FINAL REPORT

Tests of Efficient Methods for Assessing Mountain Quail Abundance

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The stated objectives of this project were to: 1) quantify the temporal patterns of Mountain Quail (MOQU, *Oreortyx pictus*) vocalizations by auditory sampling, 2) model the influence of environmental conditions on the audibility of mountain quail vocalizations, and 3) develop an auditory distance decay function for use in mountain quail density estimation.

As this project was nearing implementation, CDFW provided 13 automated recording units (ARUs), making it possible to collect more and better vocalization data than possible with the field methods originally proposed. Use of these recorders, however, necessitated that the broad-scale field surveys originally proposed (50 listening stations $\geq$1.5 km apart) be traded-off for setting up and maintaining three fixed-location ARU arrays and their requisite weather stations. Consequently, occupancy estimation and determining an effective population-level survey area were eliminated as study objectives because they would have required repeated sampling at multiple sites. Furthermore, location analysis with audio data proved to be quite error-prone, requiring much more time to process and error-check data than anticipated. Much of the time and effort originally allocated to advanced analysis and modeling was therefore consumed by data processing. This study resulted in new knowledge regarding the vocalization behavior of MOQU and new guidelines for the timing and effective survey area of future MOQU auditory surveys.

STUDY AREAS

Audio recordings were made within an approximately 170 km^2 area within the 2013 Rim Fire burn area, Stanislaus National Forest, Tuolumne County (Fig. 1). Three sites were chosen for 4-ARU microphone arrays (Blumstein et. al 2011), one each in three general habitats types: closed-canopy forest, open woodland, and chaparral. The effects of environmental influences on audibility of recorded MOQU calls were tested near Holt, CA (level barren ground) Van Nuys, CA (barren knoll), and Malibu, CA (chaparral and woodland vegetation).

METHODS

Timing

Single ARUs were deployed March 14th - April 14th, 2016, at prospective study sites for 7-10-day periods to assess local MOQU abundance - as well as gather data on the frequency of singing during the onset of breeding season. Three sites were eventually located where singing MOQU were abundant enough to study breeding density. MOQU vocalizations were systematically sampled with ARU arrays at these sites from April 16th until the first MOQU brood was observed in the study area on June 22nd (69 days). Males cease crowing, or “queerk” calling after broods appear (Gutiérrez and Delehanty 1999), because the general function of this call is sexual advertisement (Johnsgard 1973). Data processing consumed the 6-month period from July-December, 2016. Controlled experiments on distance decay of recorded MOQU "queerk" calls were conducted on December 6th, 2016, near Holt, CA, January 15th, 2017, near Van Nuys and Malibu, CA.

Data collection

Geographic locations of the ARU arrays are given in Table 1. All arrays were positioned within the upper reaches of small valleys, where the propagation of quail calls would be minimally interrupted by intervening terrain. The four ARUs comprising each array were laid out as a square, with sides measuring approximately 183 m (125-213 m) at the chaparral site, 285 m (177-412 m) at the forest site, and 450 m (390-519 m) at the woodland site. Precise locations of ARUs were estimated from the coordinate location data each unit recorded on a minute-by-minute basis (~718/day). For each day from May 1 to May 15, the data were averaged, and the 10% that varied most from the average were discarded. Final location estimates were arrived at by averaging the remaining 90% over 15 days.

Field recordings of MOQU vocalizations were made with Wildlife Acoustics SM3 GPS-synchronized automated digital recorders (Wildlife Acoustics Inc., Maynard, MA). The units were programmed to record continuously (successive 1-hour files), every day from one hour before sunrise until 5 hours after sunrise, and again from 5 hours before sunset until one hour after sunset (gain, 10 dB; sampling rate, 24 kHz). Altogether, 12 deployed ARUs recorded 9,936 hours of systematically-sampled audio data, which occupy 2.2 TB of computer memory. Individual sound files are too large (and uninformative) to submit with this report.

Weather data were recorded at each ARU array with an Onset weather data logger (Model H21-002 Hobo micro-station, Onset Co., Bourne, MA). Temperature, wind speed and direction, and barometric pressure, were sampled every five minutes, 24 hours/day, and were chronologically synchronized with audio recordings.

To test distance decay of queerk calls under controlled environmental settings, recorded calls were broadcast using an MP3 player (Model SA4111, Philips Electronics, Andover, MA) with a 15-watt amplifying speaker (Model TX15, Loud Technologies Inc., Woodinville, WA). The digital queerk recording was downloaded from www.xeno-canto.org. Broadcast amplitude was set a 90 dB, measured at 1-m distance with a sound level meter (Model 824, Larson Davis Inc., Provo, UT). 90 dB was presumed to be the natural amplitude of MOQU queerk calls, based on published amplitudes of other bird species' songs (Brackenbury 1979) and personal judgment acquired through frequent field observation. A single ARU was used for all experiments in order to ensure consistent microphone sensitivity under all conditions. In some cases the recorded queerk call was paired with a 90 dB, 1477 Hz, "test tone" download from www.thisisarecording.com. The tone is near the center of the frequency range of the queerk call, and is reminiscent of the back-up alarm of a commercial vehicle. Because the tone is acoustically simple, it is presumably easier to quantify and replicate than the more complex and varied queerk call. For each trial, the ARU was used to record the broadcasted queerk call and test tone at distances of 50, 100, 150, 200, 250, and 300 m. Broadcasted sounds were loop recordings of a single recorded sound repeated approximately every 2.5 sec. Wind speed was $\leq$0.5 m/s during each test. Call propagation over level, barren, ground - optimal conditions for uninterrupted sound propagation - was conducted over a dirt road in a fallow agricultural field near Holt, CA. Attenuation by terrain was tested by measuring call amplitude with increasing interference levels (height of interfering terrain). A flood retention dam near Van Nuys, CA, served as the interfering terrain (Fig. 2). Attenuation by chaparral vegetation was tested on a level flood plain vegetated with a dense growth of coyote bush (*Baccharis pilularis*) averaging ~1.25 m height (Fig. 3). Attenuation by woodland vegetation was tested on slightly sloping ground with a coast live oak (*Quercus agrifolia*) tree canopy averaging ~4.5 m in height and an open understory (Fig. 4).

<u>Analysis</u>

The frequency of occurrence of queerk calls was analyzed with respect to date (March - June) and time of day (40 min before sunrise - 3 hrs after sunrise). Recordings from a single ARU were sampled at 8-day intervals. If there was rain or wind (>0.5 m/s) on one of these dates, the preceding calm day was sampled. On each sample date, the number of clearly discernible queerk call recordings (both audibly identifiable during playback and visibly identifiable from a sonogram) was counted over the following 10-minute periods: 40-30 mbs (minutes before sunrise), 30-20 mbs, 20-10 mbs, 10-00 mbs, 00-10 mas (minutes after sunrise), 10-20 mas, 20 mas, and the first 10 minutes 1, 2, and 3 has (hrs after sunrise). The automated detection tool of Raven Pro sound analysis software (Cornell Laboratory of Ornithology, Ithaca, NY) was used to identify potential MOQU queerk calls (specifically, the band limited energy detector algorithm). The detector that best discriminated MOQU queerk calls used the following criteria: minimum frequency, 1350 Hz; maximum frequency, 1800 Hz; minimum duration, 0.14 sec, maximum duration, 1.7 sec; minimum separation, 0.01 sec. Functionally, the detector delineated rectangles on sonograms that outlined sounds satisfying these criteria. Many sounds other than MOQU queerk calls also satisfy these criteria, however, including multifrequency sounds like flying insects, breaking branches, rain drops striking a microphone, certain calls of finches, jays, woodpeckers, California Quail (*Callipepla californica*), and other MOQU calls including the clucking-crow and crouch-whistle (Gutiérrez and Delehanty 1999). In order to parse valid MOQU queerk calls from other auto-detected sounds, it was necessary to visually inspect a sonogram of each auto-detected sound. If the sonogram of the sound did not visually conform with an unambiguous queerk call, it was also necessary to listen to the sound. With a sample of twenty 10-min audio samples (40 mbsr-3 hasr), the proportion of potential queerk calls auto-detected by a single ARU that resulted in confirmed queerk calls averaged 18.6 % (range, 0-100 %). Hereafter, such detections are referred to as confirmed detections. Each 10-min audio sample required 5-10 min processing time to parse. Given the unanticipated amount of processing time required, analysis of queerk call frequency was limited to the chaparral array, where MOQU densities appeared to be highest.

Coordinate locations of individual calling males were determined with Sound Finder software (Wilson et al. 2014, spreadsheet version). The purpose of location analysis was to determine space-use and densities of calling males. First, Raven Pro software was used to determine the start time of confirmed, auto-detected, queerk calls across all four ARUs of an array. As with call frequency analysis, it was necessary to confirm each auto-detected queerk call both visually and auditorially. Furthermore, because Raven-tabulated start times were inaccurate and inconsistent across ARUs, it was necessary to visually determine and key-in accurate start times for each call at each ARU. Sound Finder software was then used to calculate coordinate source locations for the calls (using the speed of sound, differences in detection times across ARUs, and triangulation algorithms). The failure rate of call “sets” entered into Sound Finder was high. Furthermore, among the call sets that successfully produced location coordinates, when the coordinates were plotted on a georeferenced aerial photograph using ArcGIS (Esri Corp., Redlands, CA), many were erroneously located well beyond the sensitivity range of the ARUs. Given these sources of processing error, the proportion of verified source locations generated from auto-detected sounds was small. For a sample of twenty 10-min audio samples from a single ARU (40 mbsr-3 hasr), only ~11.8 % (9.1-16.0 %) of auto-detected sounds resulted in verified source locations. The entire procedure, from initial auto-detection to verified source locations required, with practice, 3-4 hrs to analyze a single 10-min audio sample from a single array. Because these procedures were so time consuming, location analysis was limited to three 10-min sampling periods (20-10 mbs, 0-10 mas, 20-30 mas) on two calm mornings during peak singing season at the chaparral site (May 2nd and 9th, wind speed $\leq$0.5 m/s. Because wind speed was >0.5 m/s at 20-30 mas on May 5th, data for 20-30 mas on May 1st were substituted). There are several potential explanations for the high rates of processing failure. It is possible, for example, that the "call signature" of individual quail is not as unique as we surmised, and that additional quail with identical call signatures could have called within the array during the <1.0 sec required for calls to propagate across an array. In most cases, it was necessary to have signal amplitude >50 dB from all four ARUs to achieve successful location results. If the call was detected at only three ARUs, signal power usually needed to be even higher. We also found very high inconsistencies in calculated locations that occurred outside the area delineated by the four ARUs. Mennill et al. (2012) report that location accuracy drops off outside this zone, but we found location results outside this zone to be entirely unusable due to frequent and extreme variability.

Field trials were conducted to test the effects of key environmental factors on propagation and audibility of MOQU queerk calls at increasing distances. At each test distance, the average maximum amplitude of the first five unobscured test sounds was calculated, and then plotted against distance or obstruction, creating decay curves under various environmental conditions. Because ambient noise contributes to measurements of maximum amplitude, and because ambient noise varied between field trial sites, the results of most tests are reported as percent decline in amplitude rather than raw dB. Interference by terrain was measured as the area under the profile of a hill (Fig. 5). A 2-dimensional profile was preferable to a simple vertical extent (height) because the profile incorporated a measure of increasing distance with increasing interference (to increase interference, it was necessary to move further down the back side of the hill). Data were fitted to standard regression types (linear, natural log, polynomial, exponential), and the regression with the highest r^2 value is reported. All analyses were conducted with Statistica computer software (StatSoft Inc., Tulsa, OK).

RESULTS

Figure 6 illustrates the rise and decline of queerk call frequency over the MOQU crowing season, sampled on an 8-day schedule. On the first sample day, March 16th, only a few confirmed queerk calls (n = 27) were detected, between 20 mbs and 10 mas. Over the next three sample dates (March 24th-April 8th), total confirmed calls increased ~10-fold over March 16th. Over this period, queerk-calling also become increasing well-distributed across 10-min sampling periods (in Fig. 6, bars representing $\leq$2 detections are not apparent due to scale). On April 16th, the ARU used to sample call frequency was relocated to the chaparral study site, where there were significantly more quail, perhaps several-fold more; a necessary consequence of deploying all available ARUs to microphone arrays. Although total confirmed queerk calls increased dramatically immediately after the move, total daily confirmed calls remained relatively consistent (2075 ± 810/day) through June 9th (assuming spikes at 10-00 mbs on April 17th and 20-10 mbs on May 3rd were spurious results of limited sample size). Peak daily queerk-calling appears to have occurred between April 17th and May 3rd, although relocating the recorder on April 16th might have obscured an even earlier start date.

Between April 17th and June 2nd, confirmed queerk calls occurred during all 10-min sampling periods. Across those dates, the three sampling periods between 30 mbs and sunrise had the highest frequency of queerk calls, >25 % higher than sampling periods earlier or later in the morning (Fig. 7).

Frequency of queerk-calling appeared to be broadly affected by weather, insomuch as call frequency was positively correlated with barometric pressure (r = 0.2652, P = 0.0265, Fig. 8). Low barometric pressure is associated with deteriorating or stormy weather, whereas high barometric pressure is associated with clear or improving weather. Precipitation also appeared to have a strong dampening effect on queerk-calling. On the single sample morning when there was significant rain (April 9th), no queerk calls were detected whatsoever. Wind speed and temperature, across the relatively low range of values that occurred during sampling periods (0.0-2.01 m/s and 2.7-21.5 ^{o}C, respectively), did not measurably affect queerk call frequency (Figs. 9 and 10). Higher wind speeds presumably would reduce call frequency. On a typical day, the air remained calm until late morning, after call frequency had already declined for other reasons.

So far as we can determine, individual male MOQU have unique voices (Fig. 11). This was not known previously, but is also not unexpected. Individual voices can vary, but generally not so much as to sound exactly like other nearly males. Occasionally, a male's voice "cracks", sounding more like a croak than a crow-call (Fig. 11, examples 4 & 6). Individuality of queerk calls was essential information for conducting location analysis, which was highly error-prone. The primary check against spurious location results was to confirm whether newly generated locations fell near a cluster of recent, similar, calls.

Figure 12 illustrates verified queerk source locations at the chaparral study site. By identifying clusters of data points sharing the same call signature, a total of 5 males were determined to be present within the 166 m^2 polygon defined by the ARUs. This extrapolates to roughly 182 males/100 ha. One individual was detected within the polygon on just a single day. It was apparently either silent or located outside the polygon on the alternate day. One individual occupied sites <20 m apart (center-to-center) on alternate days, whereas four other individuals occupied areas 75-160 m apart on alternate days. Four individuals occupied a series of 2-3 activity areas located 30-140 m apart during 50 min of sampling (20 mbs–30 mas). Quail were observed making such flights across the array on several occasions.

During the peak season and time of day for queerk-calling, five minutes of audio from a single ARU were sufficient to detect all five confirmed calling males within the chaparral array (sampled May 5th, beginning at 20 mbs). Three individuals were detected during the first minute, whereas the fourth and fifth were detected during the fourth minute. One of the individuals was detected on just a single occasion, 12 sec into the 4th min, so a 5-min sampling period is perhaps a minimum.

On level ground, with no air movement or vegetation, the amplitude of recorded queerk calls (broadcasted at 90 dB) declined with distance to approximately the level of ambient noise at 300 m (Fig. 13). Decay approximated the curve: dB = 143.608-18.29*log(distance). Percent decline in call amplitude with distance approximated the linear regression: Y = 79.31-0.09*(distance) (Fig. 14). Decay of the 1477 Hz test tone was statistically no different than that of the recorded call. In the same experimental setting, an experienced listener was able to distinguish recorded calls from background noise to >500 m, but the precise source location could not be ascertained. In chaparral vegetation, call amplitude declined following the curve: Y = 140.11-14.03*log(distance) (Fig. 15). In woodland vegetation, the decline was slightly steeper, approximating the curve: Y = 163.60-18.233*log(distance) (Fig. 16). Ambient noise was higher at the chaparral and woodland field trial sites than at the fallow field site, so broadcasted calls became indistinguishable at shorter distances, both on ARU recordings (Figs. 14-16) and to the human ear. The investigator was unable to distinguish recorded calls from background noise beyond 200 m at the chaparral field trial site or beyond 250 m at the forest field trial site. Attenuation of broadcasted calls by obstructing terrain followed the regression Y = 95.175-6.6874*log(distance) (Fig. 17).

CONCLUSIONS

Analysis of audio data for location analysis proved to be quite error-prone, requiring much more time to process and error-check data than anticipated. Specifically, every recorded vocalization had to be manually checked for individual identification (visual inspection of a sonogram) and also checked for location accuracy (visual confirmation of plotted locations with GIS software). Much of the time and effort originally allocated to advanced analysis and modeling was therefore consumed by data processing. The low acceptability of audio data for location analysis, and consequent effort required to parse usable data for that purpose, limited the amount of processed data available for analysis. Our findings should therefore be considered tentative until additional audio data can be processed and incorporated.

The study produced novel discoveries on the vocalization behavior of MOUQ, including evidence that individual male MOQU have acoustically unique queerk calls. Fundamental questions regarding the sociobiology of the MOQU queerk call must still be resolved before the call can be used reliably to estimate abundance. Johnsgard (1973) indicates queerk calls are not territorial proclamations by breeding males, but rather sexual announcements by *unmated* males. Gutiérrez and Delehanty (1999) report the call is also used by mated males to reinforce pair bonds, and that the frequency of use by unmated versus mated males is unknown. In order to use queerk calls to estimate populations, relative frequency of use by unmated versus mated males must be determined. This will likely require intensive observation of marked, wild, MOQU.

The use of microphone arrays to study space use by MOQU appears to be limited to singing individuals within a ≲5 ha polygon bounded by microphones. Given the high rate of erroneous location results we experienced, other methods such as satellite telemetry might be a better choice, although future software developments could reduce spurious location results. In our experience, it is nearly impossible for a human observer to accurately map locations of multiple singing MOQU from auditory cues alone. The duration between queerk calls makes it difficult to pinpoint and distinguish between multiple source locations. It might be possible with a lot of experience, but variability between observers would likely be high. Location analysis with microphone arrays should overcome this difficulty.

Our findings have important implications for future auditory surveys with regard to timing and effective survey area. In the central Sierra Nevada Mountains, auditory surveys should be conducted between April 17th and May 3rd, between 30 mbs and sunrise, in order to maximize MOQU detections. Poor or declining weather (barometric pressure) will depress queerk-calling, whereas normal daily fluctuations in wind speed and temperature will not. Additional field study is needed to determine how peak queerk-calling season varies between years and across regions. Under ideal environmental circumstances, MOQU queerk calls are reliably detectable by Wildlife Acoustics SM3 automated recorders to 300 m (with gain at 10 dB and sampling rate at 24 kHz), and by humans to >500 m. The effective survey area for SM3 ARUs under ideal environmental circumstances is therefore ~28.3 ha. Under these circumstances, queerk call detection declines ~4.5 %/50 m. Where terrain rises above a straight line from a calling quail to the ARU, call amplitude declines an additional ~1-5 %/m^2 of obstruction. If chaparral vegetation is present, amplitude declines an additional ~5.2 %/50 m over ideal circumstances, and if tree canopy is present amplitude declines an additional ~8.1 %/50 m. GIS programs such as ArcGIS offer tools to map portions of a survey site where chaparral and forest vegetation are present, as well as areas that are effectively un-surveyed due to obstruction by terrain.

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Table 1. Locations of survey sites and automated recording units (ARUs).

Survey site	ARU	Latitude, Longitude (WGS 84)
Woodland	1	N37.93022, W120.13496
	2	N37.92634, W120.13248
	3	N37.92590, W120.13728
	4	N37.92907, W120.12970
Chaparral	5	N37.88930, W120.00861
	6	N37.88937, W120.00498
	7	N37.89040, W120.00672
	8	N37.88889, W120.00620
Forest	9	N37.96634, W120.08921
	10	N37.96455, W120.08894
	11	N37.96582, W120.09258
	12	N37.96708, W120.09382

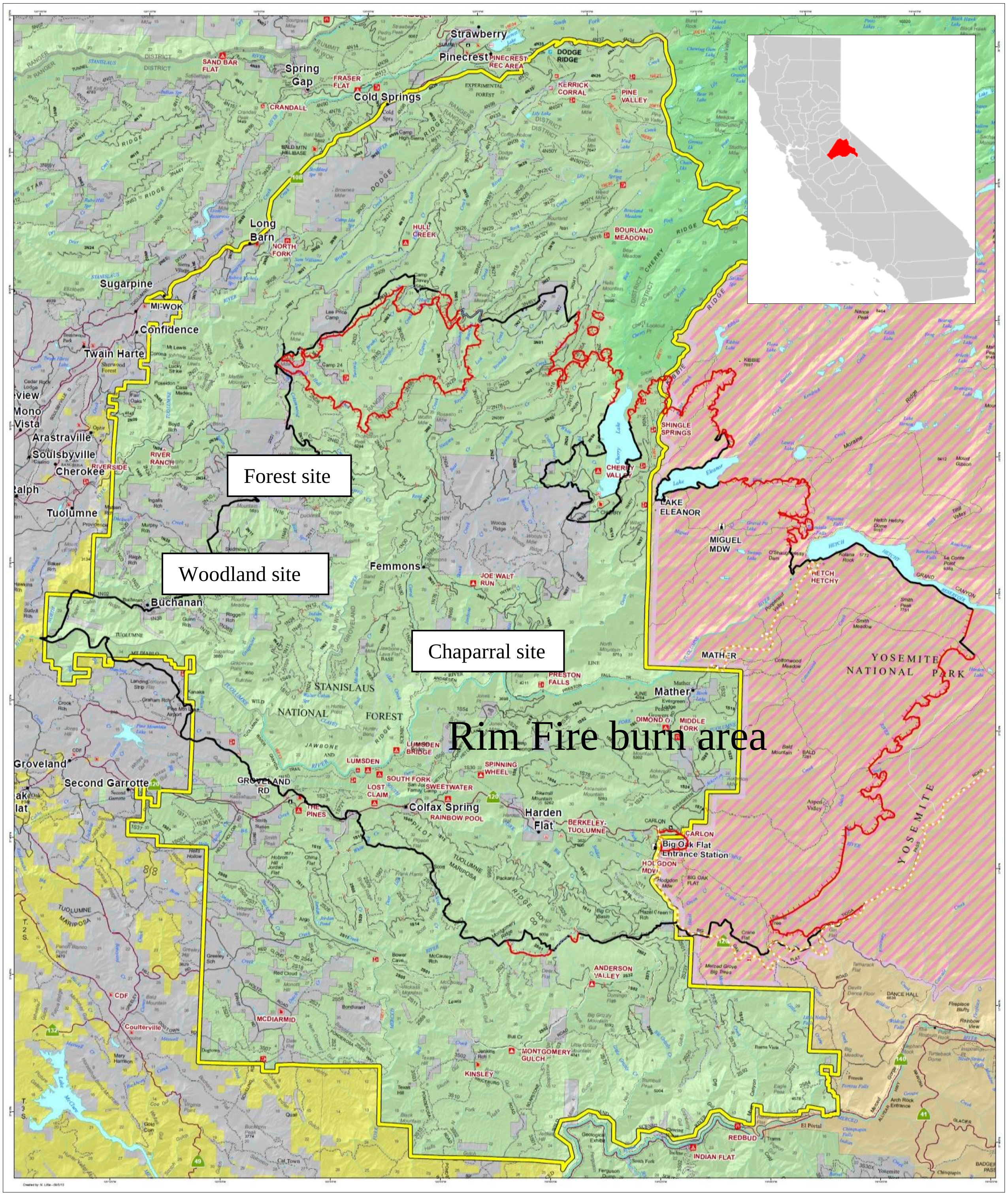

Figure 1. Study areas in Tuolumne County.

Figure 2. Flood retention dam used to test sound attenuation by terrain.

Figure 3. Level area of coyote bush (*Baccharis pilularis*) used to test decay of recorded Mountain Quail vocalizations in chaparral vegetation.

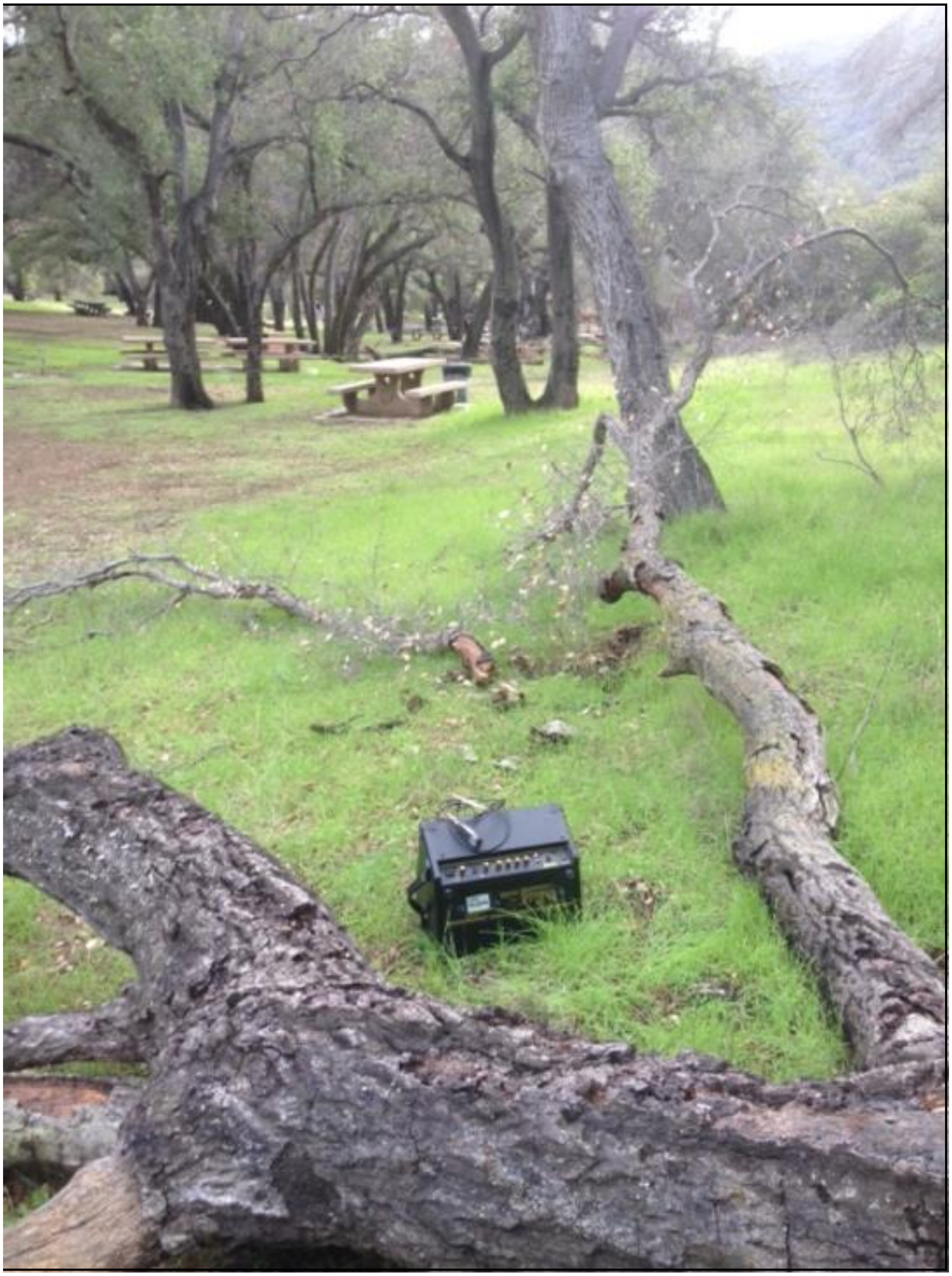

Figure 4. Gently sloping area of canyon live oak (*Quercus agrifolia*) used to test decay of recorded Mountain Quail vocalizations in woodland vegetation. Amplifying speaker in foreground.

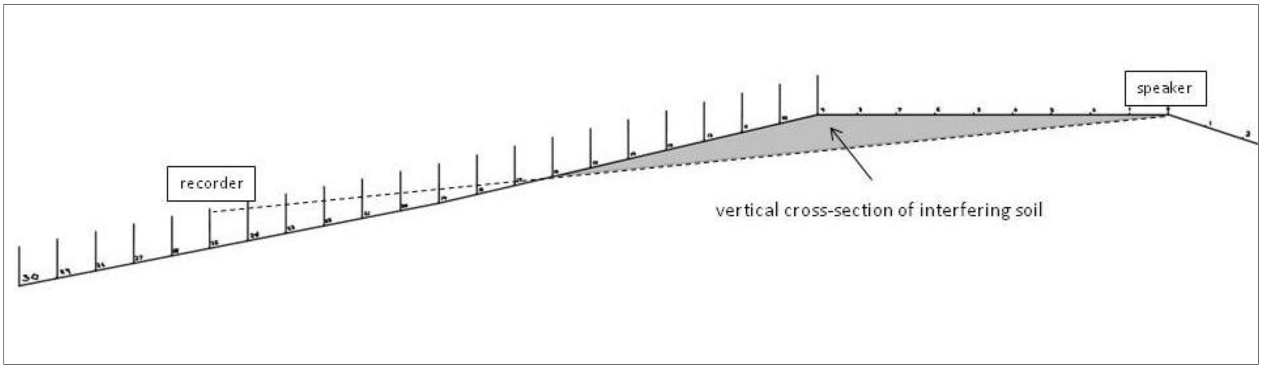

Figure 5. Profile of the retention dam used to test sound attenuation by terrain. The speaker was placed on the ground at 0 m, recorder at 1 m height at increasing distances down the back side of the dam. The m^2 area of the vertical cross-section of interfering soil was then calculated.

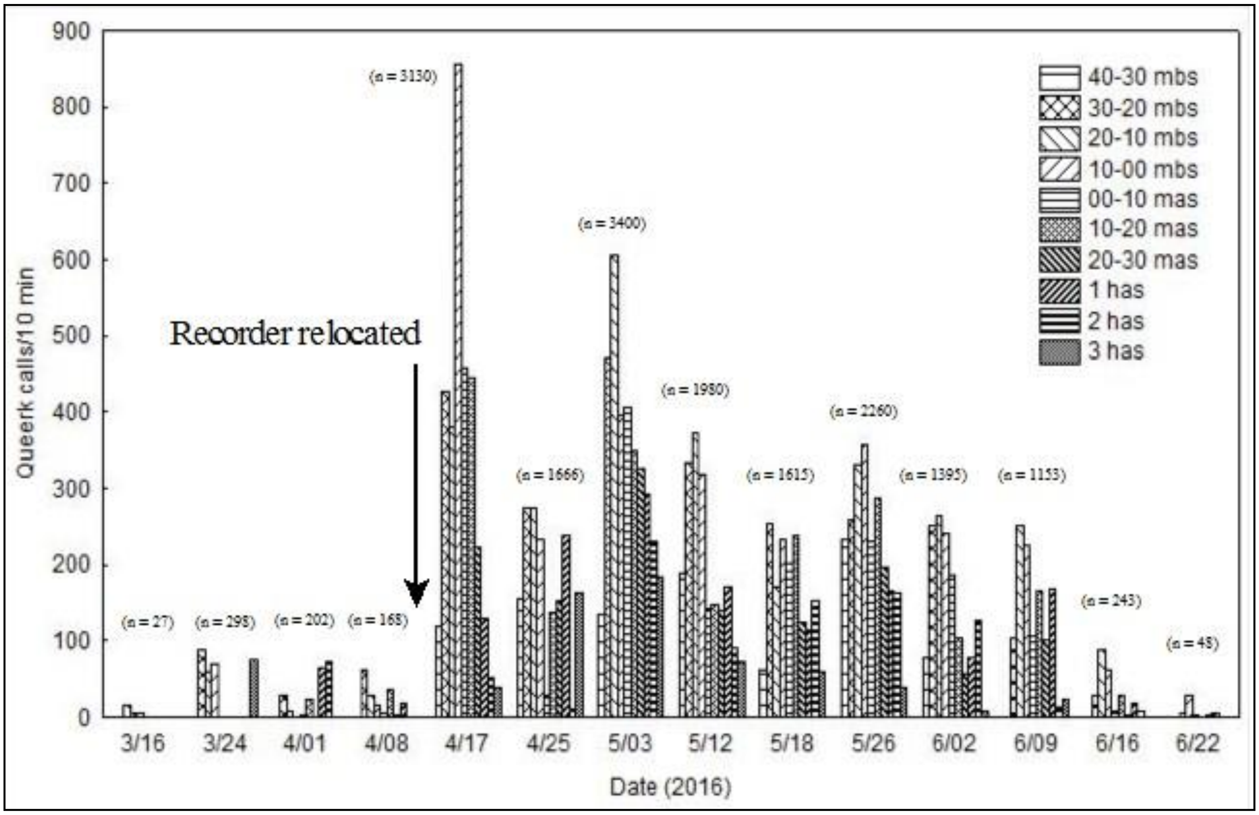

Figure 6. Frequency of confirmed queerk calls at a single automated audio recorder throughout the 2016 crow-calling season, sampled on an 8-day schedule. Detections are tallied for successive 10-min periods from 40 min before sunrise (mbs) to 30 min after sunrise (mas), and the first 10 min 1, 2, and 3 hrs after sunrise (has). Total confirmed calls for each sampling date (ten 10-min sampling periods) are indicated in parentheses. Bars representing $\leq$2 detections are not apparent at this scale. The recorder was relocated on 4/16, when the study transitioned from exploratory to systematic data collection.

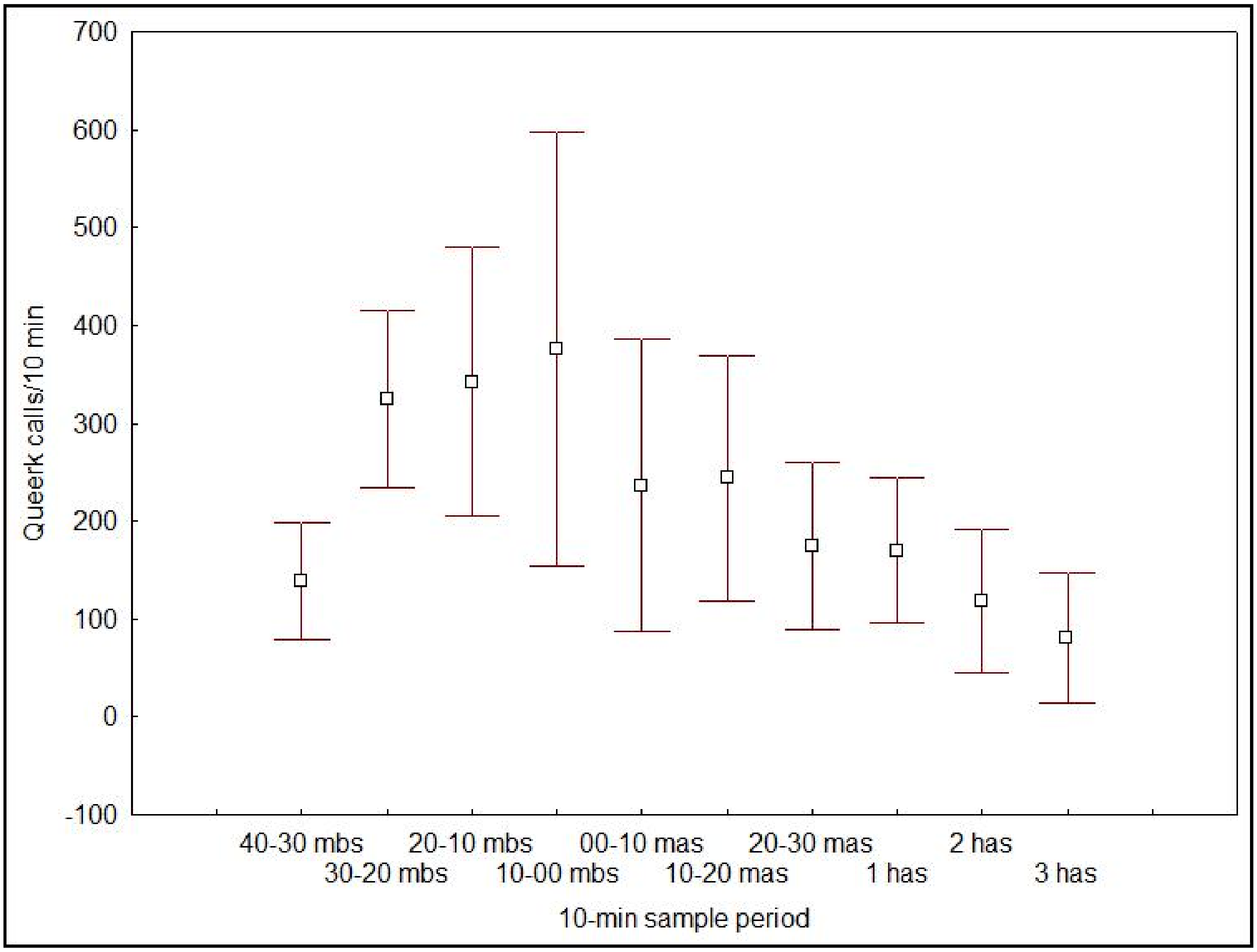

Figure 7. Confirmed queerk calls during successive 10-min sampling periods, peak queerk-calling season (April 17th-June 2nd, chaparral study site). Boxes are means, whiskers standard deviations.

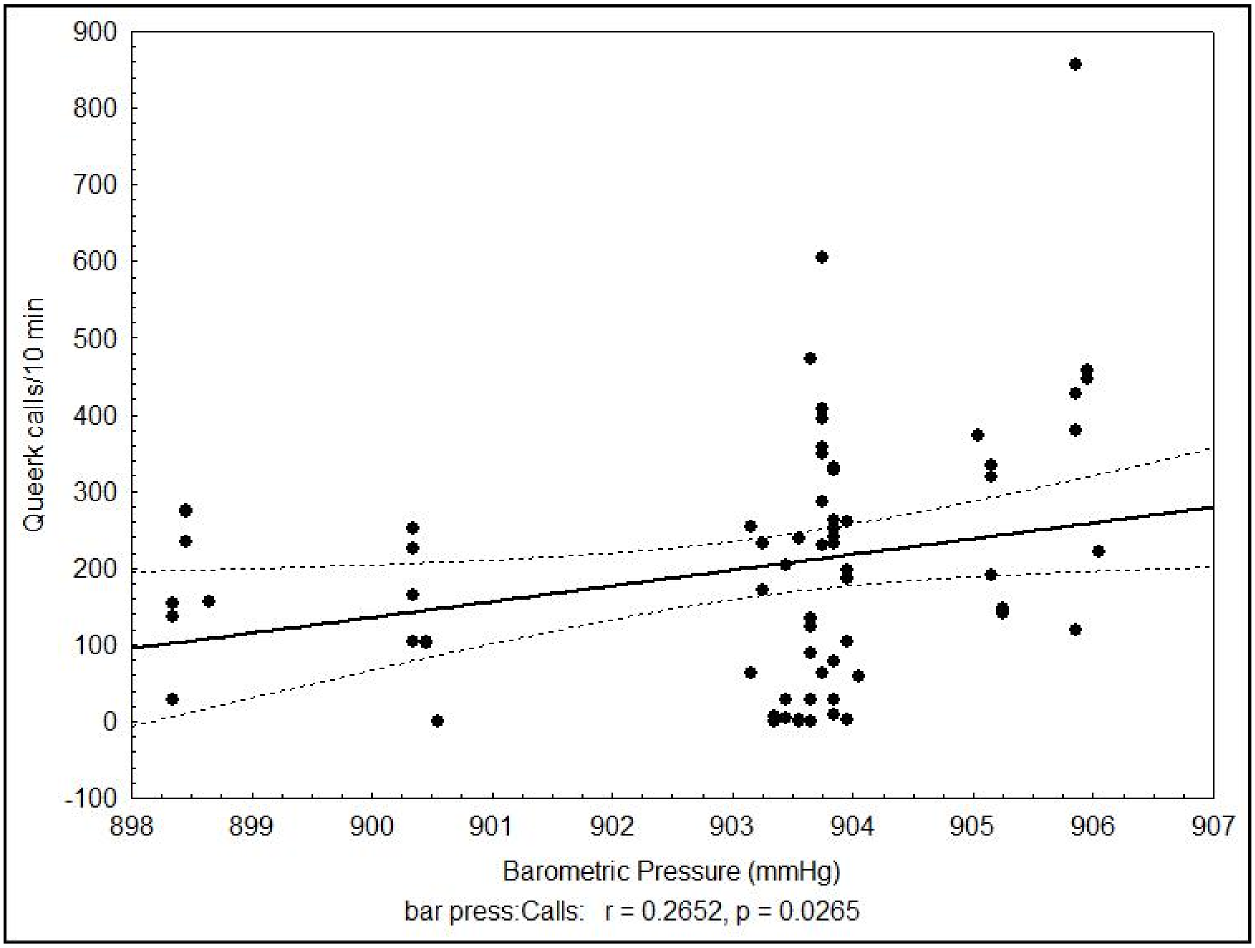

Figure 8. Effect of barometric pressure on call frequency. Dashed lines are 95 % confidence intervals.

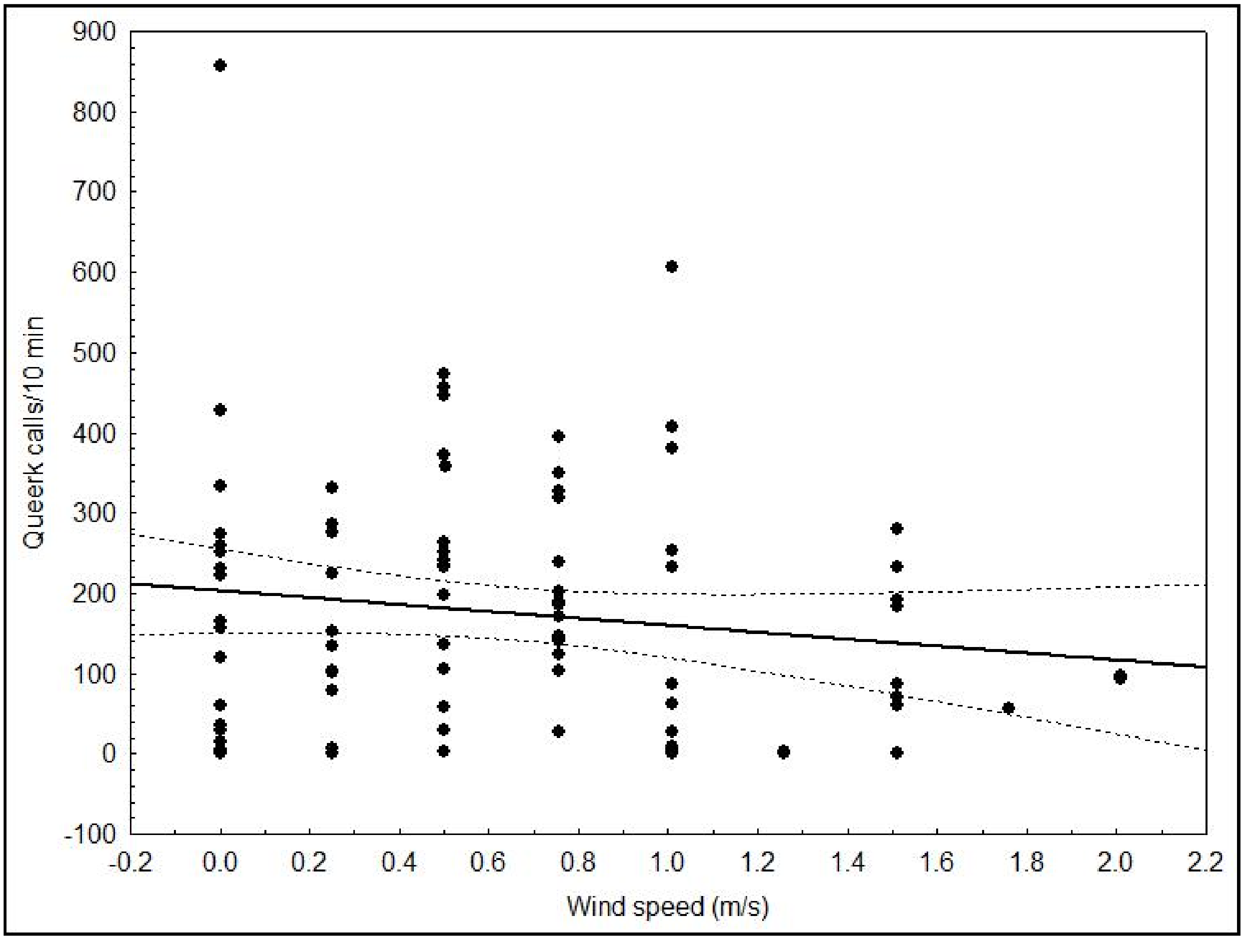

Figure 9. Effect of wind speed on call frequency. Dashed lines are 95 % confidence intervals.

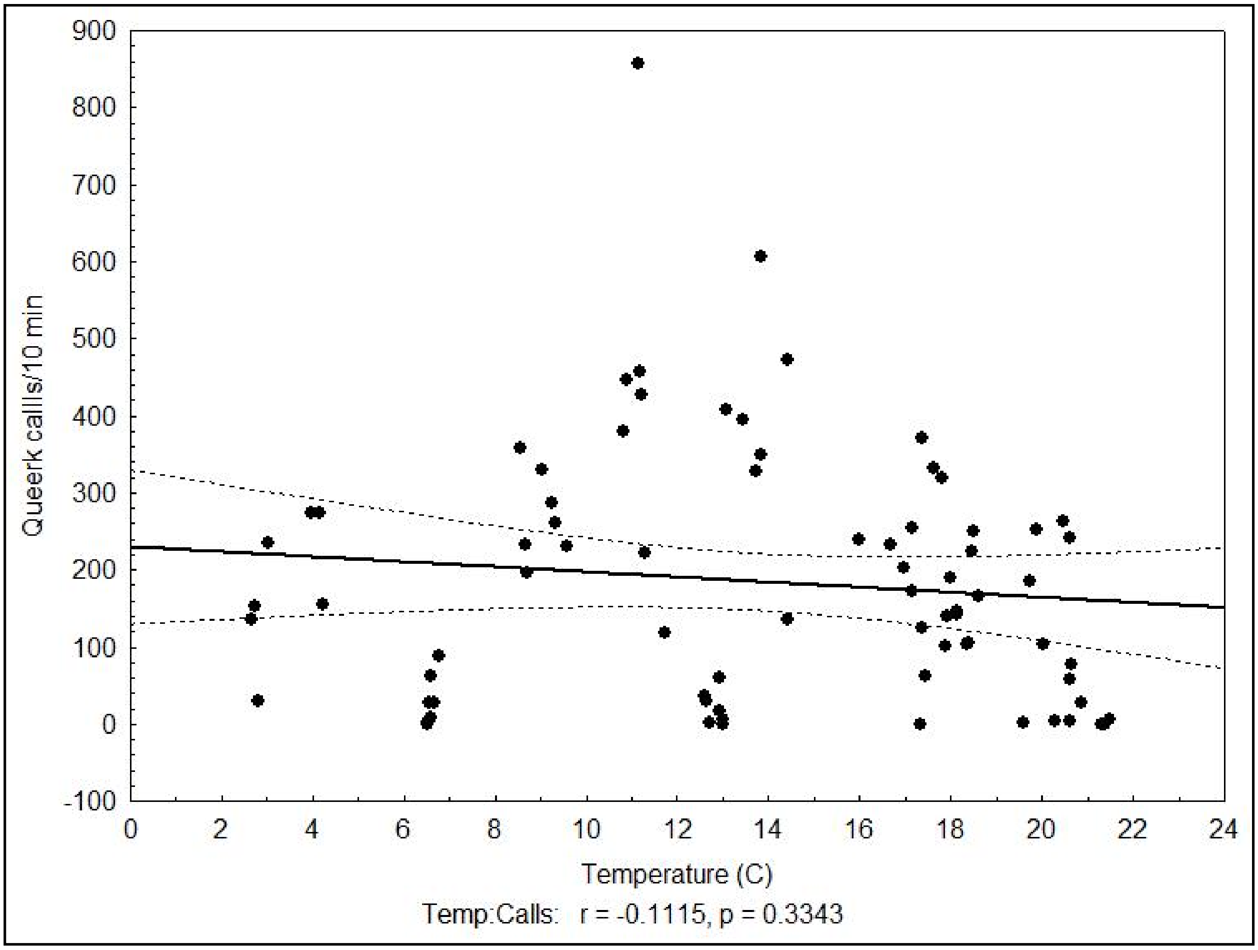

Figure 10. Effect of temperature on call frequency. Dashed lines are 95 % confidence intervals.

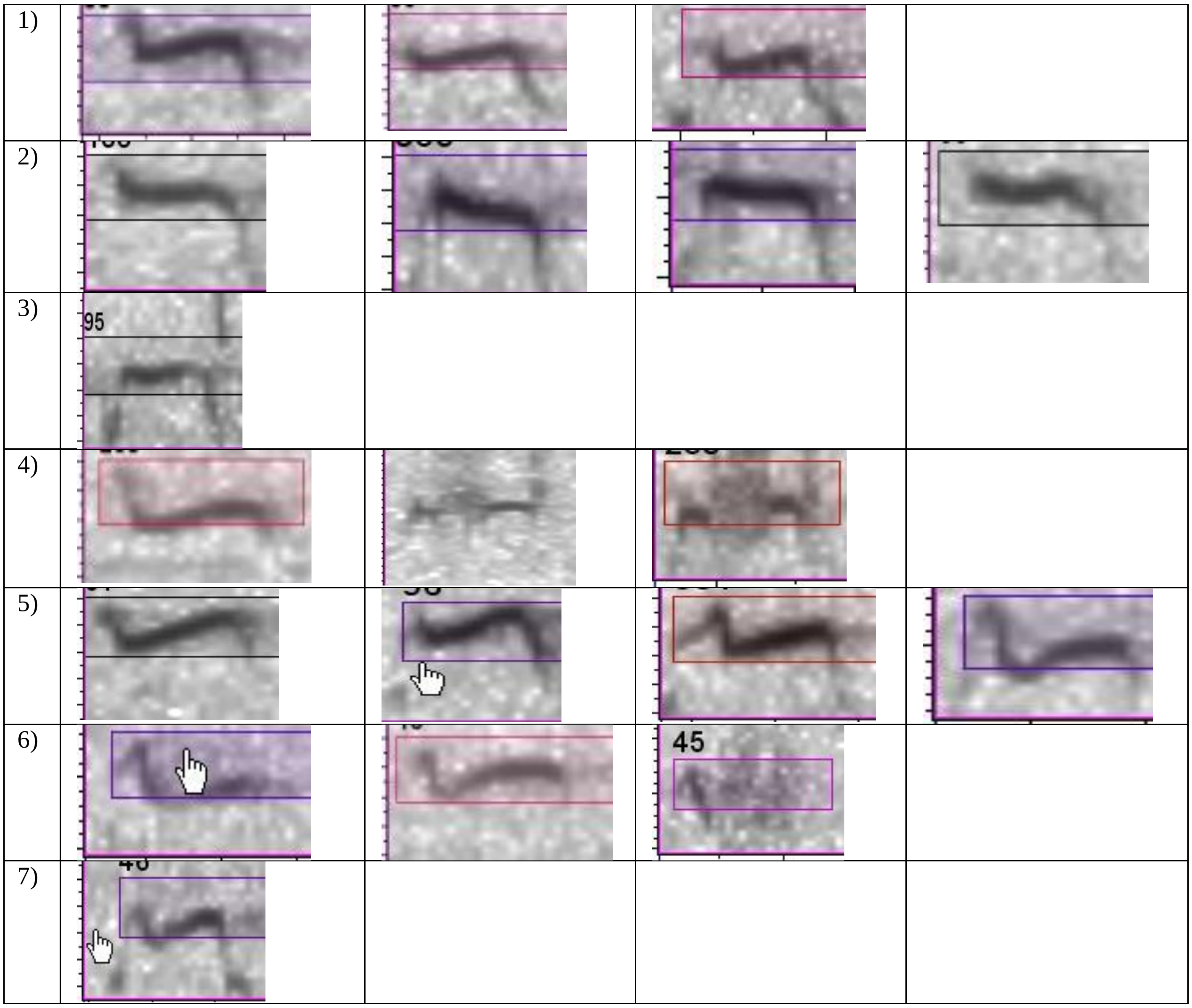

Figure 11. Sonograms of the voices of seven male MOQU, including variants. Close proximity (location clustering) was instrumental in identifying variant forms of calls. Inset rectangle indicates frequency range of 1350-1800 Hz.

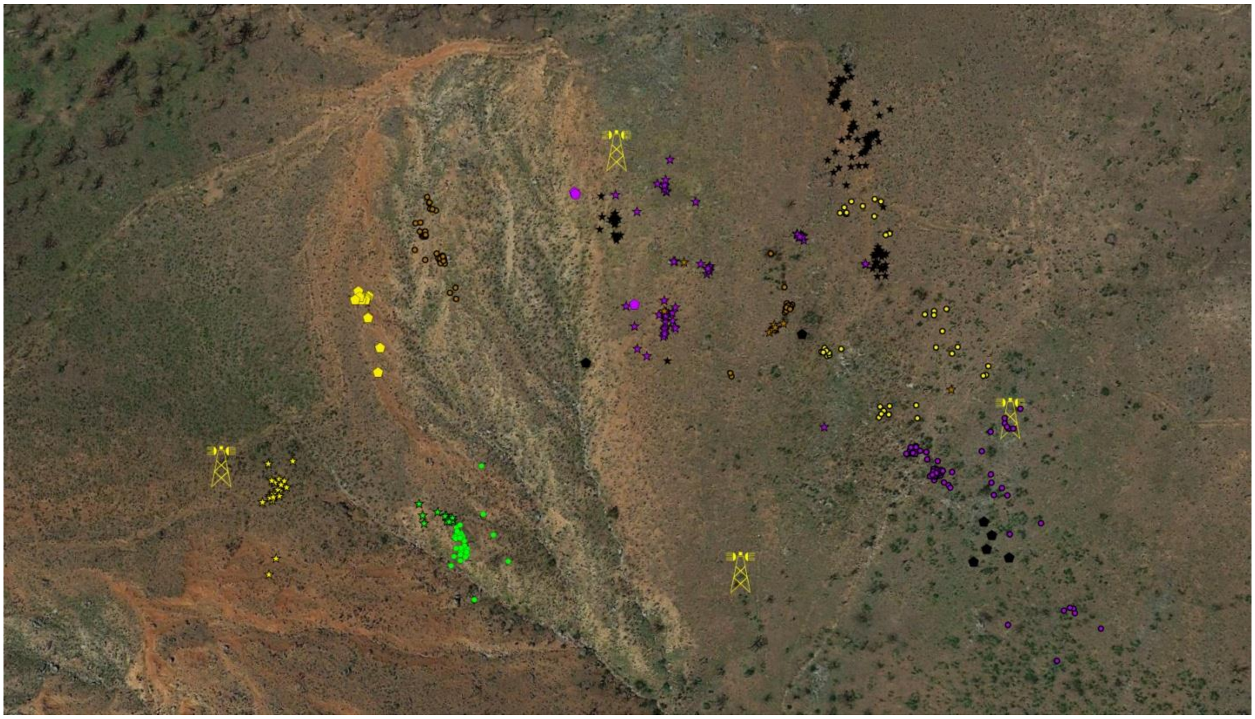

Figure 12. Verified queerk source locations at the chaparral study site, May 5th and 9th, 2016. Colors indicate different individuals identified by unique voice sonograms. Different shapes indicate morning versus evening calling periods among individuals. Yellow towers indicate ARU locations.

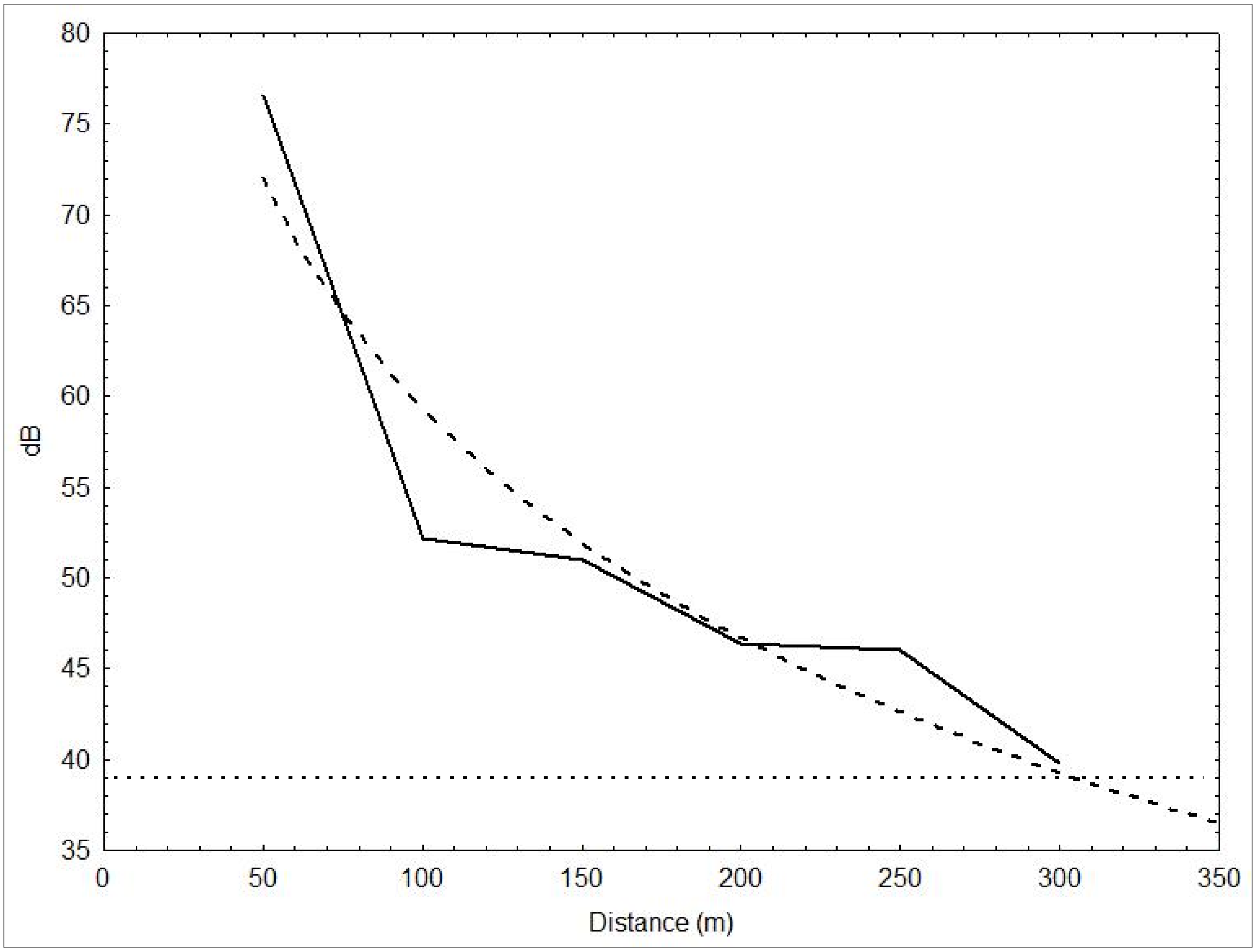

Figure 13. Amplitude decay of recorded queerk calls over distance; level ground, no air movement, and low herbaceous vegetation. Call was broadcast at 90 dB measured 1 m from the speaker. Solid line is recorded queerk call; hatched line, logarithmic curve fitted to queerk call data (dB = 143.608-18.29*log(distance)); dotted line, average ambient noise at 1350-1800 Hz.

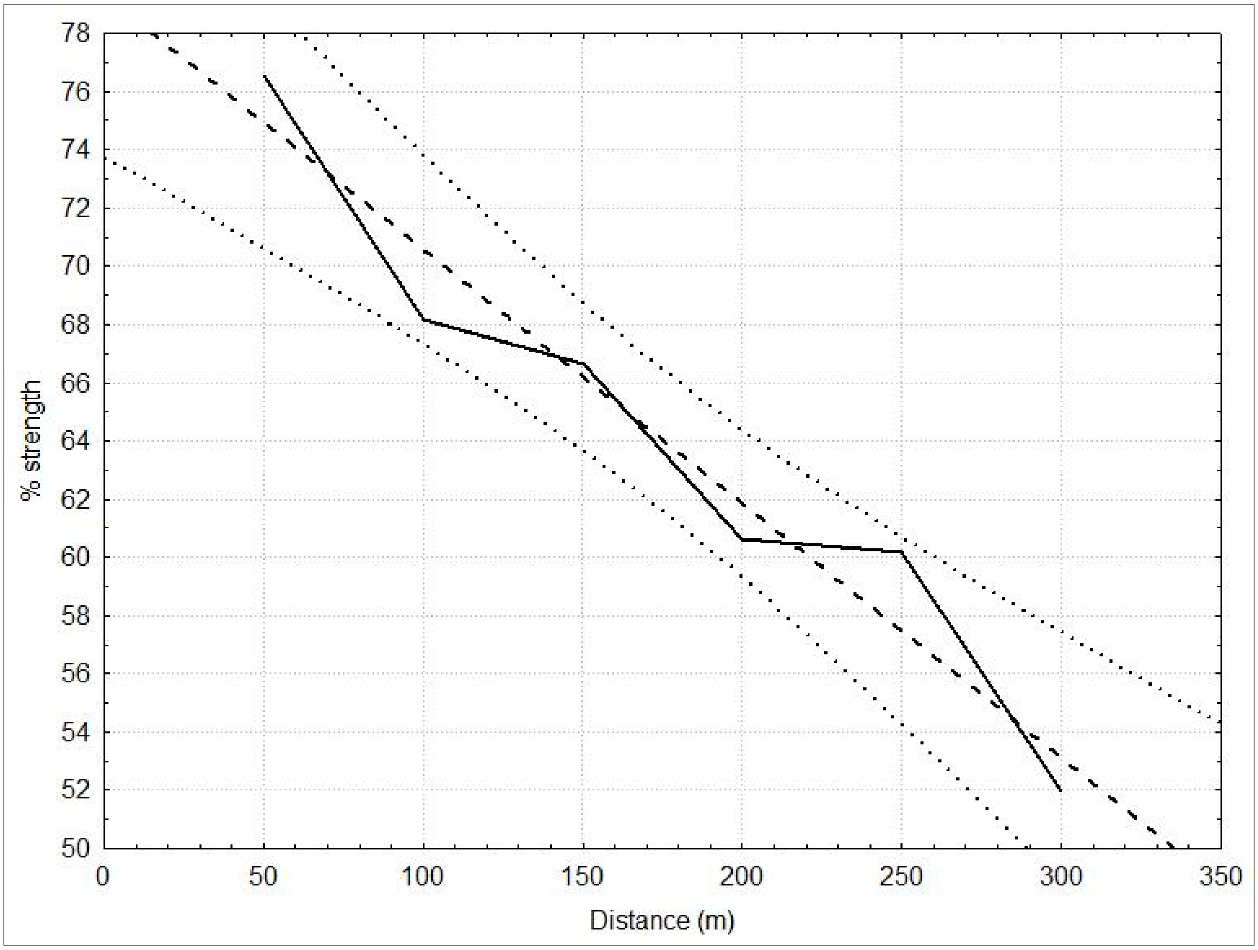

Figure 14. Percent decline of recorded queerk call amplitude over distance; level ground, no air movement, and low herbaceous vegetation. Solid line is % the amplitude measured at 1 m; hatched line, the fitted regression (Y = 79.31-0.09*(distance)); dotted lines, 95 % confidence limits.

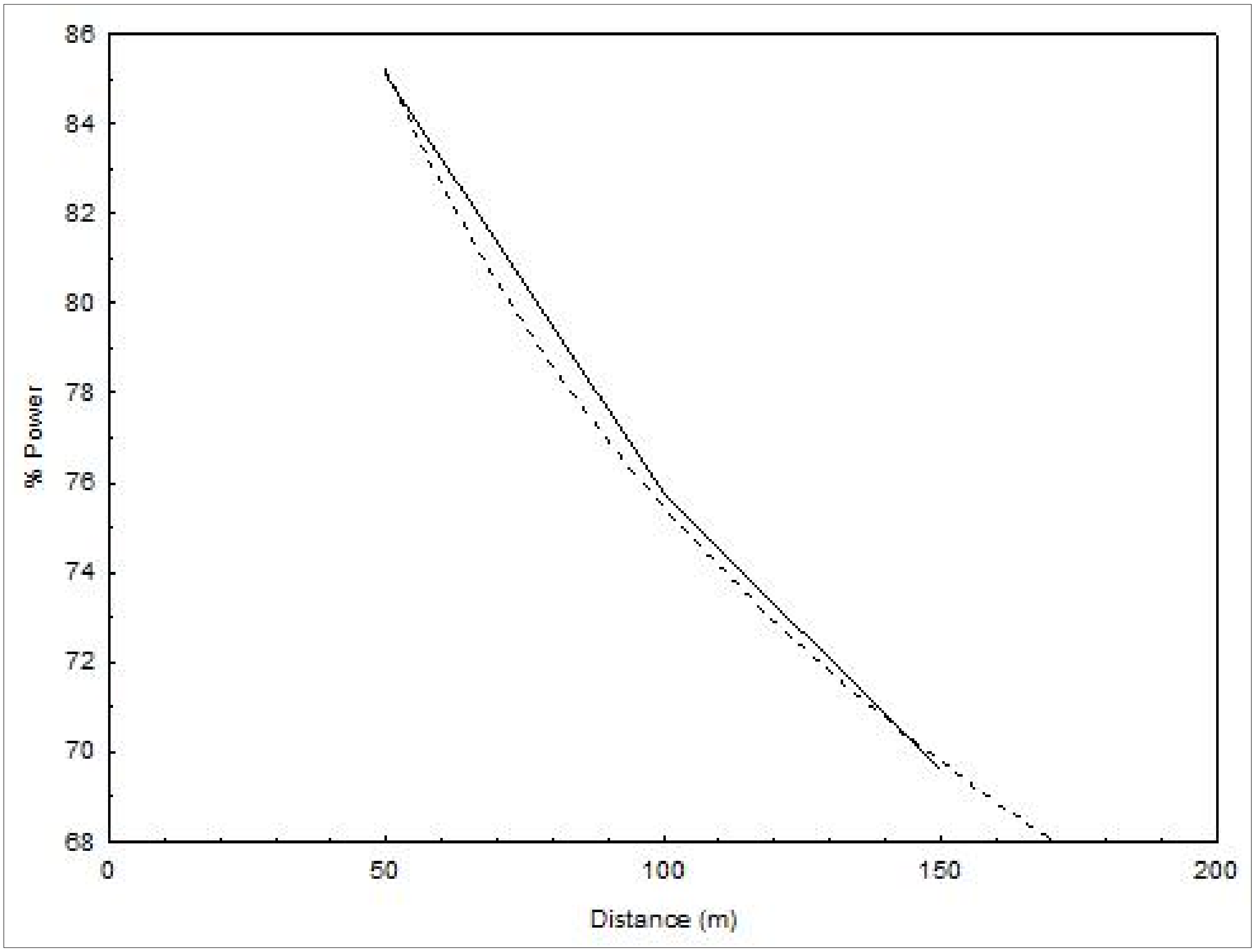

Figure 15. Percent decline of recorded queerk call amplitude over distance in chaparral vegetation. Solid line is % of the amplitude measured at 1 m; hatched line, the fitted regression (Y = 140.11-14.03*log(distance)).

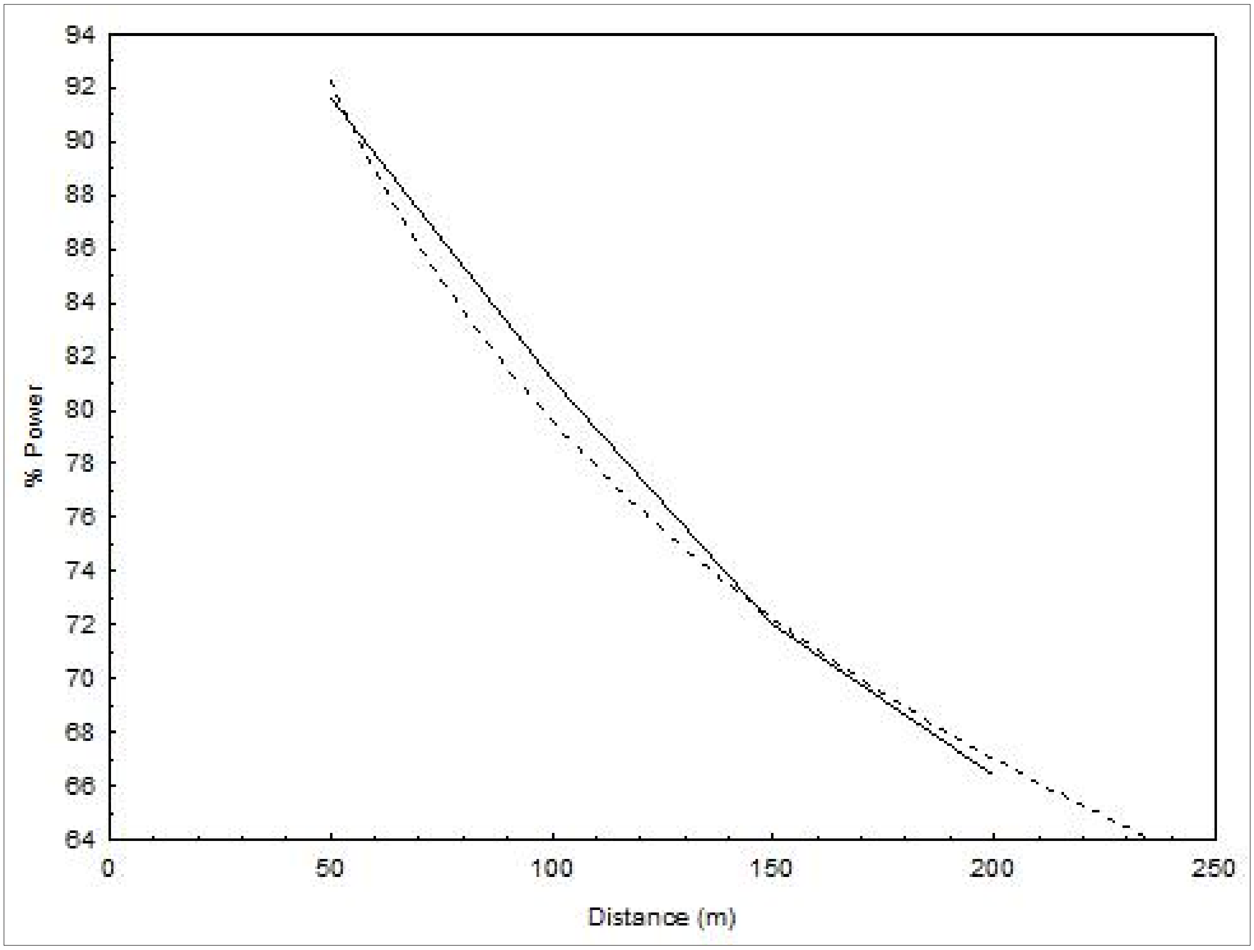

Figure 16. Percent decline of recorded queerk call amplitude over distance in woodland vegetation. Solid line is % of the amplitude measured at 1 m; hatched line, the fitted regression (Y = 163.60-18.233*log(distance)).

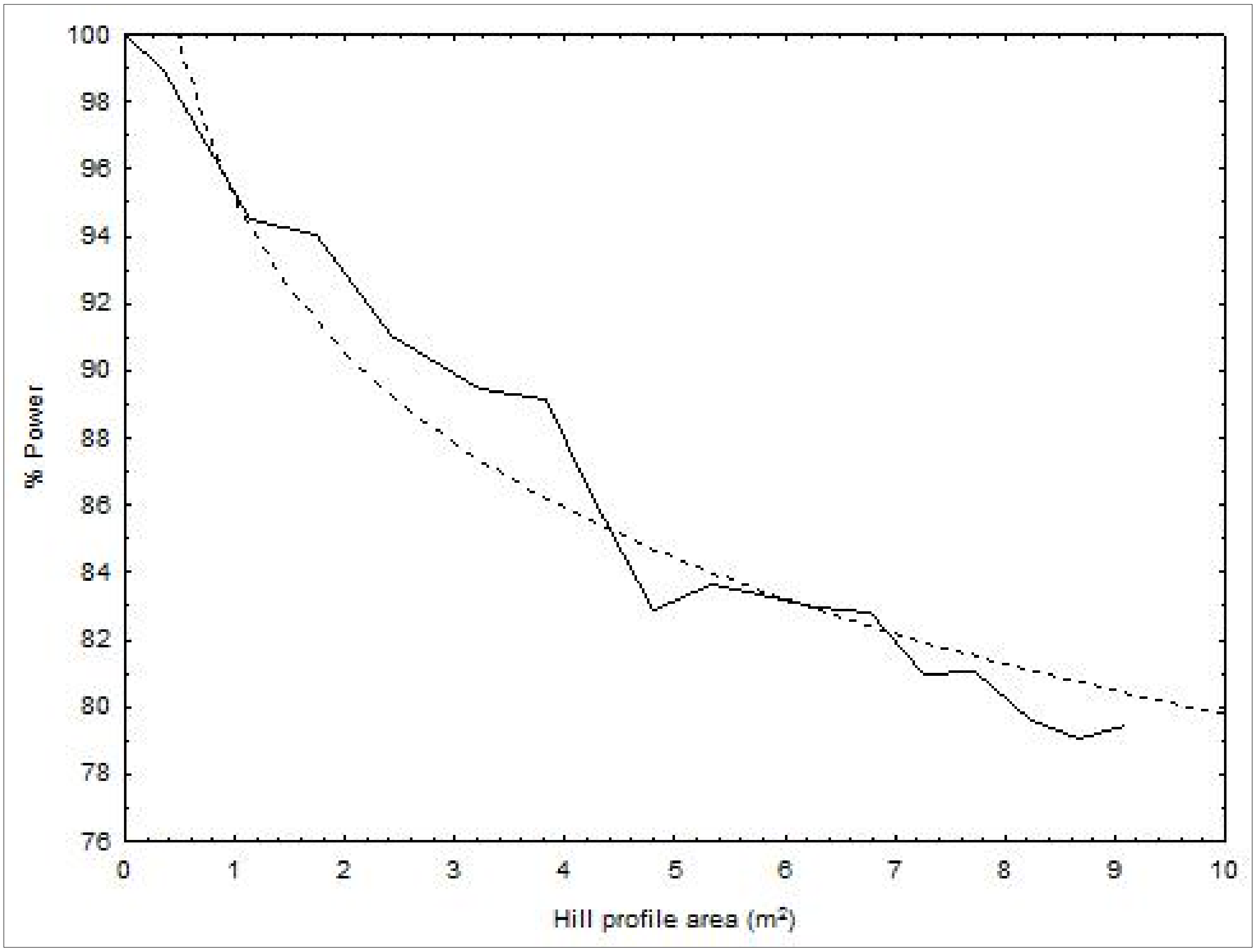

Figure 17. Attenuation of broadcast Mountain Quail queerk calls by obstructing terrain. Solid line is % of the amplitude measured at 1 m; hatched line, the fitted regression (Y = 95.175-6.6874*log(profile area).