 to 2005 in the arid San Mateo Mountains of New Mexico was caused by bats clustering around the only permanent water source (their capture site) during dry years but dispersing across the landscape in wet years when bats could frequent ephemeral water sources. Similarly, bats in semi-arid agricultural landscapes shift their distribution to match that of food resources; consumption of corn earworm moths in Texas by the Brazilian free-tailed bat (*Tadarida brasiliensis*) tracks with local changes in the insect population's abundance which varies with crop life cycles (McCracken et al., 2012). Survey and monitoring methods for bats in arid regions thus need to account for spatio-temporally variable aggregative responses to resources.

Common methods for bat surveys and monitoring (roost counts, capturing bats at known foraging sites, recording echolocation during flight), assess activity at single points (stationary methods), which may fail to account for spatial variation in bat activity and how spatial variation changes temporally (Hayes et al., 2009). Furthermore, the bat faunas of arid landscapes often comprise of species that specialize in foraging in habitats with little or no vertical complexity ("open-space bats"). Open-space bats have wing morphologies that allow them to fly fast over long distances and often at high altitudes, which makes them very difficult to catch while foraging (Norberg and Rayner, 1987; Lumsden and Bennet, 1995). Fortunately the echolocation calls used by open-space bats are typically of low frequency, high intensity (loud), and long duration which means they can be readily detected using acoustic methods (Schnitzler and Kalko, 2001). Calls are species-specific, allowing for species identification, although detailed analysis is sometimes required to separate similar species (Parsons and Szewczak, 2009). Stationary acoustic methods can be used successfully to survey and monitor bats at the landscape scale, but require a substantial investment in labor and equipment, because arrays of detectors are required (Coleman et al., 2014). Probability of detecting bats using stationary methods may be increased by selecting known areas of high bat activity, such as those around bodies of water, roosts, or linear landscape elements (Hayes et al., 2009), but selection of these sites then biases our perspective of how bats use the landscape.

Mobile acoustic methods, in which a detector is continuously moving along a predetermined route, have been proposed as a basis for a North American bat monitoring program (Loeb et al., 2015). They have been used effectively to survey bat distributions and monitor population changes in Europe and the eastern United States (Britzke et al., 2011; Roche et al., 2011; Jones et al., 2013) while also increasing the scale of surveys and monitoring without dramatically increasing cost or effort (Whitby et al., 2014), which has been useful for state, country, and regional level population size assessments. Whitby et al. (2014) found no difference in the number of species detected between stationary and mobile methods, but the study design did not allow for direct comparison of bat activity between methods as stationary data was converted to presence/absence. Before mobile acoustic methods are used for large-scale monitoring it is important to compare method efficiency in detecting overall activity as well as richness. In areas with high spatio-temporal variability in resources, such as Lubbock County, TX, we hypothesized that mobile methods would indeed detect more bat passes because maximizing geographic rather than temporal coverage at a single point would result in fewer sampling units with zero passes detected. Thus the objective of this study was to determine if mobile acoustic surveys detect more bat passes per unit of sampling time than do stationary acoustic point counts in Lubbock, Texas.

2. Methods

2.1. Study area

The study was conducted in Lubbock County, Texas, USA, which sits on the Llano Estacado, a semi-arid plateau dominated by irrigated agriculture (primarily cotton, corn, and wheat). The Llano Estacado is part of the High Plains which has an average annual rainfall from 380 to 560 mm but the region has had frequent droughts this century, the driest of which occurred October 2010 to June 2014, which was during the study period (National Weather Service, 2014; Texas Parks and Wildlife Department, 2016). The native ecosystem was short-grass prairie but less than 20% remains; today the region is mostly irrigated cropland and mesquite-juniper shrub (Samson et al., 2004; Texas Parks and Wildlife Department, 2016). Insect prey and water resources are variable in the Llano Estacado because the dominant water sources are small, ephemeral playa lakes and insect populations often track crop presence and maturation (McCracken et al., 2012; Collins et al., 2014). Acoustic surveys were conducted along a 24 km transect of public road that spans from the eastern edge of the city of Lubbock to Ransom Canyon, a small suburb surrounding a reservoir (Fig. 1). Roads are known to have a negative effect on bats through direct mortality and as a commuting barrier, but in the present study, all roads were rural two-lane roads with very little traffic that do not have as great a negative effect on bats as larger, busy roads (Medinas et al., 2013). The two crops growing along the transect road were cotton and sorghum, though ground cover was not always present. The larger lakes near Lubbock, Buffalo Springs, and Ransom Canyon always contained water, but the smaller playas scattered through the croplands were ephemeral through the study period. Lubbock County has low bat richness with only eight species and low evenness, with *T. brasiliensis* being the dominant species. We conducted acoustic surveys of bats from August to October 2012 and May to July 2013. Surveys were not conducted from November 2012 to March 2013 due to the lack of bat activity in the area.

2.2. Acoustic transects

Three acoustic survey methods were employed to assess activity along the transect: driven transects, permanent point counts, and

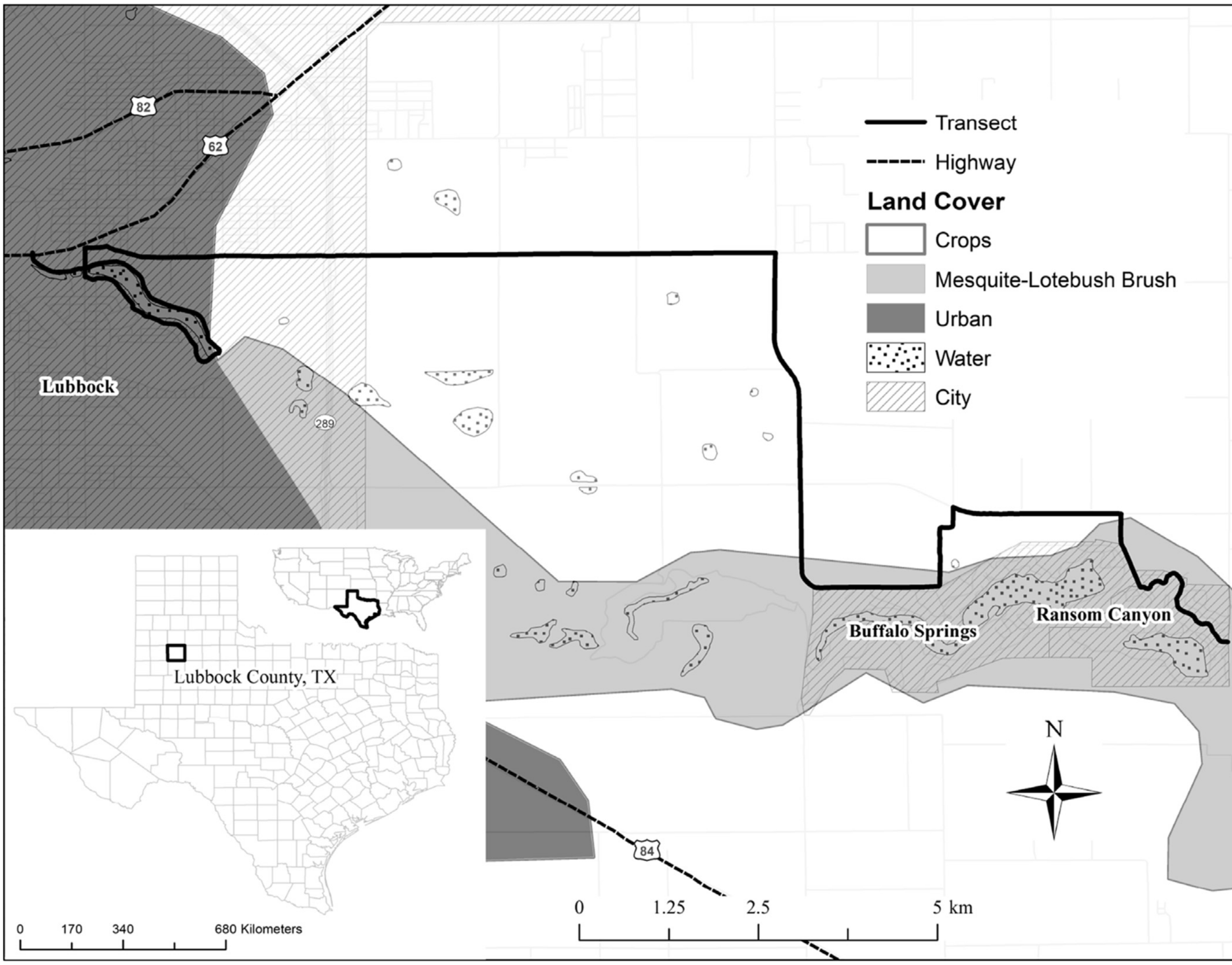

Fig. 1. Map of transect area in Lubbock County, Texas, USA. The 24 km transect is the bold line. Landcover GIS data from Texas Parks and Wildlife (http://www.tpwd.state.tx.us/landwater/land/maps/gis/data_downloads/).

nightly randomized point counts. Methods were tested in sets of three nights, with only one method per night so that each method was tested at the same time each night. Nights in a set were surveyed across sequential nights except when prohibited by rain and winds in excess of 40 km per hour, which is the wind speed at which bat activity almost ceases (Horn et al., 2008). The maximum inter-night gap in a set was two nights and ten survey sets were conducted and were separated by at least five days to ensure independence among the sets. Method order during a single set was haphazard; it was assumed that bat activity was relatively stable over the short duration of the set because it would be tied to water and food resources which vary monthly and seasonally but not weekly.

For driven transects, the transect route was driven at 24 km per hour with the bat detector recording continuously, resulting in around 70 min of survey each night. The chosen speed matches that used by monitoring schemes in Europe (e.g. Roche et al., 2011, others include iBats, French and Dutch bat monitoring schemes), though it is lower than the 32 km per hour traditionally used in the United States (Whitby et al., 2014). A lower speed was chosen to lessen the effect of wind noise on detections because the study area is frequently windy. For each point count method, five points along the transect were sampled for ten minutes each per night resulting in 50 min of survey recordings for each point method per set. All point locations were randomly generated along the transect using the random point generator in ArcGIS 10.1. Five points were randomly chosen to serve as permanent points and were surveyed in each set of method surveys. Another five points were randomly selected before each survey set to serve as the nightly randomized point counts.

For all survey methods, the same Pettersson D1000x time-expansion bat detector with sampling frequency set to 300 kHz, time expansion factor set to ten, and a constant medium-level gain (Pettersson Elektronik AB, Uppsala, Sweden) was attached to the car roof using a suction cup with a diameter of 15 cm. The detector was 1.8 m above the ground and placed at a fixed angle perpendicular to the ground. No trigger was used because in preliminary trials we found that the continuous sampling method recorded more absolute numbers of passes, which is similar to findings of Matos et al. (2013). Recordings could be continuously collected for 30 min using 32 GB compact flash memory cards (longer recordings were not viewable in BatSound Pro software). Thus every 30 min mobile transects were paused to allow the detector to save file and start a new recording file. The saving period took approximately two minutes because the car was stopped to safely access the detector and avoid failing to survey any part of the transect.

Sampling for any of the three methods began at sunset with alternation of the start point at either end of the transect between survey sets to account for an interaction of spatial and temporal variation within a night. For stationary methods, points were surveyed sequentially and occurred during the same time of night as the driven transects (finishing approximately 70 min after sunset). Transects began around sunset because preliminary work found that most detections occurred around and following sunset (MFP unpublished data), which also matches the emergence time for the most common species *T. brasiliensis* (Lee and McCracken, 2001). Headlights were turned on during driven transects for safety but were turned off during the stationary counts. We assumed headlights had no effect on level of bat activity because we never observed bats feeding in or around headlights during pre-study observations. In fact, bats were never seen during the study, which may be because bats that forage in open-areas, such as our study site, often do so at altitudes up to 900 m AGL (McCracken et al., 2008).

2.3. Bat pass analysis

We used BatSound Pro 4.01 (Pettersson Elektronik AB, Uppsala, Sweden) to analyze bat passes. A bat pass was defined as two or more pulses on the spectrogram, at least one of which was visible on the default oscillogram amplitude scale. The default amplitude scale has a minimum and maximum of ±100%, which can be decreased if desired in BatSound. If the interval between pulses was twice the length of the interval between previous pulses the second pulse was counted as part of a new bat pass. We chose this relaxed, 2-pulse, definition of a pass because the bats were at low density and few passes were recorded. Bats were not identified to species level because the objective of the study was to examine total bat activity for the landscape, which is applicable to the first step in developing a bat monitoring plan and comparable to metrics used in other mobile acoustic studies (Roche et al., 2011; Whitby et al., 2014). We assumed all bats belonged to the open-air foraging functional group as Lubbock County has little to no vertical vegetation structure and low species richness.

2.4. Statistical analysis

To compare mobile to stationary methods, we used ten minute segments as our sample unit. We split each mobile set into seven continuous ten-minute segments. For those few transects which were a few minutes longer than 70 min due to traffic conditions, we selected the middle 70 min for the seven samples.

Differences in bat activity between mobile and stationary methods were tested by comparing number of passes per ten-minute segment using generalized linear mixed effect models (GLMM) with Poisson distribution and log-link functions. The Poisson distribution is most appropriate for these data because they are count data (Bolker et al., 2009). We first tested for a difference between the two stationary point methods, and finding none, pooled the stationary methods so that all subsequent analyses treated sampling method as a two-level factor (mobile or stationary). We fit a Poisson GLMM to the count data treating number of passes per ten-minute segment as the dependent variable (nested within transect), sampling method (driving vs stationary) as a fixed effect and set identity as a random effect. We fit models using the lmer function in the lme4 package for R (Bates et al., 2013). Coefficients were estimated with restricted maximum likelihood estimation. To calculate confidence intervals for the Poisson parameter estimated by GLM (λ, log of mean number of bat passes per ten minutes), we created a multi-level bootstrap routine which selected, with replacement, ten-minute segments from both driving and stationary transects while maintaining transect and set identity. We then fit the GLM to each bootstrap replicate and recorded the coefficient estimates. Using the results from 10,000 bootstrapped replicates, we calculated the 95% confidence intervals for the coefficient estimates which represent the overall mean number of passes per ten-minute segment (λ) and the effect of sampling method on this mean. All statistical analysis was completed in the R Statistical Environment (R Core Team).

3. Results

The total number of passes recorded on driven transect nights, permanent point nights, and random point nights were 206, 70, and 56 respectively. On four nights, at least one of the stationary methods detected no bat passes, which never occurred with the driven transects. There was a significant effect of sampling method on passes per ten-minute segment GLMM (fixed effect $P < 0.001$, Table 1). Furthermore, the bootstrapped means and 95% confidence intervals (CI) for the fixed effect coefficients show that the mobile method detected significantly more passes per ten-minute segment than did the stationary methods (Table 1) because the CI's do not overlap (Gardner and Altman, 1986). After transforming the effect coefficients into counts, the mean number of passes per ten minutes for the mobile method detected was 2.14 (CI: 1.45–2.99) and 0.98 (CI: 0.77–1.21) for the stationary methods (Fig. 2). Thus, the estimated number of passes per ten minutes for the mobile method was double that of the pooled stationary methods. Although the objective of the study did not involve species level identification, it is likely that *T. brasiliensis* was the dominant species in the recordings based on observations of the recordings during analysis.

4. Discussion

Well-designed surveys and monitoring projects are a balance between spatial and temporal coverage; the importance of maximizing either depends on the purpose of the research, available resources, habitat type, and characteristics of the focal/dominant species. When resource variability is high, encounter rates of highly mobile species can be low if geographic coverage is not maximized. For our semi-arid and patchy transect, maximizing geographic coverage using mobile transects resulted in higher encounter rates. Mobile acoustic transects detected significantly more bat passes per 10 min than stationary methods and resulted in fewer sampling units with no bat passes recorded.

Mobile methods maximize spatial coverage, which may be effective when sampling in habitats that have high spatio-temporal variability in resources. The habitat of the Llano Estacado represents a semi-arid landscape with a complex matrix of crops, grasslands, and urban centers (Samson et al., 2004). Similar to Geluso and Geluso (2012), the distribution of bats over the Llano Estacado is expected to track changes in spatio-temporal patchy resource distribution, specifically drinking water and insect prey. Although we cannot comment on yearly changes in bat abundance and distribution, bat activity levels were not consistent from set to set (Fig. 2). Furthermore, locations of high bat activity along the transect were not consistent from set to set (MFP unpublished data). For example, during one set many bat passes were detected over a sorghum field but during subsequent sets bats were never detected over that field. This high seasonal variation in bat activity made mobile methods the ideal method for surveying and monitoring bats over the Llano Estacado landscape because ephemeral

Table 1
Summary of GLMM statistics for effect of method on number of bat passes per ten minutes. Note that because GLMM errors are not normally distributed (Bolker et al., 2009), we do not rely on the GLM standard errors for confidence intervals but instead bootstrapped the GLM for 10,000 replicates and calculated the 95% confidence interval for the coefficient estimates.

Parameter	Estimate	SE	Z-value	P-value	Bootstrapped estimate mean	Bootstrapped estimate 95% CI
Mobile	0.887	0.1913	4.636	<0.001	0.762	0.369–1.094
Stationary	0.083	0.1134	−7.087	<0.001	−0.024	−0.267–0.192

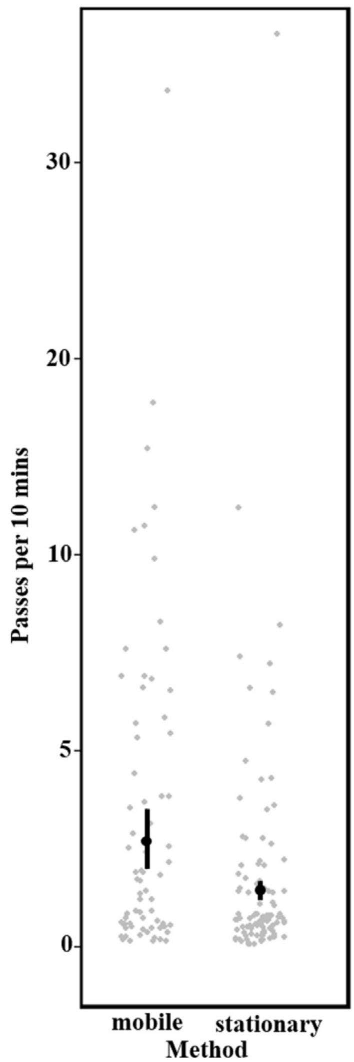

Fig. 2. Difference in the number of passes between mobile and stationary methods. Points represent the number of passes in each 10-min segment for each set. Overlaying the points are the exponentially transformed bootstrapped GLMM fixed effect coefficient means and 95% CI's.

patches of bat activity have a greater probability of being detected.

Low species evenness may be a limitation for this study, however the dominant species *T. brasiliensis* is an open-space specialist representative of species found in arid, high intensity agricultural, and/or open habitats across the globe (Lumsden and Bennet, 1995). *T. brasiliensis* is a small to medium sized (forearm <45 mm) free-tailed bat (Family Molossidae) that feeds on insects and can forage at high altitudes and over long distances (up to 100 km) in a single night (Lumsden and Bennet, 1995; McCracken et al., 2008). High and fast fliers that forage over open landscapes, like the molossids, typically possess wing morphology with high aspect ratio and wing loading (long, narrow wings) (Norberg and Rayner, 1987). Bats with this wing morphology (e.g. Families Molossidae and Rhinopomatidae) are globally distributed in arid and semi-arid regions, and found on every continent except Antarctica. Ecological characteristics of *T. brasiliensis* and the Llano Estacado probably contributed to the success of the mobile methods over the stationary methods in this study.

The foraging characteristics of the bats in this study make it an ideal research model for resource pulse research in arid systems. Insectivorous bats are tracking changes in insect distributions (McCracken et al., 2012) and water availability (Geluso and Geluso, 2012). Moreover, the underlying insect population is tracking the availability of their own food and water across time and space (Kwok et al., 2016). Resource pulses, in water particularly, drive landscape spatio-temporal clustering in most arid taxa (e.g. birds, insects, terrestrial mammals) (Whitford, 2002; Letnic and Dickman, 2010). Research and improvements in mobile methods may allow scientists to more effectively track population and distributional changes in a variety arid species that respond to resource pulses.

Even in situations where stationary methods may be more effective, such as at sites where spatio-temporal variation in activity is low and species can be reliably associated with landscape features, such high activity sites can only be leveraged if identified prior to the establishment of a survey or monitoring plan. Despite the high variability in bat activity during our study, we did identify a single geographic feature, a man-made lake at the western-end of the transect (Fig. 1), that consistently had bat activity throughout the study and would be suitable for long-term monitoring. The mobile method allowed us to identify trends in the spatio-temporal patchiness of bat activity along the transect with a single bat detector without incurring the high equipment or labor costs associated with deploying several stationary points along the transect (Coleman et al., 2014). The lower equipment and labor costs of mobile acoustic methods make them ideal for incorporation into national monitoring plans and citizen-science initiatives.

As this is the first study to directly compare differences in bat activity recorded by mobile and stationary acoustic methods, there are many future directions for assessing the effectiveness of mobile methods. We found that mobile methods detect more bat passes in an arid and anthropogenic landscape but this result should be compared to studies carried out in different habitats. Habitats that have less spatio-temporal patchiness or higher densities of bats may benefit from greater temporal coverage achieved with stationary methods. Call quality differences between mobile and stationary acoustic methods should be empirically assessed given that successful species-specific monitoring depends on reliable species identification. The proportion of low quality calls (few pulses and low intensity) in this study was high, which contrasts with previous studies (Roche et al., 2011; Whitby et al., 2014), which may have been caused by the continuous recording methodology. Trigger settings may filter out low quality passes due to their short duration and low intensity, which would improve the overall quality of passes detected but does result in fewer passes being recorded (Matos et al., 2013; personal observations). Finally, future studies could employ occupancy modeling to directly incorporate detection probability measures in to assessments of changes in perceived occupancy between methods (MacKenzie et al., 2006). Occupancy modeling would require at least two replicates of each method within a "season", which is a time period where detection probabilities are assumed to stay the same. The high spatio-temporal variability present in arid systems may cause short-term or non-intuitive changes in detection probabilities thus seasons would need to be rigorously defined before research is conducted. Effective use of finite resources requires knowledge of which method performs best per unit of effort. This study highlights the importance of comparing acoustic methodologies in order to maximize encounter rates.

Mobile acoustic methods may be particularly effective as we move into a future where arid, open-space, and patchy landscapes are increasing in frequency and extent. Agricultural fields, grasslands, and deserts are already some of the most common habitats in the United States (Fry et al., 2011). Forty percent of the terrestrial environment is agricultural and urban landscapes and natural areas are most frequently embedded within converted patches, which increases the spatial variability of the landscape (Ellis et al., 2010). Globally, arid regions have been increasing since 1950 and are predicted to increase over the next century due to climate change (Dai, 2011). Climate change will not only increase global average temperature but is also projected to increase the temporal variability in climatic events (IPCC, 2013) and thereby the spatio-temporal variability of resources across landscapes. Cost-effective and improved methods able to characterize the activity, abundance, and distribution of arid species across such dynamic landscapes are needed. Mobile acoustic transects offer an effective way to increase the geographic scope of surveys and monitoring efforts under increasingly variable landscape conditions.

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References

Abrams, P.A., Ginzburg, L.R., 2000. The nature of predation: prey dependent, ratio dependent or neither? Trends in Ecology & Evol. 15 (8), 337–341.
Bates, D., Maechler, M., Bolker, B., Walker, S., 2013. lme4: Linear Mixed-effects Models Using Eigen and S4. R package version, 1.
Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H., White, J.S.S., 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology & Evol. 24 (3), 127–135.
Britzke, E.R., Herzog, C., Ewing, B., 2011. Observations and initial results from three years of sampling bats along acoustic transects. Bat Res. News 52, 62.
Caro, T., 2011. On the merits and feasibility of wildlife monitoring for conservation: a case study from Katavi National Park, Tanzania. Afr. J. Ecology 49 (3), 320–331.
Comazzi, C., Mattiello, S., Friard, O., Filacorda, S., Gamba, M., 2016. Acoustic monitoring of golden jackals in Europe: setting the frame for future analyses. Bioacoustics 25, 1–12.
Coleman, L.S., Ford, W.M., Dobony, C.A., Britzke, E.R., 2014. Effect of passive acoustic sampling methodology on detecting bats after declines from white nose syndrome. J. Ecology Nat. Environ. 6 (2), 56–64.
Collins, S.D., Heintzman, L.J., Starr, S.M., Wright, C.K., Henebry, G.M., McIntyre, N.E., 2014. Hydrological dynamics of temporary wetlands in the southern Great Plains as a function of surrounding land use. J. Arid Environ. 109, 6–14.
Conway, C.J., Simon, J.C., 2003. Comparison of detection probability associated with burrowing owl survey methods. J. Wildl. Manag. 67, 501–511.
Dai, A., 2011. Drought under global warming: a review. Wiley Interdiscip. Rev. Clim. Change 2 (1), 45–65.
Dawson, D.K., Efford, M.G., 2009. Bird population density estimated from acoustic signals. J. Appl. Ecology 46 (6), 1201–1209.
Ellis, E.C., Klein Goldewijk, K., Siebert, S., Lightman, D., Ramankutty, N., 2010. Anthropogenic transformation of the biomes, 1700 to 2000. Glob. Ecol. Biogeogr. 19 (5), 589–606.
Fry, J.A., Xian, G., Jin, S., Dewitz, J.A., Homer, C.G., Limin, Y., Barnes, C.A., Herold, N.D., Wickham, J.D., 2011. Completion of the 2006 national land cover database for the conterminous United States. Photogrammetric Eng. Remote Sens. 77 (9), 858–864.
Gardner, M.J., Altman, D.G., 1986. Confidence intervals rather than P values: estimation rather than hypothesis testing. Br. Med. J. 292, 746–750.
Geluso, K.N., Geluso, K., 2012. Effects of environmental factors on capture rates of insectivorous bats, 1971–2005. J. Mammalogy 93 (1), 161–169.
Hayes, J.P., Ober, H.K., Sherwin, R.E., 2009. Survey and monitoring of bats. In: Kunz, T.H., Parsons, S. (Eds.), Ecological and Behavioral Methods for the Study of Bats. John Hopkins University Press, Baltimore, pp. 112–129.
Horn, J.W., Arnett, E.B., Kunz, T.H., 2008. Behavioral responses of bats to operating wind turbines. J. Wildl. Manag. 72 (1), 123–132.
IPCC, 2013. Climate change 2013: the physical science basis. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 1535 pp.
Jeliazkov, A., Bas, Y., Kerbiriou, C., Julien, J.F., Penone, C., Le Viol, I., 2016. Large-scale semi-automated acoustic monitoring allows to detect temporal decline of bush-crickets. Glob. Ecology Conservation 6, 208–218.
Jones, G., Jacobs, D.S., Kunz, T.H., Willig, M.R., Racey, P.A., 2009. Carpe noctem: the importance of bats as bioindicators. Endanger. Species Res. 8 (1–2), 93–115.
Jones, K.E., Russ, J.a., Bashta, A.T., Bilhari, Z., Catto, C., Csősz, I., Gorbachev, A., Győrfi, P., Hughes, A., Ivashkiv, I., Koryagina, N., Kurali, A., Langton, S., Collen, A., Margiean, G., Pandourski, I., Parsons, S., Prokofev, I.,A., Szodoray-Paradi, A., Szodoray-Paradi, F., Tilova, E., Walters, C.L., Weatherill, A., Zavarzin, O., 2013. Indicator bats program: a system for the global acoustic monitoring of bats. In: Collen, B., Pettorelli, N., Baillie, J.E.M., Durant, S.M. (Eds.), Biodiversity Monitoring and Conservation: Bridging the Gap between Global Commitment and Local Action. Wiley-Blackwell, Oxford, UK. http://dx.doi.org/10.1002/9781118490747.ch10.
Korine, C., Pinshow, B., 2004. Guild structure, foraging space use, and distribution in a community of insectivorous bats in the Negev Desert. J. Zoology 262 (2), 187–196.
Korine, C., Adams, R., Russo, D., Fisher-Phelps, M., Jacobs, D., 2016. Bats and water: anthropogenic alterations threaten global bat populations. In: Voigt, C.C., Kingston, T. (Eds.), Bats in the Anthropocene: Conservation of Bats in a Changing World. Springer, Switzerland. http://dx.doi.org/10.1007/978-3-319-25220-9_8.
Kwok, A.B., Wardle, G.M., Greenville, A.C., Dickman, C.R., 2016. Long-term patterns of invertebrate abundance and relationships to environmental factors in arid Australia. Austral Ecology 41, 480–491.
Lee, Y.-F., McCracken, G.F., 2001. Timing and variation in the emergence and return of Mexican free-tailed bats, *Tadarida brasiliensis mexicana*. Zool. Stud. 40, 309–316.
Letnic, M., Dickman, C.R., 2010. Resource pulses and mammalian dynamics: conceptual models for hummock grasslands and other Australian desert habitats. Biol. Rev. 85 (3), 501–521.
Loeb, S.C., Rodhouse, T.J., Ellison, L.E., Lausen, C.L., Reichard, J.D., Irvine, K.M., Ingersoll, T.E., Coleman, J.T., Thogmartin, W.E., Sauer, J.R., Francis, C.M., 2015. A Plan for the North American Bat Monitoring Program (NABat).
Lumsden, I.F., Bennet, A.F., 1995. Bats of a semi-arid environment in south-eastern Australia: biogeography, ecology and conservation. Wildl. Res. 22, 217–239.
MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L.L., Hines, J.E., 2006. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Academic Press.
Matos, M., Pinto, N.L., Pereira, M.J.R., Fonseca, C., 2013. Triggering bat detectors: automatic vs. manual mode. Mammalia 77 (4), 461–466.
McCracken, G.F., Gillam, E.H., Westbrook, J.K., Lee, Y.F., Jensen, M.L., Balsley, B.B., 2008. Brazilian free-tailed bats (Tadarida brasiliensis: Molossidae, Chiroptera) at high altitude: links to migratory insect populations. Integr. Comp. Biology 48 (1), 107–118.
McCracken, G.F., Westbrook, J.K., Brown, V.A., Eldridge, M., Federico, P., Kunz, T.H., 2012. Bats track and exploit changes in insect pest populations. PLoS ONE 7, e43839. http://dx.doi.org/10.1371/journal.pone.0043839.
Medinas, D., Marques, J.T., Mira, A., 2013. Assessing road effects on bats: the role of landscape, road features, and bat activity on road-kills. Ecol. Res. 28, 227–237.
Morton, S.R., Smith, D.S., Dickman, C.R., Dunkerley, D.L., Friedel, M.H., McAllister, R.R.J., Reid, J.R.W., Roshier, D.A., Smith, M.A., Walsh, F.J., Wardle, G.M., 2011. A fresh framework for the ecology of arid Australia. J. Arid Environ. 75, 313–329. http://dx.doi.org/10.1016/j.jaridenv.2010.11.001.
Müller, J., Mehr, M., Bässler, C., Fenton, M.B., Hothorn, T., Pretzsch, H., Klemmt, H.J., Brandl, R., 2012. Aggregative response in bats: prey abundance versus habitat. Oecologia 169, 673–684.
National Weather Service, 2014. October 2010-Present Drought. Retrieved February, 12, 2016 from. http://www.srh.weather.gov/lub/?n=events-2010-2014-drought.
Norberg, U.M., Rayner, J.M., 1987. Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. Philosophical Trans. R. Soc. Lond. B Biol. Sci. 316, 335–427.
Parsons, S., Szewczak, J.M., 2009. Detecting, recording, and analyzing the vocalizations of bats. In: Kunz, T.H., Parsons, S. (Eds.), Ecological and Behavioral Methods for the Study of Bats. John Hopkins University Press, Baltimore,

pp. 91–111, 920 pp.
Razgour, O., Korine, C., Saltz, D., 2011. Does interspecific competition drive patterns of habitat use in desert bat communities? Oecologia 167, 493–502.
Roche, N., Langton, S., Aughney, T., Russ, J.M., Marnell, F., Lynn, D., Catto, C., 2011. A car-based monitoring method reveals new information on bat populations and distributions in Ireland. Anim. Conserv. 14, 642–651.
Samson, F.B., Knopf, F.L., Ostlie, W.R., 2004. Great Plains ecosystems: past, present, and future. Wildl. Soc. Bull. 32, 615.
Sandoval, M.L., Barquez, R.M., 2013. The Chacoan bat fauna identity: patterns of distributional congruence and conservation implications. Rev. Chil. Hist. Nat. 86, 75–94.
Sauer, J.R., Link, W.A., Fallon, J.E., Pardieck, K.L., Ziolkowski Jr., D.J., 2013. The North American breeding bird survey 1966-2011: summary analysis and species accounts. North Am. Fauna 79 (79), 1–32.
Schnitzler, H.U., Kalko, E.K., 2001. Echolocation by insect-eating bats. Bioscience 51, 557–569.
Sueur, J., Pavoine, S., Hamerlynck, O., Duvail, S., 2008. Rapid acoustic survey for biodiversity appraisal. PloS one 3 (12), e4065.
Texas Parks and Wildlife Department, 2016. Texas Ecoregions. Retrieved February, 12, 2016 from. https://tpwd.texas.gov/education/hunter-education/online-course/wildlife-conservation/texas-ecoregions.
Tucker, D., Gage, S.H., Williamson, I., Fuller, S., 2014. Linking ecological condition and the soundscape in fragmented Australian forests. Landsc. Ecol. 29 (4), 745–758.
Whitby, M.D., Carter, T.C., Britzke, E.R., Bergeson, S.M., 2014. Evaluation of mobile acoustic techniques for bat population monitoring. Acta Chiropterologica 16, 223–230.
Whitford, W.G., 2002. Ecology of Desert Systems. Academic Press.
Zach, R., Falls, J.B., 1979. Foraging and territoriality of male ovenbirds (Aves: Parulidae) in a heterogeneous habitat. J. Animal Ecology 48, 33–52.