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Impacts to Quail Space Use and Demographics from Oil and Gas Development

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IMPACTS TO QUAIL SPACE USE AND DEMOGRAPHICS FROM OIL AND GAS DEVELOPMENT

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ABSTRACT

Southern Texas contains some of the last relatively unfragmented habitat for northern bobwhite (*Colinus virginianus*; hereafter, bobwhite) and scaled quail (*Callipepla squamata*) in the United States. Development of the Eagle Ford Shale hydrocarbon formation in this region could negatively impact quail and their habitat. Our objective was to examine the indirect effects of oil and gas activity (traffic and noise) on bobwhite and scaled quail on 2 private ranches in southern Texas. In 2015 and 2016, we radio-marked bobwhite and scaled quail in 2 areas where oil and gas activity was occurring (disturbed treatment) and 2 areas where little oil and gas activity occurred (undisturbed treatment). We measured vehicle passages and modeled noise propagation from oil and gas infrastructure at 2 biologically relevant frequencies (250 Hz and 1,000 Hz) in our study area to quantify oil and gas disturbance and examine its effects on quail space use (site selection and home range size) and demographics (survival, nest success, and density). Bobwhite and scaled quail selected areas 0–200 m and >425 m, respectively, from the primary, high-traffic roads in the disturbed treatment. In the undisturbed treatment, bobwhite and scaled quail selected areas 0–425 m and 0–300 m from primary roads, respectively. Bobwhite and scaled quail selected areas with sound levels 0–1.6 and 0–2.2 dB above ambient levels at the 250-Hz frequency level, respectively. At 1,000 Hz, bobwhite and scaled quail selected areas with sound levels 0–2 and 0–3.2 dB above ambient levels, respectively. We found no evidence that disturbance variables affected bobwhite and scaled quail home range size, survival, or density. We found bobwhite nest success decreased as sound levels (dB) at 250 Hz increased; we found no relationship between nest success and disturbance for scaled quail, possibly as they avoided major oil and gas disturbances. In calculations of the total footprint of quail habitat loss, indirect loss due to oil and gas activity needs to be considered in addition to direct loss due to conversion of rangeland to oil and gas infrastructure.

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Key words: *Callipepla squamata*, *Colinus virginianus,* northern bobwhite, noise, oil and gas, scaled quail, traffic

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Northern bobwhite (*Colinus virginianus*; hereafter, bobwhite) and scaled quail (*Callipepla squamata*) are the two most widespread species of quail in Texas, USA. Despite their relatively large geographic range in the state, both species have been in population decline for decades (Brennan 1991, Church et al. 1993, Brennan et al. 2005). Although many hypotheses regarding this decline have been proposed, habitat loss and fragmentation are reported to be the primary reasons for the decline (Brennan 1991, Brennan et al. 2005, Hernández et al. 2013). The decline has been smaller in the Tamaulipan Biotic Province of southern Texas and northern Mexico than other regions because large parcels (>5,000 ha) of unfragmented habitat remain (Fulbright and Bryant 2004). However, the recent increase in oil and gas exploration in this area, in particular above the Eagle Ford Shale hydrocarbon formation, has the potential to adversely affect quail and their habitat.

The Eagle Ford Shale is a hydrocarbon-producing geological formation spanning 4 million ha from the Texas-Mexico border into East Texas (EIA 2016, RRC 2021). Since the first well was drilled in 2008, the Eagle Ford Shale has been rapidly developed in nearly 30 counties in Texas. For example, the number of production sites increased from 98 wells in 2009 to over 24,000 wells in 2021 (a 24,000% increase; RRC 2021). Currently, little is known about how disturbance from hydrocarbon development may impact quail populations. Furthermore, other important regions for bobwhite and scaled quail in the United States, such as the Southwest, Southeast, and Midwest, potentially also could be impacted by oil and gas disturbance as the demand for these resources continues.

It is widely accepted that surface development and subsequent habitat loss and fragmentation from hydrocarbon development will have a negative impact on quail (Brennan 1991, Brennan et al. 2005, Hernández et al. 2013). However, the extent to which this development will hinder quail is unknown.

Construction of roads, drilling pads, flowlines, pipelines, pits, and other infrastructure often causes both acute and long-term direct loss of habitat. Quail are displaced when habitat is lost, and their survival may decrease. Habitat fragmentation due to road systems and other rights-of-way also can cause habitat loss. For example, quail can be killed by vehicles on roads and roads can be barriers to quail, as these birds prefer concealment during travel. Roads also can act as corridors for nonnative plant invasions (Tyser and Worley 1992, Gelbard and Belnap 2003). Nonnative grass invasions can create barriers to travel and render sites unusable to quail as nonnative grasses replace native vegetation (quail habitat; Kuvlesky et al. 2002, Sands et al. 2012).

Along with direct effects from oil and gas infrastructure, noise and traffic from oil and gas activity have the potential to cause indirect loss of habitat for quail by affecting behavior and physiology (Francis and Barber 2013). For example, noise can cause physical damage to ears; increased stress levels; and changes in temporal site use patterns, communication, predator and prey relationships, reproduction, and populations (Barber et al. 2009, Ortega 2012, Francis and Barber 2013). Oil and gas exploration is usually accompanied by a surge in vehicles and sound levels above levels typical of the ambient environment.

One way that indirect habitat loss may be manifested is through changes in space use by birds. For example, vehicle disturbance from natural gas development near greater sage-grouse (another member of the Galliformes; *Centrocercus urophasianus*) leks increased the distance from leks that hens moved when selecting nest sites (Lyon and Anderson 2003). The probability of lek abandonment by greater sage-grouse increased near oil and gas development in Montana and Wyoming, USA (Walker et al. 2007, Hess and Beck 2012). In a study during winter, greater sage-grouse in Wyoming avoided sagebrush habitat with coal-bed natural gas wells (Doherty et al. 2008).

Another way that oil and gas activity can indirectly impact quail and other birds is through changes in reproduction and survival. Noise caused by traffic resulted in lower reproductive success for great tits (*Parus major*; Halfwerk et al. 2011). The smaller clutches laid and fewer young fledged by great tits in areas with traffic noise were most likely due to the masking of the great tit's song by traffic noise, decreased parent-offspring communication, and stress (Halfwerk et al. 2011). Furthermore, habitat fragmentation from roads and rights-of-way may increase predator search efficiency for nests and individuals (Robinson et al. 1995, Hernández et al. 2013). Anthropogenic noise can interfere with birds' ability to hear predators (Ortega 2012). Yearling greater sage-grouse reared in areas with natural gas infrastructure had lower annual survival than those in areas without it, although the specific cause of this finding was unknown (Holloran et al. 2010). Both direct and indirect effects of oil and gas development on quail represent an area in need of study, especially in a landscape with great conservation value for wild quail.

Large areas over hydrocarbon formations support the last vestiges of wild quail across the United States, so it is imperative to understand how oil and gas exploration of these formations and the associated disturbance may affect quail populations. Our objective was to determine how bobwhite and scaled quail respond to localized oil and gas disturbance. Specifically, our goal was to document how this disturbance affected their 1) space use (site selection and fidelity) and 2) demographic performance (seasonal survival, nest success, and abundance). We predicted that both bobwhite and scaled quail would avoid sites with greater disturbance and that demographic performance would be lower in these areas.

STUDY AREA

Our study took place on 2 adjacent private ranches in southwestern Dimmit County, Texas. These ranches were within the subtropical steppe climate within the western portion of the Tamaulipan biotic province of southern Texas (Blair 1950). Rainfall was variable between years but averaged 51 cm annually (1981–2010; WRCC 2014). Rainfall amounts peaked in May and October. The average annual high temperature was 28.8° C, and the average annual low temperature was 14.9° C (1981–2010; WRCC 2014). The ranches consisted of gently undulating (0–5% slopes) gravelly, loam, and sand hills. The dominant soil series were Dilley fine sandy loam, Antosa-Bobillo association, and Randado fine sandy loam (USDA NRCS 2014*b*). We grouped ecological sites (USDA NRCS 2014*a*) within the study area as "deep sands" and "shallow ridges." Vegetation on deep sands sites was composed of mottes of honey mesquite (*Prosopis glandulosa*), granjeno (*Celtis ehrenbergiana*), brasil (*Condalia hookeri* var. *hookeri*), and pricklypear (*Opuntia engelmannii* var. *lindheimeri*), interspersed within a matrix of little bluestem (*Schizachyrium scoparium*), Lehmann's lovegrass (*Eragrostis lehmanniana*), tanglehead (*Heteropogon contortus*), and purple threeawn (*Aristida purpurea*). Shallow ridges were dominated by blackbrush acacia (*Acacia rigidula*), guajillo (*Acacia berlandieri*), and cenizo (*Leucophyllum frutescens*). Common herbaceous species on shallow ridges included common curly mesquite (*Hilaria belangeri*), red grama (*Bouteloua trifida*), Hall's panicum (*Panicum hallii*), and purple threeawn (USDA NRCS 2015). Both ecological sites also contained a wide variety of other woody and herbaceous plant species (>500).

METHODS

We studied an 11.6-km-long oil and gas exploration corridor (primary roads, pipelines, flowlines, and pads) that straddled the border between the 2 ranches. Some disturbed surfaces in the corridor (such as pipeline and flowline rights-of-way) were restored to ecotypic, native herbaceous vegetation (South Texas Natives, Kingsville, TX, USA). We monitored birds for the effects of oil and gas disturbance in 2 spatially independent (separated by 2.3 km) 300-ha focal areas along 6.8 km of this corridor. These 2 areas were paired with 2 300-ha experimental controls ≥0.4 km away, which were undisturbed by oil and gas surface development. Focal area pairs were grouped by ecological type (deep sands and shallow ridges) to represent typical bobwhite and scaled quail habitat, respectively, in southern Texas.

There were a single disturbed experimental unit and a single undisturbed experimental unit for each quail species (i.e., the treatments were unreplicated in each study). However, the inferential statistics used herein were valid, as we intended to apply inferences to quail populations within the 2 units for each species.

Disturbance Measurement

We measured indirect habitat loss via disturbance along roads (vehicle passages and noise) and at point sources of noise in the exploration corridor and their respective paired control areas from March through September (2015 and 2016) to coincide with the quail breeding season. We estimated vehicle passage rate (vehicles/week) in each of the 4 focal areas using 4 Traffic Tally 2 single road tube accumulators (hereafter, traffic counters; Diamond Traffic Products, Oakridge, OR, USA). When a vehicle drove over the traffic counter, air was compressed within the road tube, which sent a pulse of air into the monitoring unit, resulting in a tally of axle passes. Two axle passes counted as 1 vehicle pass. We deployed traffic counters continuously for 1-week periods along each respective road segment and rotated among road segments in each focal area. We classified road segments as any road traversable by passenger vehicle which branched off another road. Road segments that changed direction (curve or bend), but did not cause a vehicle to leave the segment, were not considered an independent segment. We placed traffic counters on the ground 50 m from the beginning of each road segment. At the end of the week-long monitoring period, we moved traffic counters to a new road segment in each of the respective focal areas.

Similar to traffic monitoring, we characterized the noise environment along each road segment March through August (2015 and 2016) with a SoundTrackLxT® Class 1 sound level meter (hereafter, SLM; Larson Davis, Depew, NY, USA). We placed the SLM 100 m from the beginning of each road segment so that the sound of air pulses from the traffic counter would not be measured by the SLM. Since the noise environment is known to vary by time period (California Department of Transportation 2003), we stratified the deployment of the SLM among 4 3-hr time periods (sunrise–0900, 0901–1200, 1201–1500, and 1501–sunset) each day. The SLM was deployed and monitored for 1 hr during each sampling interval. We recorded the sound metrics, maximum sound level (L_{max}) and equivalent average sound level (L_{eq}), and the 1/3-octave band frequency profile, using an A-weighted filter in 1-sec intervals throughout the 1-hr period to produce the maximum and average sound level per second (dBA/sec; Pater et al. 2009, Blickley and Patricelli 2012). A-weighting excludes high and low frequencies to create a profile similar to what a human ear can hear (Blickley and Patricelli 2012), but has been shown to be best for bird studies (Dooling and Popper 2007). Generally, bobwhite can detect sounds that are about 15 dB at their most sensitive frequencies (1,000 and 3,500 Hz); sounds must be about 39 dB at their least sensitive frequencies (250 and 8,000 Hz) for a bobwhite to detect them (Barton et al. 1984). We took sound measurements during optimum weather conditions (27–41° C, wind speeds <18 km/hour, 60–90% humidity) so that measurements were comparable across time periods and focal areas (California Department of Transportation 2003). We excluded measurements during periods in which we could detect additional sources of anthropogenic noise not relevant to the study, such as aircraft noise (e.g., fighter jets passing over), or during nontypical weather events, such as thunderstorms.

In addition to taking disturbance measurements along road segments, we measured the noise environment around point sources, including compressor stations, generators, and pump jacks. We took these measurements with the SLM during May through September (2015 and 2016), using the sound metrics described previously. At each point source of noise, the SLM was placed 3 m away in a randomly chosen cardinal direction (N, S, E, or W). However, because sound varies in relation to the distance from a unique point source, monitoring of sound from point sources was conducted at stratified distances of 200 and 400 m away in each of the 4 cardinal directions (9 sampling points/point source). The SLM was deployed for 20 min at each of the 9 points, once per field season during optimum weather conditions and similar time periods (sunrise–0900).

Trapping and Radio-telemetry

To determine effects of hydrocarbon exploration on bobwhite and scaled quail space use and demographics during the breeding season, we trapped quail February through July (2015 and 2016) and we tracked quail March through September (2015 and 2016). Handling procedures followed the protocols of the Texas A&M University-Kingsville Institutional Animal Care and Use Committee (permit 2015-03-23). We stratified trap-site placement by using the Create Fishnet tool in ArcMap 10 (Esri Inc., Redlands, CA, USA) to create a grid with 10-ha cells where 1 trap site was selected per grid cell for a total of 24 funnel traps/focal area (96 total; Stoddard 1931). We placed trap sites under dense-canopied shrubs with lateral screening cover to protect birds from heat and predators. Before trapping, we baited trap sites with 1.7 L of grain sorghum (*Sorghum bicolor*) every 4 days before trapping commenced at 12 days. As trapping began, we set and baited funnel traps at 4:00 a.m. We checked traps every 3 hr throughout the day and we closed traps before twilight (Abbott et al. 2005). If temperatures reached 35° C during midday, we set and checked traps only during morning and evening periods. Initially, we trapped quail February through March until a total sample size of 40 quail were fitted with transmitters (10 quail × 4 focal areas = 40 quail, evenly divided between bobwhite and scaled quail). Thereafter, we trapped throughout the field season as needed to maintain the sample size of 40. Trapping effort remained standardized among focal areas. Our goal was to trap bobwhite within the 2 focal areas exhibiting bobwhite habitat (deep sands) and scaled quail in the 2 focal areas exhibiting their habitat (shallow ridges). All captured quail were weighed (g), aged (hatch year or after hatch year), sexed, and leg-banded with a size 7 aluminum leg band (Rosene 1969, Fair et al. 2010). We fitted 40 quail with a 6 g, 150–151.999 MHz, necklace-style radio transmitter (American Wildlife Enterprises, Monticello, FL, USA) if they weighed >150 g (Hernández et al. 2004). Our sample was skewed toward females when possible; a 3:1 ratio of females to males was used to ensure the location of nests. We radio-marked ≤3 quail/trap site to ensure even sampling distribution over the focal areas.

From March through September (2015 and 2016), we located radio-marked quail 2–3 times/ week with a day between locations. We approached quail on foot using a handheld, 3-element Yagi antenna and a 150–151 MHz receiver (Advanced Telemetry Systems Inc., Isanti, MN, USA) until the bird was located via homing. Tracking times for all birds were stratified into 4 time periods throughout the day (sunrise–0900 hours, 0901–1200 hours, 1201–1500 hours, and 1501 hours–sunset) as quail site use is known to vary by time period (Lehmann 1984). Visitation time for each quail was stratified so that each bird eventually had an equal number of locations taken during each time period throughout the course of the field season. We recorded locations using a Garmin Dakota® 20 handheld Global Positioning System (GPS) unit (accuracy <10 m; Garmin International, Inc., Olathe, KS, USA). Data collected at each quail location included the date, time of day, the quail's association with other quail (single, paired, number in the covey, number of chicks present), plant species present within a volumetric 0.25-m^2 quadrat, and any other pertinent observations. When a mortality signal was detected, we retrieved the collar and attempted to determine the cause of mortality.

Nest locations found as a result of monitoring radio-marked birds were recorded using the handheld GPS unit. We did not flush birds off the nest, but rather, we documented clutch size and nesting substrate when the bird was absent from the nest, usually during late evening. Nests were checked 3 times/week without disturbing the hen during typical radio-telemetry sessions. If the radio-telemetry signal was strong at the nest location, it was assumed that the hen was on the nest. Once nesting concluded, we documented nest fate (depredation, destruction, abandonment, successful hatch, or other) and attempted to determine the cause of depredation, destruction, or abandonment.

Data Analysis

Vegetation.—We digitally classified woody cover within our focal areas to link this potentially important variable to site fidelity (home range and core area sizes) and demographic parameters (survival and nest success) for quail. Woody cover is important to quail for loafing, roosting, thermal protection, and protection from predators (Hernández and Peterson 2007, Silvy et al. 2007). To conduct this classification, we obtained 1-m Digital Orthophoto Quarter Quad (DOQQ) imagery from 2014 (TNRIS 2016) and used unsupervised classification in ERDAS IMAGINE (Hexagon Geospatial, Madison, AL, USA). Spatial data from 2014 were the nearest known temporal imagery to our study years and woody cover was similar between years. We performed an accuracy assessment to achieve an accuracy of ≥85% (Congalton 1991). We then related this classified woody cover to quail by creating a 10-m buffer around each quail or nest location with the Buffer tool in ArcMap 10. We then used the Split Raster tool in ArcMap 10 to divide the land cover classification raster into individual raster datasets, using the 10-m buffers as the templates. We used the percentage of landscape (PLAND) calculation in FRAGSTATS (University of Massachusetts, Amherst, MA, USA) to obtain percent woody cover in each individual raster. We then found the mean percent woody cover per quail (for home range size and survival models) by averaging the percent woody cover from all the rasters surrounding an individual quail's locations. Percent woody cover for a nest location was the percentage obtained from the single raster surrounding each nest.

Disturbance.—We conducted analyses in the area available for quail to use, not the original 300-ha focal areas. We determined the area available for use by creating a 402.3-m buffer around all trap sites in each of the 4 focal areas with the Buffer Tool in ArcMap 10. We chose this distance because it represents the average daily movement of a bobwhite (50% of bobwhite spend their life within 0.25 mile of where they hatched; Stoddard 1931). The new area (ha) for the disturbed deep sands, undisturbed deep sands, disturbed shallow ridge, and undisturbed shallow ridge sites were 554 ha, 531 ha, 535 ha, and 506 ha, respectively.

Indirect disturbance was compared between focal areas and modeled to determine effects on quail space use and demographics. For simple comparisons between focal areas, we reported means ± standard error (SE) for vehicle passage rates (vehicles/week) and sound levels (dB) at 250 and 1,000 Hz along primary roads between disturbed and undisturbed treatments in each study year for each ecological type.

To determine the impact of indirect disturbance on quail space use and demographics, we examined effects of distance to nearest road, mean vehicle passage rates of the nearest road, and mean sound level from point sources of oil and gas noise on 3 dependent variables (home range and core area size, seasonal adult survival, and nest success) using multiple regression analyses. We also examined the effect of distance to nearest road and mean sound level from point sources of oil and gas noise on another dependent variable, quail site selection, using continuous selection functions.

We assigned vehicle passage rates to roads in the study area to use distance to nearest road and vehicle passage rates of the nearest road as covariates in the models for home range size, core area size, seasonal adult survival, and nest success. We digitized roads in our study area into polygons with the Create Features tool in ArcMap 10 at a 1:3,000-m scale. Mean weekly vehicle passage rates/year (2015 and 2016) from traffic counter data were assigned to each road segment. We used the Generate Near Table tool in ArcMap 10 to find distance to the nearest road and vehicle passage rate of the nearest road from quail or nest point locations. We modeled noise propagation (dB; monthly average) from oil and gas point sources across our study area for each month of our study using the SPreAD-GIS tool (Reed et al. 2012). Each month during each study year (March though September 2015 and 2016) was modeled independently because noise propagation varies by weather conditions and the point sources present. The tool was implemented in ArcMap 10 and required the following inputs: 1) the point source location, 2) desired model extent (study area), 3) desired frequency level (250 or 1,000 Hz), 4) sound level (dB) of point sources at a specified frequency level (250 or 1,000 Hz), 5) measurement distance (3 m) from point sources, 6) a 30-m resolution digital elevation model (USGS 2016*b*), 7) a 30-m resolution land cover classification (unsupervised classification of LANDSAT 8 imagery from July 2016; USGS 2016*a*), 8) air temperature (°C), 9) relative humidity (%), 10) wind direction (°), 11) wind speed (km/hr), and 12) a 30-m resolution raster layer of ambient sound levels (dB) at a specified frequency level (250 or 1,000 Hz).

We chose to model noise propagation at 2 different frequency levels: 250 and 1,000 Hz. Two hundred fifty Hz is at the lower limit of bobwhite hearing and 1,000 Hz is a maximum level of hearing sensitivity for bobwhite (Barton et al. 1984). The lower limit of bobwhite hearing was chosen because most oil and gas or other human-generated noise has the highest intensity at frequencies below 1,000–2,000 Hz (Dooling 2002, Pohl et al. 2009). We assumed scaled quail had the same sensitivity as bobwhite at these frequencies as no known published information is available for their range of hearing. For the input of sound level of point sources at each of the 2 frequency levels, we used average values for each point source from the 1/3-octave band frequency profile. For land cover classification input, we performed unsupervised classification of 30-m LANDSAT 8 imagery from July 2016 (USGS 2016*a*) in ERDAS IMAGINE. The image was classified into woody, bare ground, herbaceous, impervious anthropogenic surface (e.g., paved roads, barns, houses), and water cover classes. We performed an accuracy assessment to achieve an accuracy of ≥85% (Congalton 1991). For weather data, we used monthly averages of daytime temperature, relative humidity, wind direction, and wind speed from the KFTN weather station (Iowa State University 2017) located ≤10.6 km away on the study site.

To create the final noise propagation models, we assigned ambient sound levels (dB) to each land cover class. Ambient sound levels were environmental sound levels recorded with no interference from vehicle, aircraft, or oil and gas activity for woody, bare ground, and herbaceous cover classes. Default ambient values for impervious anthropogenic surface and water classes were suggested from Harrison et al. (1980). After ambient sound levels were determined, a raster layer of modeled noise propagation was created for each individual point source per month. We then "summed" all raster layers for individual point sources in each month with the SPreAD-GIS tool to create a final raster layer of cumulative noise propagation across the study area per month (March through September 2015 and 2016).

The modeled sound environment in SPreAD-GIS must be validated with field measurements (Reed et al. 2012). Therefore, we tested the accuracy of the 250 and 1,000 Hz models using sound levels (dB) corresponding to each frequency level that we measured in the field (observed values) at each point source and at 200 and 400 m away from each point source in each of the 4 cardinal directions (n = 109). We tested for significant differences ($P < 0.05$) between means of observed values and modeled values. If the means were different, we regressed the observed values against the corresponding modeled values to correct the modeled raster layers in ArcMap 10.

Quail space use.—We conducted all analyses independently by quail species (bobwhite and scaled quail). We hypothesized that quail captured within the disturbed areas would use sites farther from the primary corridor road and there would be no trends in site in relation to the primary roads in undisturbed

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areas. We also hypothesized that quail would exhibit greater use of sites closer to ambient sound levels than those sites with sound above ambient levels. We used simple saddlepoint approximation (SSA) to calculate continuous selection functions (DeMaso et al. 2011) to examine quail site use in response to exploration disturbance metrics. We used SSA to algebraically approximate the probability density function (pdf), f(x), of 3 selected variables (proximity of quail locations to the primary corridor road in disturbed areas, proximity of quail locations to the primary road in undisturbed areas, and modeled sound levels at quail locations). We also approximated the pdf, g(x), for the same 3 variables with randomly generated points (we created an equal number of randomly generated points in the area available for quail to use; DeMaso et al. 2011). The continuous selection functions were calculated with $u(x) = f(x)/g(x)$. A selection function value (hereafter, selection ratio) $u(x) > 1$ represented site selection (use greater than availability), $u(x) < 1$ represented site avoidance (use less than availability), and $u(x) = 1$ represented random use of the site (Guthery 1997, Kopp et al. 1998, DeMaso et al. 2011).

We calculated home range and core area sizes to examine second-order (Johnson 1980) site fidelity for quail in which ≥20 locations were collected because site fidelity is likely to be correlated to home range and core area sizes. Home range sizes were calculated using a 95% fixed kernel density estimator with least squares cross validation to choose the smoothing parameter (Seaman and Powell 1996) in BIOTAS (Ecological Software Solutions LLC, Hegymagas, Hungary). Core area sizes were calculated using a 50% fixed kernel density estimator with least squares cross validation to choose the smoothing parameter. Locations where a quail was found on a nest, except the initial location when the nest was discovered, were not included in the analysis of home range and core area sizes.

We used multiple linear regression to test for a relationship between home range and core area size (dependent variables) and independent variables with PROC GLM (generalized linear model procedure) in SAS 9.4 (SAS Institute Inc., Cary, NC, USA). One scaled quail was removed from the regression analysis because its home range size (78 ha) was 204% larger than the mean of the other individuals', and was therefore considered an outlier. Independent variables included in the models were 1) quail age (hatch year or after hatch year), 2) the year in which the quail was monitored (2015 or 2016), 3) mean percent woody cover in a 10-m buffer zone around all locations for each quail, 4) mean sound level at 250 Hz of all locations per quail, 5) mean sound level at 1,000 Hz of all locations per quail, 6) mean distance to the nearest road of all locations per quail, and 7) mean weekly vehicle passage rate of the nearest road of all locations per quail.

Quail demographics.—We estimated indirect oil and gas disturbance effects on the following bobwhite and scaled quail demographics: seasonal adult survival, nest success, and abundance. We calculated seasonal 7-month (Mar–Sep) survival of radio-marked quail with the known-fate model in Program MARK (White and Burnham 1999). Quail that survived ≤14 days were censored from the analysis to account for capture-related mortalities (Cox et al. 2004). Independent variables included in models potentially influencing survival (individual covariates; Table 1) were 1) a linear time trend, 2) encounter occasion, 3) quail age, 4) sex of quail, 5) year the quail was monitored, 6) mean percent woody cover in a 10-m buffer zone around all locations for each quail, 7) mean sound level at 250 Hz of all locations for each quail, 8) mean sound level at 1,000 Hz of all locations for each quail, 9) mean distance to the nearest road of all locations for each quail, and 10) mean weekly vehicle passage rate of the nearest road of all locations for each quail. We used these covariates to select 19 *a priori* candidate models (Table 1); the same models were used for both species. These were ranked using Akaike's Information Criterion corrected for small sample size (AIC_c; Hurvich and Tsai 1989). We chose the model with the highest AIC_c as the top model, if the parameter estimates in the model had confidence intervals that did not include 0. Models within 2 ΔAIC_c of the top model, which differed from the top model

Table 1. *A priori* candidate models used to assess seasonal (7-month; Mar–Sep) survival probability (S) of northern bobwhite (*Colinus virginianus*) and scaled quail (*Callipepla squamata*) using known fate models in Program MARK, Dimmit County, Texas, USA, 2015–2016.

Model number	Model	Number of parameters
1	S (T[a])	2
2	S (t[b])	31
3	S (Age[c])	2
4	S (Sex[d])	2
5	S (Year[e])	2
6	S (Woody[f])	2
7	S (dB250[g])	2
8	S (dB1000[h])	2
9	S (Road Dist[i])	2
10	S (Traffic[j])	2
11	S (.[k])	1
12	S (T + Age)	3
13	S (T + Sex)	3
14	S (Age + Sex + Age × Sex)	4
15	S (dB250 + Age + dB250 × Age)	4
16	S (dB1000 + Age + dB1000 × Age)	4
17	S (Road Dist + Traffic)	3
18	S (Road Dist + Age + Road Dist × Age)	4
19	S (Traffic + Age + Traffic × Age)	4

[a] Linear trend across time
[b] Encounter occasion
[c] Quail age
[d] Quail sex
[e] Year quail was monitored
[f] Percent woody cover
[g] Sound level (dB) at 250 Hz
[h] Sound level (dB) at 1,000 Hz
[i] Distance to nearest road
[j] Vehicle passage rate
[k] Constant probability

by one parameter and had essentially the same values of the maximized log-likelihood, were not considered competitive with the top model (Burnham and Anderson 2002, Arnold 2010). We used the derived estimate from the top model for each species to obtain the seasonal survival estimate.

We calculated probability of nest success with the Nest Survival model in Program MARK. Independent variables (individual covariates; Table 2) were 1) a linear time trend, 2) encounter occasion, 3) quail age, 4) year the quail was monitored, 5) mean percent woody cover in a 10-m buffer zone around each nest location, 6) mean sound level at 250 Hz of each nest location, 7) mean sound level at 1,000 Hz of each nest location, 8) mean distance to the nearest road of each nest location, and 9) mean weekly vehicle passage rate of the nearest road to each nest location. We used these covariates to select 12 *a priori* candidate models (Table 2); the same models were used for each species. These were ranked using AIC_c (Hurvich and Tsai 1989). We chose the model with the highest AIC_c as the top model, if the parameter estimates in the model had confidence intervals that did not include 0. Models within 2 ΔAIC_c of the top model, which differed from the top model by one parameter and had essentially the same values of the maximized log-likelihood, were not considered competitive with the top model (Burnham and Anderson 2002, Arnold 2010). We raised daily nest survival rate for each species (either from the top model or model averaging) to the 23rd power (23 days is the average incubation period for both species) to obtain an estimate of nest success.

Table 2. *A priori* candidate models used to assess northern bobwhite (*Colinus virginianus*) and scaled quail (*Callipepla squamata*) probability of nest success (S) with nest survival models in Program MARK, Dimmit County, Texas, USA, 2015–2016.

Model number	Model	Number of parameters
1	S (T[a])	2
2	S (t[b])	13
3	S (Age[c])	2
4	S (Year[d])	2
5	S (Woody[e])	2
6	S (dB250[f])	2
7	S (dB1000[g])	2
8	S (Road Dist[h])	2
9	S (Traffic[i])	2
10	S (.[j])	1
11	S (T + Age)	3
12	S (Road Dist + Traffic)	3

[a] Linear trend across time
[b] Encounter occasion
[c] Quail age
[d] Year quail was monitored
[e] Percent woody cover
[f] Sound level (dB) at 250 Hz
[g] Sound level (dB) at 1,000 Hz
[h] Distance to nearest road
[i] Vehicle passage rate
[j] Constant probability

We estimated density (ha/quail) with the Density Using Telemetry model in Program MARK for all quail, comparing disturbed and undisturbed areas within the 2 ecological sites. All quail, regardless of species, were considered in density estimates because both species were found in all focal areas (though there was definite resource partitioning). We also estimated density of each species in its respective focal areas (bobwhite in deep sands sites and scaled quail within shallow ridge sites). Density Using Telemetry models require encounter history of banded individuals from trapping, and the proportion of telemetry locations within the study site (of banded and radio-marked individuals) after trapping has ended. Encounter histories from all banded quail in the first trapping interval of the season were used because they took place before the peak nesting season began. This interval was chosen to help meet the model assumption of a closed demographic population (no births or deaths). We used the subsequent 4 telemetry locations after the trapping of each banded and radio-marked quail to estimate density because 4 locations would have been obtained within 2 weeks. Because trap sites were not perfectly spaced within focal areas, traps were buffered to 316.2 m (the length of one side of a 10-ha, square, trapping grid cell) with the Buffer tool in ArcMap 10 to create 4 polygons in which to determine if a telemetry location was in or out of the study site. Mean density estimates (±SE) for each species were reported for disturbed and undisturbed sites across both study years.

RESULTS

Habitat Loss

Although direct habitat loss is known to occur with oil and gas development, temporary habitat loss due to indirect effects has been less clear. We measured indirect habitat loss by measuring vehicle passage rates and the sound environment. Mean vehicle passage rates (vehicles/week) along primary roads during 2015–2016 were 444.2 ± 136.8 ($\bar{x} \pm SE$) in the disturbed deep sands site, 762.6 ± 229.3 in the disturbed shallow ridge site, 51.5 ± 15.1 in the undisturbed deep sands site, and 11.7 ± 4.0 in the undisturbed shallow ridge site. Mean sound levels (dB) at 250 Hz along primary roads during 2015–2016 were 39.9 ± 2.3 ($\bar{x} \pm SE$) in the disturbed deep sands site, 42.4 ± 2.7 in the disturbed shallow ridge site, 27.5 ± 1.8 in the undisturbed deep sands site, and 23.3 ± 0.7 in the undisturbed shallow ridge site. Mean sound levels (dB) at 1,000 Hz along primary roads during 2015–2016 were 34.3 ± 1.8 in the disturbed deep sands site, 36.5 ± 3.6 in the disturbed shallow ridge site, 21.0 ± 1.6 in the undisturbed deep sands site, and 17.5 ± 1.6 in the undisturbed shallow ridge site.

There were 11 point sources of oil and gas noise within the study area in 2015. Two of these ceased operations in 2016, so there were 9 point sources of noise within the study area in 2016. The mean ambient sound levels (dB) for the woody, bare ground, and herbaceous classes were 27.8 ($n = 3$ recordings) and 22.4 (*n* = 3 recordings) for the 250 Hz and 1,000 Hz frequency levels, respectively. Although ambient sound level estimates were based on 3 field measurements from the study site, they were similar to ambient levels for shrubland reported by Harrison et al. (1980). Sound levels (dB) at the actual location of point sources for the 250 Hz frequency level averaged 71.1 for compressor stations (*n* = 4 recordings), 69.3 for diesel-powered generators (*n* = 1 recording), 64.4 for gas-powered generators (*n* = 4 recordings), and 55.0 for pump jack motors (*n* = 4 recordings). Furthermore, sound levels (dB) at the actual location of point sources for the 1,000 Hz frequency level averaged 57.8 for compressor stations (*n* = 4 recordings), 70.1 for diesel generators (*n* = 1 recording), 62.8 for gas generators (*n* = 4 recordings), and 55.7 for pump jack motors (*n* = 4 recordings). When modeling sound away from point sources, we found that the SPreAD-GIS software underestimated sound levels at both frequency levels when compared to observed values in the study area. We corrected the modeled values for each month of the study with a regression equation ($y = 13.50 + 1.16x$, $r^2 = 55.7$, $P \leq 0.001$ for 250 Hz; $y = 4.47 + 2.05x$, $r^2 = 53.7$, $P \leq 0.001$ for 1,000 Hz) specific to each frequency level**.**

Quail Space Use

We assessed bobwhite and scaled quail site use by analyzing selection in relation to 1) the primary roads in disturbed focal areas and the primary roads in undisturbed focal areas and 2) sound levels. We also estimated site fidelity of bobwhite and scaled quail through home range and core area sizes, as the size of these areas is likely to be correlated to fidelity of a given area. We banded 192 bobwhite and 197 scaled quail and radio-marked 68 bobwhite and 50 scaled quail during the study. In the disturbed area, bobwhite selected for areas 0–200 m from the primary road (Figure 1A) and selected for areas 0–425 m from primary roads in the undisturbed area (Figure 1B). Scaled quail selected for areas >425 m from the primary road in the disturbed area (Figure 1A) and selected for areas 0–300 m from primary roads in the undisturbed area (Figure 1B).

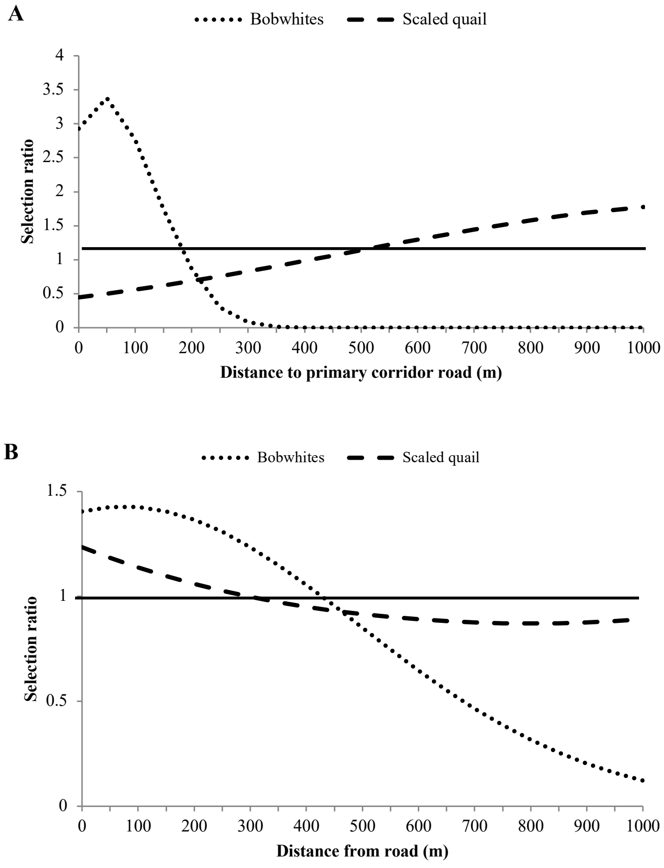

Fig. 1. Continuous selection functions for northern bobwhite (*Colinus virginianus*; dotted line) and scaled quail (*Callipepla squamata*; dashed line) distance A) to the primary road in the disturbed focal areas and B) to primary roads in the undisturbed focal areas, Dimmit County, Texas, USA, 2015–2016. Selection ratios >1 indicate selection and ratios <1 indicate avoidance.

In addition to measuring site use in relation to primary roads, we measured selection in relation to the sound environment. Bobwhite selected for areas with sound levels 0–1.6 dB above ambient levels and avoided areas >1.6 dB above ambient levels at the 250 Hz frequency level (Figure 2A). At the 1,000 Hz frequency level, bobwhite selected for areas with sound levels 0–2 dB above ambient levels and avoided areas >2 dB above ambient levels (Figure 2B). Scaled quail selected for areas with sound levels 0–2.2 dB above ambient levels and avoided areas >2.2 dB above ambient levels at the 250 Hz frequency level (Figure 2A). At the 1,000 Hz frequency level, scaled quail selected for areas with sound levels 0–3.2 dB above ambient levels and avoided areas >3.2 dB above ambient levels (Figure 2B).

Although there was no oil and gas surface development in the undisturbed sites, modeled sound levels were greater than ambient levels in some parts of the undisturbed sites due to noise propagation from the disturbed sites. Therefore, habitat loss from oil and gas noise was estimated in both the disturbed and undisturbed sites. Based on sound modeling from SPreAD-GIS and sound level avoidance by bobwhite at the 250 Hz frequency (Figure 2A), we estimated that 43.0% (238.4 ha) and 13.2% (70.1 ha) of habitat may have been temporarily lost in 2015 in the disturbed deep sands site and undisturbed deep sands site, respectively. Furthermore, in 2016, we estimated that 47.4% (262.4 ha) and 21.5% (114.2 ha) of the total area within these focal areas may have been temporarily lost in the disturbed deep sands site and undisturbed deep sands site, respectively, based on bobwhite sound level avoidance at the 250 Hz frequency. Based on sound level avoidance by bobwhite at the 1,000 Hz frequency (Figure 2B), we estimated that 23.9% (132.4 ha) and 14.7% (77.9 ha) of habitat may have been temporarily lost in 2015 in the disturbed deep sands site and undisturbed deep sands site, respectively. In 2016, we estimated that 11.5% (63.9 ha) and 14.2% (75.4 ha) of the total area within these focal areas may have been temporarily lost in the disturbed deep sands site and undisturbed deep sands site, respectively, based on bobwhite sound level avoidance at the 1,000 Hz frequency.

For scaled quail, we estimated that 26.9% (144.1 ha) and

13.5% (68.5 ha) of habitat may have been temporarily lost in 2015 in the disturbed shallow ridge site and the undisturbed shallow ridge site, respectively, based on scaled quail sound level avoidance at the 250 Hz frequency (Figure 2A). In 2016, 26.8% (143.1 ha) and 3.4% (17.4 ha) of habitat may have been temporarily lost in the disturbed shallow ridge site and undisturbed shallow ridge site, respectively, based on scaled quail sound level avoidance at the 250 Hz frequency. Based on scaled quail avoidance at the 1,000 Hz frequency (Figure 2B), we estimated that 12.6% (67.4 ha) and 10.9% (55.4 ha) of habitat may have been temporarily lost in 2015 in the disturbed shallow ridge site and the undisturbed shallow ridge site, respectively. In 2016, 16.6% (88.8 ha) and 9.9% (50 ha) of habitat may have been temporarily lost in the disturbed shallow ridge site and undisturbed shallow ridge site, respectively, based on scaled quail sound level avoidance at the 1,000 Hz frequency.

We used home range and core area size as estimators of site fidelity. Home range and core area size estimates ($\bar{x}$ ± SE) were pooled by quail species, between disturbed and undisturbed focal areas, and between years because of sample size. Bobwhite home range size averaged 19.7 ± 3.1 ha (2015–2016) and bobwhite core area size averaged 3.6 ± 0.8 ha (2015–2016). Scaled quail home range size averaged 27.7 ± 2.9 ha (2015–2016) and scaled quail core area size averaged 4.9 ± 0.6 ha (2015–2016). For bobwhite, mean home range size was not statistically different ($F_{1, 19} = 0.32$, $P = 0.580$) between disturbed (21.9 ± 5.0 ha, $n = 8$) and undisturbed areas (18.2 ± 4.1 ha, $n = 12$*;* Figure 3A). Mean core area size for bobwhite also was not different ($F_{1, 19} = 0.27$, $P = 0.610$) between disturbed (4.1 ± 1.3 ha, $n = 8$) and undisturbed areas (3.2 ± 1.1 ha, $n = 12$*;* Figure 3B). For scaled quail, mean home range size was not different ($F_{1, 25} = 0.62$, $P = 0.438$) between disturbed (29.9 ± 4.04 ha, $n = 14$) and undisturbed areas (25.2 ± 4.4 ha, $n = 12$; Figure 3A). Mean core area size for scaled quail also was not different ($F_{1, 25} = 0.73$, $P = 0.402$) between disturbed (5.4 ± 0.9 ha, $n = 14$) and undisturbed areas (4.3 ± 0.9 ha, $n = 12$; Figure 3B). Home range and core area sizes for both species, however, were smaller in undisturbed areas compared to disturbed focal areas.

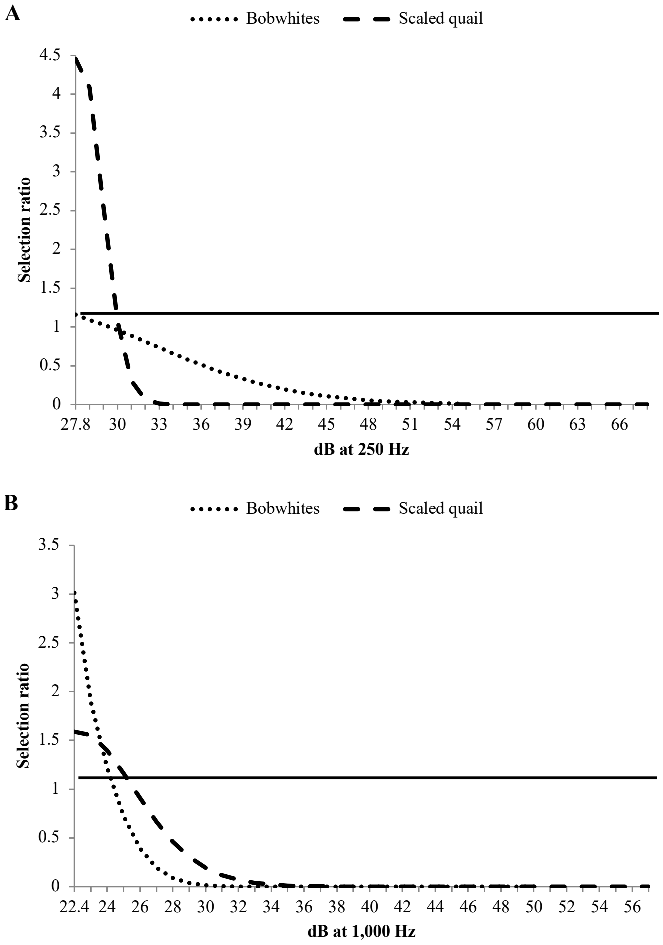

Fig. 2. Continuous selection functions for northern bobwhite (*Colinus virginianus*; dotted line) and scaled quail (*Callipepla squamata*; dashed line) at sound levels at the A) 250 Hz and B) 1,000 Hz frequency levels, Dimmit County, Texas, USA, 2015–2016. Selection ratios >1 indicate selection and ratios <1 indicate avoidance. The x-axes begin at ambient sound levels.

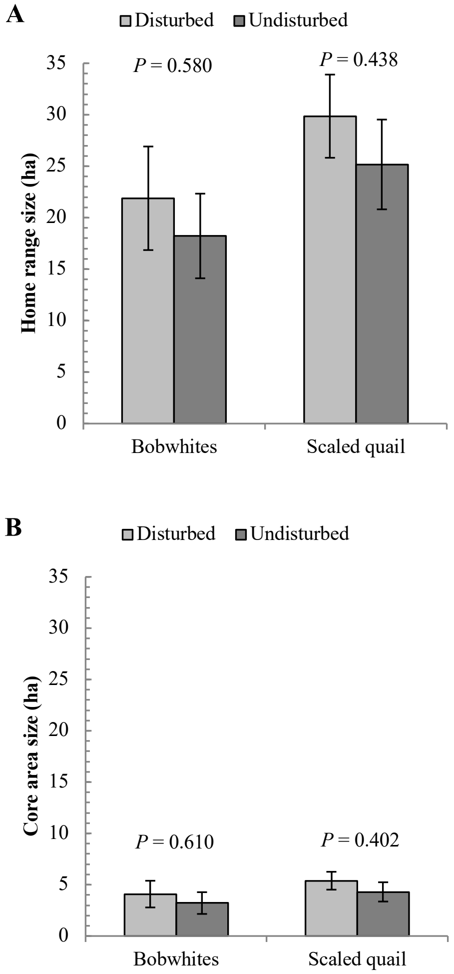

Fig. 3. Mean size (ha; $\bar{x}$ ± standard error) of A) home ranges and B) core areas of northern bobwhite (*Colinus virginianus*) and scaled quail (*Callipepla squamata*) in disturbed and undisturbed focal areas, Dimmit County, Texas, USA, 2015–2016.

We found no significant ($P > 0.359$ for bobwhite, $P > 0.127$ for scaled quail) effects (year, age, mean % woody cover, mean dB level at 1,000 Hz, mean dB level at 250 Hz, mean distance to the nearest road, and mean weekly vehicle passage rate) on home range and core area size for either species of quail ($n = 20$ for bobwhite, n = 25 for scaled quail).

Quail Demographics

Survival.—Bobwhite and scaled quail seasonal (7-month; Mar–Sep) survival averaged 11.9 ± 5.1% ($\bar{x}$ ± SE, $n = 44$) and 43.8 ± 9.0% ($\bar{x}$ ± SE, $n = 44$), respectively. According to AIC_c model rank, time since capture had the greatest influence on bobwhite survival probability. The model S(T) was competitive with the top model because it was within 2 ΔAIC_c of the top model and 95% confidence intervals around the parameter estimates did not include 0. The two models with the highest AIC_c had parameter estimates with 95% confidence intervals that included 0 (Table 3, Figure 4), so they were not considered the top model. According to AIC_c model rank, the null model best explained scaled quail survival (the model S[.] was the top model and models within 2 ΔAIC_c had parameter estimates with 95% confidence intervals that included 0; Table 4). We did not find any effects of oil and gas disturbance (sound levels at 250 Hz or 1,000 Hz, distance to the nearest road, and vehicle passage rates of the nearest road) on survival for either species of quail.

Nest success.—During the study, we located 26 bobwhite and 17 scaled quail nests. We monitored 1 quail nest (that was eventually unsuccessful) in 2016 that had 10 bobwhite eggs and 5 scaled quail eggs, and was incubated by a radio-marked bobwhite hen. We designated this nest as a bobwhite nest. Bobwhite and scaled quail nest success averaged 49.8 ± 12.4% ($\bar{x}$ ± SE, $n = 26$) and 38.1 ± 18.9% ($\bar{x}$ ± SE, $n = 17$), respectively. According to AIC_c model rank, bobwhite nest success was influenced the most by sound levels at 250 Hz (the model S[dB250] was the top model, 95% confidence intervals around the parameter estimates did not include 0, and there were no models within 2 ΔAIC_c of the top model; Table 5, Figure 5). According to AIC_c model rank, scaled quail nest success was influenced the most by study year (the model S[Year] was the top model, 95% confidence intervals around the parameter estimates did not include 0, and there were no models within 2 ΔAIC_c of the top model; Table 6).

Abundance.—Density of all quail (ha/quail; $\bar{x}$ ± SE) in both the deep sands site and shallow ridge site pooled across study years was not statistically different between disturbed and undisturbed areas as standard errors overlapped (Figure 6A). Density of just bobwhite in the deep sands site was not statistically different in disturbed (1.5 ± 0.5; $n = 40$) and undisturbed (1.5 ± 0.4; $n = 39$) areas as standard errors overlapped (Figure 6B). Density of just scaled quail in the shallow ridge site was 150% lower in the disturbed area (8.5 ± 3; $n = 7$) than in the undisturbed area (3.4 ± 1.1; $n = 16$; Figure 6B).

Table 3. Candidate models and their associated Akaike's Information Criterion (AIC_c) model rank, ΔAIC_c, number of parameters, and model weight used in seasonal (7-month; Mar–Sep) survival probability (S) analysis of northern bobwhite (*Colinus virginianus*), Dimmit County, Texas, USA, 2015–2016.

Model	AIC_c	ΔAIC_c	Number of parameters	AIC_c weight
S (T[a] + Sex[b])	217.5076	0.0000	3	0.2161
S (T + Age[c])	217.9236	0.4160	3	0.1755
S (T)	218.1207	0.6131	2	0.1591
S (.[d])	226.2356	8.7280	1	0.0028
S (Sex + Age + Sex × Age)	226.6847	9.1771	3	0.0022
S (Sex)	227.1913	9.6837	2	0.0017
S (Year[e])	227.3012	9.7936	2	0.0016
S (Age)	227.3819	9.8743	2	0.0016
S (dB250[f])	227.5340	10.0264	2	0.0014
S (Woody[g])	228.0885	10.5809	2	0.0011
S (Road Dist[h])	228.1296	10.6220	2	0.0011
S (Traffic[i])	228.2508	10.7432	2	0.0010
S (dB1000[j])	228.2509	10.7433	2	0.0010
S (dB250 + Age + dB250 × Age)	229.7362	12.2286	4	0.0005
S (Traffic + Road Dist)	230.1210	12.6134	3	0.0004
S (Road Dist + Age + Road Dist × Age)	230.4299	12.9223	4	0.0003
S (Traffic + Age + Traffic × Age)	230.9610	13.4534	4	0.0003
S (dB1000 + Age + dB1000 × Age)	231.3884	13.8808	4	0.0002
S (t[k])	245.7296	28.2220	31	0.0000

[a] Linear trend across time
[b] Encounter occasion
[c] Quail age
[d] Constant probability
[e] Year quail was monitored
[f] Sound level (dB) at 250 Hz
[g] Percent woody cover
[h] Distance to nearest road
[i] Vehicle passage rate
[j] Sound level (dB) at 1,000 Hz
[k] Encounter occasion

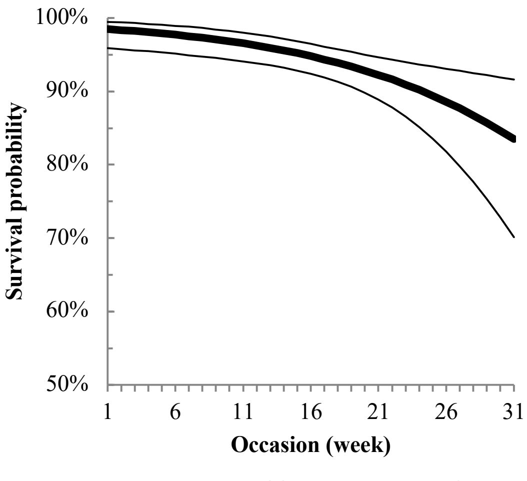

Fig. 4. Northern bobwhite (*Colinus virginianus*) seasonal (7-month; Mar–Sep) survival probability estimates (%; $\bar{x}$ ± standard error) across time since capture, Dimmit County, Texas, USA, 2015–2016.

Table 4. Candidate models and their associated Akaike's Information Criterion (AIC_c) model rank, ΔAIC_c, and number of parameters used in seasonal (7-month; Mar–Sep) survival probability (S) analysis of scaled quail (*Callipepla squamata*), Dimmit County, Texas, USA, 2015–2016.

Model	AIC_c	ΔAIC_c	Number of parameters	AIC_c weight
S (.[a])	150.0378	0.0000	1	0.1564
S (Road Dist[b])	150.8863	0.8485	2	0.1023
S (dB1000[c])	151.1821	1.1443	2	0.0883
S (Year[d])	151.5791	1.5413	2	0.0724
S (T[e])	151.6140	1.5762	2	0.0711
S (Age[f])	151.6673	1.6295	2	0.0692
S (Traffic[g])	151.7826	1.7448	2	0.0654
S (dB250[h])	151.9162	1.8784	2	0.0611
S (Woody[i])	151.9496	1.9118	2	0.0601
S (Sex[j])	152.0445	2.0067	2	0.0573
S (dB1000 + Age + dB1000 × Age)	152.7672	2.7294	4	0.0400
S (Road Dist + Traffic)	152.8058	2.7680	3	0.0392
S (T + Age)	153.1707	3.1329	3	0.0327
S (T + Sex)	153.6329	3.5951	3	0.0259
S (Road Dist + Age + Road Dist × Age)	153.6329	3.8500	4	0.0228
S (Traffic + Age + Traffic × Age)	153.8878	4.7584	4	0.0145
S (dB250 + Age + dB250 × Age)	154.7962	5.1599	4	0.0119
S (Age + Sex + Age × Sex)	155.6502	5.6124	4	0.0095
S (t[k])	189.7412	39.7034	31	0.0000

[a] Constant probability
[b] Distance to nearest road
[c] Sound level (dB) at 1,000 Hz
[d] Year quail was monitored
[e] Linear trend across time
[f] Quail age
[g] Vehicle passage rates
[h] Sound level (dB) at 250 Hz
[i] Percent woody cover
[j] Quail sex
[k] Encounter occasion

Table 5. Candidate models and their associated Akaike's Information Criterion (AIC_c) model rank, ΔAIC_c, and number of parameters used in probability of nest success (S) analysis of northern bobwhite (*Colinus virginianus*), Dimmit County, Texas, USA, 2015–2016.

Model	AIC_c	ΔAIC_c	Number of parameters	AIC_c weight
S (dB250[a])	66.9639	0.0000	2	0.3970
S (.[b])	69.5655	2.6016	1	0.1081
S (Road Dist[c])	70.0746	3.1107	2	0.0838
S (Year[d])	70.0790	3.1151	2	0.0836
S (dB1000[e])	70.0881	3.1242	2	0.0833
S (T[f])	70.8887	3.9248	2	0.0558
S (Woody[g])	70.9455	3.9816	2	0.0542
S (Age[h])	71.4454	4.4815	2	0.0422
S (Traffic[i])	71.5056	4.5417	2	0.0410
S (Road Dist + Traffic)	72.1076	5.1437	3	0.0303
S (T + Age)	72.8937	5.9298	3	0.0205
S (t[j])	82.4627	15.4988	13	0.0002

[a] Sound level (dB) at 250 Hz
[b] Constant probability
[c] Distance to nearest road
[d] Year quail was monitored
[e] Sound level (dB) at 1,000 Hz
[f] Linear trend across time
[g] Percent woody cover
[h] Quail age
[i] Vehicle passage rate
[a] Encounter occasion

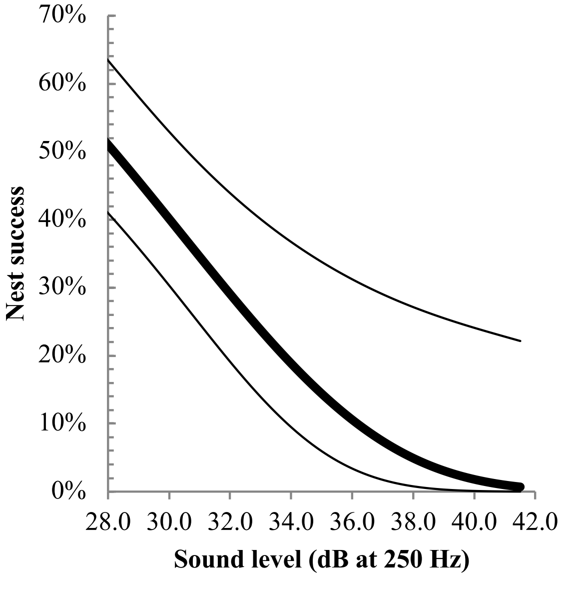

Fig. 5. Northern bobwhite (*Colinus virginianus*) nest success estimates ($\bar{x}$ ± standard error) across sound levels (dB) at the 250 Hz frequency level, Dimmit County, Texas, USA, 2015–2016.

Table 6. Candidate models and their associated Akaike's Information Criterion (AIC_c) model rank, ΔAIC_c, and number of parameters used in probability of nest success (S) analysis of scaled quail (*Callipepla squamata*), Dimmit County, Texas, USA, 2015–2016.

Model	AIC_c	ΔAIC_c	Number of parameters	AIC_c weight
S (Year[a])	43.1704	0.0000	2	0.2321
S (dB1000[b])	46.3150	3.1446	2	0.0482
S (.[c])	46.4215	3.2511	1	0.0457
S (Age[d])	46.4828	3.3124	2	0.0443
S (Road Dist[e])	46.9223	3.7519	2	0.0356
S (T[f])	46.9699	3.7995	2	0.0347
S (T + Age)	47.6830	4.5126	3	0.0243
S (dB250[g])	47.8073	4.6369	2	0.0228
S (Woody[h])	48.1627	4.9923	2	0.0191
S (Traffic[i])	48.4711	5.3007	2	0.0164
S (Road Dist + Traffic)	48.9945	5.8241	3	0.0126
S (t[j])	160.2032	117.0328	10	0.0000

[a] Year quail was monitored
[b] Sound level (dB) at 1,000 Hz
[c] Constant probability
[d] Quail age
[e] Distance to nearest road
[f] Linear trend across time
[g] Sound level (dB) at 250 Hz
[h] Percent woody cover
[i] Vehicle passage rate
[j] Encounter occasion

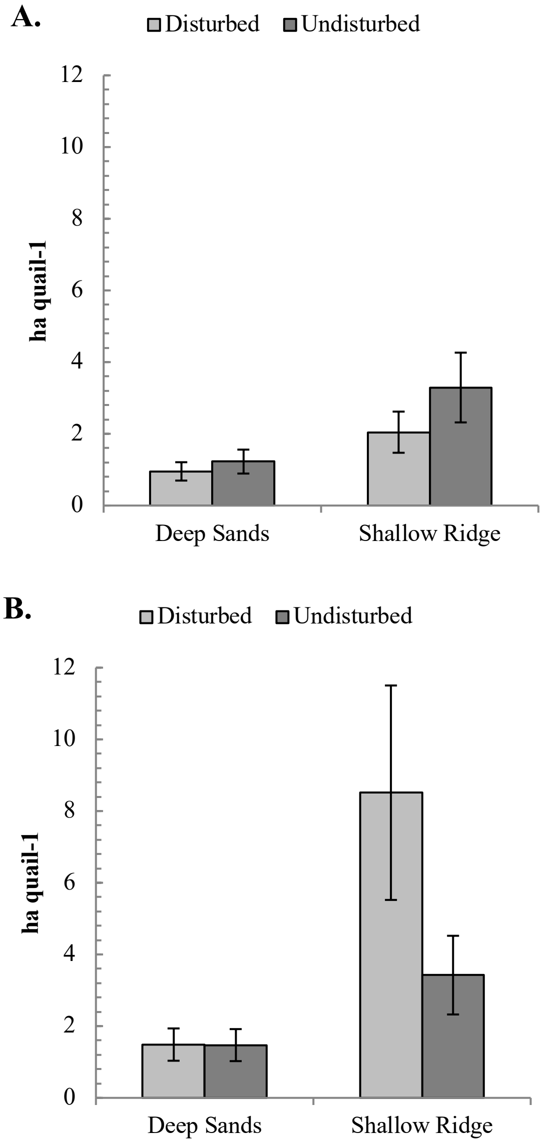

Fig. 6. Density (ha/quail; $\bar{x}$ ± standard error) pooled across study years of A) all quail (northern bobwhite [*Colinus virginianus*] and scaled quail [*Callipepla squamata*]) and B) just northern bobwhite in deep sands sites and just scaled quail in shallow ridge sites, Dimmit County, Texas, USA, 2015–2016.

DISCUSSION

We examined the effects of oil and gas activity on bobwhite and scaled quail space use and demographics. Site selection of quail was affected by disturbance along roads and among various sound levels. We found no evidence that sound levels or vehicle passages affected site fidelity (represented by home range and core area sizes) or quail survival. Bobwhite nest success decreased as sounds levels increased; we found no effects of disturbance on scaled quail nest success. Density of bobwhite was not different between treatments. Density of scaled quail was lower in the disturbed area than in the undisturbed area. We suggest that noise and traffic activity may cause indirect loss of habitat for quail (in addition to direct, physical loss of habitat caused by habitat destruction or habitat fragmentation due to development) by influencing their space use and nest success. This indirect loss potentially could be temporary if activity ceased.

Quail Space Use

Both bobwhite and scaled quail selected for sites close to primary roads in the undisturbed areas. However, site use varied by species in disturbed areas as bobwhite selected for areas near the primary road while scaled quail avoided areas near the primary road. There have been other studies that report differences in avian species responses to anthropogenic disturbance. For example, Sutter et al. (2016) found greater abundance of vesper sparrow (*Pooecetes gramineus*) nests near a pipeline right-of-way during construction and clean-up activity in Canada, while Sprague's pipit (*Anthus spragueii*) nests were evenly distributed. Additionally, Bogard and Davis (2014) observed that some species of grassland songbirds were less abundant near natural gas wells in Canada, whereas abundance of other avian species was higher near gas wells or not affected. One possible reason quail species responded differently in our study is that bobwhite may be more tolerant of human-generated disturbance. Furthermore, bobwhite may have preferred disturbed areas along the road because soils disturbed by pads, pipelines, and flowlines were reseeded with native herbaceous plants. This practice may have improved potentially limiting habitat attributes for bobwhite such as nesting sites (bunchgrasses) in an otherwise xeric plant community. Third, traffic rates were highly variable on primary roads in disturbed areas; we were not able to associate site selection of roads with traffic levels as traffic levels were long-term averages. Bobwhite could have avoided these roads during high-traffic periods but selected for them during low-traffic periods. Last, it is possible that different responses between disturbed and undisturbed treatments for bobwhite or between quail species in the disturbed treatments were due to differences in overall habitat structure and select vegetation metrics.

Both bobwhite and scaled quail appeared to avoid use of sites with sound levels from point sources greater than about 2–3 dB above estimated ambient sound levels. Chronic noise from generators, compressor stations, and pumpjack motors may have caused quail to avoid loud noise due to increased stress or an inability to communicate (Blickley et al. 2012, Francis and Barber 2013). Our findings of quail site avoidance of high-noise areas were similar to those of Francis et al. (2009) and Blickley et al. (2012). The earlier study found that 4 species of passerines avoided using nest sites near well pads with noisy compressors (Francis et al. 2009). The other study found that greater sage-grouse had reduced attendance at leks subjected to playback of recorded natural gas drilling and traffic noise (Blickley et al. 2012).

We expected quail to have greater home range and core area size in disturbed areas. Although mean home range and core area size were not statistically different between disturbed and undisturbed areas for either species, mean sizes were greater in disturbed areas for both species. Sample sizes could have been too low to detect a significant difference in home range and core area sizes. Additionally, we did not detect an effect of sound levels or vehicle passage rates on home range and core area sizes. Our findings were generally similar to those of Drolet et al. (2016), as they found no effect of drilling noise on the home range sizes of white-tailed deer (*Odocoileus virginianus*). They suggested that philopatry of their home range or tolerance of the noise kept deer from changing their home range size. Our findings were dissimilar to those of Webb et al. (2011), as they found home range and core area size for female elk (*Cervus canadensis*) were negatively influenced by the proportion of human development in their respective ranges. Although elk had high levels of site fidelity (represented by home range and core area overlap) in the presence of human development, site fidelity level decreased as development increased. In our study, because quail avoided using areas with high sound levels from point sources, home range and core area sizes were not likely to be affected. This is similar to an explanation by Hershey and Leege (1982), who suggested that animals may not abandon home ranges if they have undeveloped areas to use in other portions of their home range. Alternatively, disturbance from sound or vehicles (or both) may have caused localized movements (such as flushing from a threat), but these movements may not have impacted home range or core area size.

Quail Demographics

We expected survival of both quail species to decrease as sound levels and vehicle passage rates increased because vehicle passage rate could result in increased collisions and noise could obscure sounds of approaching predators (Francis et al. 2012) or result in movements that could increase predation risk. For example, mortality of adult Florida scrub-jays (*Aphelocoma coerulescens*) living along a 2-lane highway was higher than birds not living along roads, due to vehicle collisions (Mumme et al. 2000). Similarly, yearling greater sage-grouse reared in areas with natural gas infrastructure had lower annual survival than those in areas without it (Holloran et al. 2010). It is not necessarily surprising that there was no impact of vehicle passages on scaled quail as they avoided the area along the primary road in the disturbed area. We did find an unmarked bobwhite on the primary exploration road during our study that apparently had been killed in a vehicle collision. Both quail species appeared to avoid noisy areas and therefore were less likely to be impacted by noise.

We may not have found an effect of disturbance on survival because we used average vehicle passage rates of the nearest road at quail locations as covariates in our models for quail survival. These measurements may not have been fine-scale enough to detect a one-time event that would cause quail death, such as being struck by a vehicle or intermittent traffic noise obscuring the sound of a predator. It should be noted that bobwhite had lower survival probability than scaled quail, which avoided the primary road in the disturbed area. Furthermore, survival probability of bobwhite was lower than other estimates reported in the literature (Burger et al. 1995, Sisson et al. 2009, Downey et al. 2017).

We found that nest success of bobwhite decreased as sound levels from point sources increased (at the 250 Hz frequency level). Other researchers have found similar impacts of noise-related disturbance on birds. For instance, Strasser and Heath (2013) found that American kestrels (*Falco sparverius*) had higher stress hormones in areas with traffic disturbance and human development, which led to increased nest abandonment. We did not detect impacts of oil and gas disturbance on scaled quail nest success. Again, this result is not surprising, as similar to adult site use, scaled quail generally placed nests

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out of the range of sound above ambient levels at 250 Hz. As a comparison, bobwhite placed nests in areas ranging from ambient levels to 13.7 dB above ambient levels. The narrow range used by scaled quail when selecting nest sites suggests that scaled quail may be more sensitive to noise disturbance than bobwhite. Alternatively, bobwhite and scaled quail may have different ranges of hearing sensitivity.

We expected sound levels at 1,000 Hz also to impact nest success. However, both quail species selected nest sites with relatively low average sound levels at 1,000 Hz (ambient to 4.2 dB and 7.5 dB above ambient for bobwhite and scaled quail, respectively); therefore, nests were not subject to potential impacts of high sound levels. Similar to our findings, Pitman et al. (2005) reported that lesser prairie-chickens (*Tympanuchus pallidicinctus*) in Kansas, USA avoided areas near well heads and compressor stations when selecting nest sites, but they were unable to link apparent nest success to distance from these structures. In contrast to our findings for both quail species, gray flycatcher (*Empidonax wrightii*) nest success increased in areas with gas well compressor noise in New Mexico due to decreased nest predation by California scrub-jays (*Aphelocoma californica*; Francis et al. 2011). Similarly, sharp-tailed grouse (*Tympanuchus phasianellus*) nests had a higher chance of succeeding in an area of high-intensity energy development than in a low-intensity area in North Dakota, USA (Burr et al. 2017). Abundance of nest predators may be lower in noisier areas, which could actually increase nest success (Francis et al. 2012).

We expected quail density to be lower in disturbed areas than in undisturbed areas due to quail avoidance of disturbance. We found that density of all quail species was statistically similar between treatments. When examining density by individual quail species, we found that density of bobwhite was similar between disturbed and undisturbed areas. However, we found that density of scaled quail was lower in disturbed areas than in undisturbed areas. Although we did not observe a significant difference in densities for bobwhite between treatments, it can take time for demographics to impact population size when noise disturbance is new to an area (Francis and Barber 2013). Additionally, greater density is not necessarily an indicator of habitat quality (Van Horne 1983). Survival and reproduction of a population, along with density, better describe habitat quality, as high population size is not always an indicator of increased survival and reproduction (Francis and Barber 2013). Greater population sizes in the presence of disturbance could be a result of 1) chance or 2) immigration into an area representing an ecological trap. Oil and gas wells can remain in production as long as 20–30 years, which could be enough time for potential changes in behavior and physiology caused by anthropogenic disturbance to impact quail population size.

Currently, most hydrocarbon exploration takes place by giving exploration companies the greatest leeway in extracting oil and gas. This practice includes decisions made almost purely on a geological and economical basis, with little consideration of surface impacts, especially those unseen in regard to wildlife. Oil and gas could just as successfully be extracted after environmental impacts are considered. For landowners and managers, one key factor must be negotiated for landscapes where wildlife (including quail) and energy development are expected to coexist. Landowners and managers must negotiate a surface use agreement that takes into account both the needs of the exploration company(s) and surface use (wildlife). Informed by our study and partly by recommendations from prominent oil and gas attorneys, some key factors to include in order to mitigate impacts to quail are: 1) keeping all infrastructure in areas of lowest quality (areas not including habitat) and as concentrated as possible on a given parcel of land, 2) avoiding placement of oil and gas infrastructure in the proximity (<400 m) of scaled quail or their habitat, 3) mitigating, to the best extent possible, sources of indirect habitat loss from traffic and sound, and 4) negotiating the restoration of previously disturbed areas using the best management practices available (this step almost always includes care in handling topsoil and the reseeding of native ecotypic plant materials). To use contextual examples from our study site, oil and gas infrastructure could be placed in areas exhibiting monotypic stands of nonnative grass (e.g., buffelgrass [*Pennisetum ciliare*], or old-world bluestems [*Bothriochloa* spp.]), monotypic closed-canopy woodlands dominated by honey mesquite as a result of previous misguided brush management practices, or in areas with preexisting anthropogenic infrastructure (e.g., existing roadways or old exploration pads or flowlines). Exploration infrastructure must be kept out of large parcels of diverse natural rangeland if at all possible. In the case of the easement that we studied, nearly all oil and gas infrastructure was located in one area along the periphery of the ranches, and this disturbance was kept as concentrated as possible. If infrastructure were less concentrated, noise and traffic disturbance potentially could affect more habitat area and could have a greater impact on quail space use and demographics. Furthermore, all disturbed sites were restored to the best extent possible using practices such as the soil conservation strategies of double-ditching (preventing mixing of topsoil and subsoil when burying pipelines) and stockpiling (storing original topsoil on-site for future reclamation of well pads) in addition to reclamation efforts via pad reductions, soil restoration, and the subsequent seeding of ecotypic native plants. We attribute our results regarding bobwhite site selection to these practices, which very likely helped to minimize both direct and indirect habitat loss for quail.

MANAGEMENT IMPLICATIONS

Oil and gas production in the Eagle Ford Shale play has been increasing since 2008. New development directly decreases the amount of habitat available to quail. Furthermore, noise and vehicle disturbance from exploration and production activities have the potential to cause indirect habitat loss by influencing quail space use and nest success. Managers should avoid locating new development in areas of prime quail habitat if possible and should concentrate development along existing roads and corridors to combat direct and indirect habitat loss. Future research should focus on long-term direct and indirect impacts of oil and gas disturbance on quail at a landscape scale.

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