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A PRESENCE–ABSENCE SURVEY TO MONITOR MONTEZUMA QUAIL IN WESTERN TEXAS

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ABSTRACT

Developing an effective monitoring program for Montezuma quail (*Cyrtonyx montezumae*) is challenging because the technique must be practical for surveying vast, remote landscapes while accounting for the species' low detectability. We used call-back surveys within a presence–absence framework to estimate occupancy and detection probability of Montezuma quail and used this information in conjunction with habitat data to develop an estimated probability of occurrence map for the species. We established survey points at 4 sites in western Texas ($n = 20\text{--}30$ points/site) and conducted 5 repeat surveys/season during June–August 2007 and 2008. We documented abiotic conditions (temperature, time of day, survey number, and year) during surveys and quantified microhabitat (% bare ground, food-plant density, vegetation height, and visual obstruction) and macrohabitat (vegetation type, elevation, aspect, and slope) at survey points. We then used an information-theoretic approach to evaluate the influence of micro- and macro-habitat on detection probability and occupancy at a local and regional scale, respectively. At a microhabitat scale, the most parsimonious model ($\Delta AIC_c < 2$; Nagelkerke's $R^2 = 0.46$) suggested detection probability was influenced primarily by year ($\beta_{\text{year}} = 0.91$, 95% CI = 0.24–1.57), with occupancy being influenced primarily (but minimally) by year ($\beta_{\text{year}} = -59.7$, 95% CI = -179.0–59.6) and vegetation-height ($\beta_{\text{VH}} = 67.7$, 95% CI = -71.9–207.4). This model indicated that detection probability decreased from 2007 (0.40; 95% CI = 0.31–0.49) to 2008 (0.21; 95% CI = 0.14–0.32), as did occupancy (1.00 vs. 0.72, respectively), which corresponded to a transition from a relatively wet to dry year. At a macrohabitat scale, the most parsimonious model ($\Delta AIC_c < 2$; Nagelkerke's $R^2 = 0.20$) suggested occupancy was influenced by elevation ($\beta_{\text{Elevation}} = 1.11 \pm 0.56$) and vegetation type ($\beta_{\text{Vegetation type 2}} = -3.17 \pm 1.26$; $\beta_{\text{Vegetation type 3}} = -1.20 \pm 1.18$), and we used these variables to construct a first-approximation, probability of occupancy map. Given our findings, presence–absence surveys may be a viable approach for monitoring Montezuma quail populations through time, and use of a probability of occupancy map can help with efficient allocation of survey points and effort. However, the viability of using a presence–absence approach to monitor Montezuma quail populations will depend on whether sampling effort can be increased sufficiently to obtain more precise estimates of occupancy. In addition, our probability of occupancy map should be regarded as a first approximation and further research should be conducted to refine the relationships.

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Key words: call-back surveys, *Cyrtonyx montezumae*, detection probability, Mearn's quail, occupancy modelling, predictive distribution map

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Montezuma quail (*Cyrtonyx montezumae*) is a species whose distribution occurs primarily in Mexico and reaches its northern limits in Arizona, New Mexico, and Texas. They inhabit perennial grasslands and oak woodlands and are one of the least known North American quail species because their secretive nature and cryptic plumage makes obtaining basic ecological information difficult (Brown 1989, Stromberg 2000, Hernández et al. 2006a, Harveson et al. 2007). This lack of ecological knowledge is problematic because the distribution and population size of Montezuma quail in Texas have declined over the past century, and the conservation status of the species is unknown despite it being a hunted species in the Southwest (Oberholser 1974, Gehlbach 1981, Harveson et al. 2007).

The practice of monitoring wildlife in order to manage their populations is a fundamental tenet of wildlife conservation and management (Leopold 1933). The cost of not having an effective monitoring program for species carries ecological, cultural, and political consequences (MacKenzie 2005). For example, although a general consensus exists that the geographic distribution of Montezuma quail has decreased and some local populations have become extirpated, no data exist on current densities, population trends, or contemporary distribution (Harveson et al. 2007), especially in Texas. Montezuma quail is a harvested species in Arizona and New Mexico but classified as a game bird but with no open season in Texas. In 2006, a proposal was presented in Texas to open a hunting season for the species but the proposition met considerable public resistance and eventually was withdrawn because of lack of supportive demographic data for the proposal.

Several challenges have impeded the development of an effective program for monitoring populations of Montezuma quail, such as their low detectability and occurrence on vast, remote landscapes. Traditional survey methods used for quail, such as whistling male counts, covey call counts, and roadside counts, do not work well with Montezuma quail because of their cryptic coloration, defense strategy of a tendency to crouch rather than flush, and infrequent calling (Harveson et al. 2007). Thus, researchers have attempted monitoring techniques such as “dig” counts, maps of foraging signs, line-drive techniques, radiotelemetry, and mark–recapture but have encountered limited success (Brown 1976, Bristow and Ockenfels 2000, Stromberg 2000, Robles et al. 2002, Hernández et al. 2006b, Harveson et al. 2007). However, recent theoretical advancements in monitoring techniques involving presence–absence data may provide a practical solution for reliably monitoring rare or elusive species over large scales (Thompson 2004, MacKenzie 2005). Geissler and Fuller (1987) proposed that data from repeated surveys could be used to estimate detection probabilities, and Azuma et al. (1990) demonstrated that repeated site visits could also be used to estimate occupancy while accounting for imperfect detection. The ability to obtain unbiased occupancy estimates has implications from a monitoring perspective because occupancy can be used as an index of population size, particularly for cryptic or low-density species, and

occupancy estimation permits proper characterization of habitat models and resource selection functions (Vojta 2005, MacKenzie et al. 2006).

Call-back surveys have been used to monitor secretive bird species that are inconspicuous, inhabit dense cover, and/or are difficult to visually or aurally detect (Legare et al. 1999, Lor and Malecki 2002, Allen et al. 2004, and Conway and Gibbs 2005). Call-back surveys increase detection rates, decrease the proportion of survey points with no detections, and decrease coefficients of variation of population estimates beyond those of passive surveys (Allen et al. 2004, Conway and Gibbs 2005). For example, call-back surveys increased detection rates of 5 species of secretive marsh birds by factors of 2.4–7.0 over passive surveys (Allen et al. 2004). Thus, a monitoring program that used call-back surveys within an occupancy framework may provide a solution for monitoring Montezuma quail.

The purpose of our research was to evaluate a presence–absence approach using call-back surveys as a potential monitoring technique for Montezuma quail in western Texas. Our objectives were to 1) estimate occupancy rate and detection probability of Montezuma quail using call-back surveys, and 2) explore the development of a predictive distribution map for Montezuma quail in western Texas based on probability of occupancy as a function of habitat characteristics.

STUDY AREA

Our study was conducted on 4 study areas in western Texas: 1) Elephant Mountain Wildlife Management Area (Elephant Mountain WMA; Brewster County), 2) Davis Mountain Preserve of The Nature Conservancy (Davis MP; Fort Davis County), 3) a survey road route we called the Uvalde route (UVR; Uvalde, Real, Edwards, and Val Verde counties), and 4) a second survey road route we called the Del Rio route (DRR; Val Verde, Terrell, Pecos, and Brewster counties). The Elephant Mountain WMA and Davis MP were located within the Trans-Pecos Mountains and Basins ecoregion, whereas the Uvalde route was located within the Edwards Plateau ecoregion (Gould 1975). The Del Rio route was located in the transition zone between the Edwards Plateau and Trans-Pecos Mountains and Basins ecoregions.

Elephant Mountain Wildlife Management Area (Elephant Mountain WMA) is a 9,300-ha property of Texas Parks and Wildlife Department that was located approximately 40 km south of Alpine, Brewster County, Texas, USA (Hughes 1993, Hernández et al. 2006b). Elephant Mountain WMA has an elevation of 1,900 m and rises about 609 m above the surrounding lowlands (Hughes 1993). Mean annual precipitation ranged from 38 to 51 cm, with most of the precipitation occurring as summer monsoon rains during July–August. Soils varied in texture, and were developed from outwash materials from the surrounding mountains (Correll and Johnston 1979). The top of the mountain consists of an undulating plain that dips eastward and was dominated by desert grassland vegetation. The mesa drops off sharply along

steep slopes, cliffs, and ledges to the surrounding lowlands. Vegetation on Elephant Mountain proper consisted of grasslands dominated by native grasses including sideoats grama (*Bouteloua curtipendula*), black grama (*B. eriopoda*), tobosa grass (*Pleuraphis mutica*), and bristlegrass (*Setaria* spp.). Woody vegetation was characterized by sparse patches of small shrubs including oak (*Quercus* spp.), mountain laurel (*Sophora secundiflora*), and fragrant sumac (*Rhus aromatica*) that were mostly associated with steep slopes, ravines, and the edges of exposed bedrock and talus (Hernández et al. 2006b).

The Davis Mountain Preserve (Davis MP) is an 11,500-ha nature preserve owned by The Nature Conservancy and located in Jeff Davis County, Texas (The Nature Conservancy 2006). The Davis MP is located approximately 40 km north of Fort Davis in the central region of the Davis Mountains. The Davis Mountains, along with the Guadalupe and Chisos mountains, form the “sky islands” of the Trans-Pecos Mountains and Basins ecoregion (Warshall 1995, DeBano and Ffolliott 2005). The Davis Mountains Preserve contains Mount Livermore, the second tallest peak in Texas at 2,225 m. Annual precipitation ranged from 28 to 57 cm, occurring mainly during the monsoon season (Jun–Sep). Soils were drained, hilly to steep, loamy, shallow to deep, and noncalcareous (Soil Conservation Service 1977). Dominant vegetation types were perennial grasslands, evergreen oak, oak–conifer woodlands, and oak–conifer forests. The Davis MP consists of a continuous extensive habitat for Montezuma quail; whereas, Elephant Mountain WMA is a small island habitat on top of Elephant Mountain proper. Perennial flowing drainages were common with alluvial soils and mountainous peaks that ranged in elevation from 1,500 to 2,200 m (King 2003). The Davis MP has not been grazed by livestock since its purchase in the early 1990s, but is grazed by native herbivores including elk (*Cervus elaphus*), white-tailed deer (*Odocoileus virginianus*), and mule deer (*O. hemionus*). The Davis MP has reintroduced fire to the Davis Mountains ecosystem to reduce heavy fuel loads and catastrophic wildfire threats and to mimic natural ecosystem processes (The Nature Conservancy 2006).

The Uvalde route (UVR) was a road route that included the following counties: Uvalde, Real, Edwards, and Val Verde. The UVR began outside of Leaky, Texas, on Ranch Road 337 and ran due west to Campwood, Texas. It continued north along Ranch Road 55 to Rocksprings, Texas, where it joined Ranch Road 337 to Carta Valley, Texas. Upon reaching Highway 227, it continued due south on Highway 227 until reaching Del Rio, Texas. The area surveyed included counties that are known for sheep–goat–cattle operations (Albers and Gehlbach 1990). The Edwards Plateau ecoregion was an uplifted and elevated region originally formed from marine deposits of sandstone, limestone, shales, and dolomites 100 million years ago during the Cretaceous Period when this region was covered by an ocean (Texas Parks and Wildlife Department 2007a). The Edward Plateau was composed primarily of grassland savanna with shrubs and low trees along rocky slopes and

drainages (Correll and Johnston 1970, Stanford 1976, Weniger 1988, Hatch et al. 1990, Baccus and Eitniear 2007). Before European settlement, recurrent fires suppressed woody plants and maintained the open, grassy nature of the landscape on relatively level ground but not on steeper slopes and canyon walls (Weniger 1988, Baccus and Eitniear 2007). However, European settlement resulted in livestock overgrazing and the depletion of grasses and their replacement by less desirable woody shrubs (Schmidly 2002). Many of the plants found in the Edwards Plateau included oaks (*Quercus* spp.), ashe and redberry juniper (*Juniperus* spp.), mesquite (*Prosopis* spp.), lotebush (*Ziziphus obtusifolia*), yucca (*Yucca* spp.), pricklypear (*Opuntia* spp.), persimmon (*Diospyros* spp.), hackberry (*Celtis* spp.), catclaw (*Acacia* spp.), pricklyash (*Zanthoxylum* spp.), and sumac species (*Rhus* spp.) that contributed to habitat for many wildlife species as food and cover (Texas Parks and Wildlife Department 2007a).

The Del Rio Route (DRR) was a roadside route that surveyed the transition from the Edwards Plateau ecoregion into the Trans-Pecos Mountains and Basins ecoregion and included the following counties: Brewster, Pecos, Terrell, and Val Verde. The DRR consisted of a stretch of road on Highway 90 from Alpine, Texas to Del Rio, Texas. This transition zone consisted of low-elevation desert shrublands that transitioned into high-elevation desert grasslands and mountains. This unique combination contributed to tremendous vegetation diversity in the region that included ≥ 268 grass species and 447 species of woody plants (Texas Parks and Wildlife Department 2007c). However, the vegetation and wildlife has changed dramatically during the past 120 years as a result of drought, livestock grazing, and suppression of fire (Texas Parks and Wildlife Department 2007c). Prominent invaders of the low-elevation desert shrublands and grasslands included creosotebush (*Larrea tridentata*), tarbush (*Flourensia cernua*), whitethorn acacia (*Vachellia constricta*), mesquite, and cacti (*Opuntia* spp.). Prominent invaders of the higher elevation plains included catclaw (*Senegalia greggii*), sacahuista (*Nolina microcarpa*), cane cholla (*Cylindropuntia imbricata*), broom snake-weed (*Gutierrezia sarothrae*), and prickly pear species (Texas Parks and Wildlife Department 2007c). The DRR traversed 13 vegetation types including creosotebush–tarbush shrub, creosotebush–mesquite shrub, creosotebush–lechuguilla (*Agave lecheguilla*), or cenizo (*Leucophyllum frutescens*)–blackbrush (*Acacia rigidula*)–creosotebush (Texas Parks and Wildlife Department 2007c).

METHODS

Occupancy and Probability of Detection

Survey points.—We conducted call-back surveys during July–August 2007 and June–August 2008 only at Elephant Mountain WMA and Davis MP. In 2008, we added the UVR and DRR road routes to obtain a wider representation of vegetation communities within the ecoregion and species’ geographic distribution. We chose June–August to conduct surveys because these months

represent the approximate occurrence of the monsoon rains in the Trans-Pecos Mountains and Basins ecoregion and corresponded to the period of peak calling by Montezuma quail (D. Holdermann, Texas Parks and Wildlife Department, unpublished report).

We selected survey points at Elephant Mountain WMA and Davis MP in 2007 by overlaying a $400 \times 400\text{-m}^2$ grid over a map of each respective study area using geographic information systems (GIS) and ArcGIS® 9.2. We chose a $400 \times 400\text{-m}^2$ grid based on Bishop (1964), who stated that the approximate radius of audibility of a male Montezuma quail buzz call was approximately 200 m. Each grid was given a numbered centroid, and we randomly selected 30 survey points using Microsoft Office Excel 2003® (Microsoft, Redmond, WA, USA). In 2008, we increased the grid size ($800 \times 800\text{-m}^2$) to minimize the probability of double-counting. This increase in grid size resulted in fewer points occurring within the original monitoring area. First year results indicated complete occupancy within our original monitoring area, so we placed the “extra” points in new, surrounding areas to include suboptimal habitat. We defined suboptimal habitat as vegetation communities where Montezuma could be found but were not the preferred community (i.e., oak woodland). The placement of these extra points was stratified by vegetation community within this suboptimal category. Such a change was designed to increase the range of occupancy and diversity of vegetation types surveyed and therefore provide better habitat data for modeling occupancy and detection probability. We were able to retain 14 of the original 30 points at Elephant Mountain WMA, resulting in 16 points being placed in suboptimal habitat still within Elephant Mountain WMA. At Davis MP, we were able to retain 10 of the original 30 survey points; the other 20 points had to be placed in areas outside of Davis MP. Eight of these new points were located on Highway 118 north between Alpine, Texas and Fort Davis, Texas. Three more points were located on Highway 17 due south of Fort Davis and the remaining 9 points were located on Highway 17 due north of Fort Davis. For DRR and UVR, we used the vegetation-types map of Texas Parks and Wildlife Department to select survey points along roads. We established 5 survey points/vegetation type on DRR ($n = 20$ survey points) and UVR ($n = 25$ survey points). We allocated survey points with the goal of sampling as many vegetation types as logistically possible.

Call-back surveys.—We used a playback recording of a male buzz call or combination of a male buzz call and a covey-assembly call to detect presence (S. Sorola, retired wildlife biologist, Texas Parks and Wildlife Department, personal communication). Call-back surveys consisted of playing the recording for 1.5 minutes with a 30-second pause to listen for a Montezuma quail response. If no calls were heard, we continued to play the call for 30 seconds more followed by a 30-second pause. We repeated this call-back protocol for 5 minutes. We recorded the number of individuals calling and total calls heard for each survey. We also recorded survey date, time of day, temperature, humidity, and wind speed during each survey. We measured temperature, humidity and wind speed using a

Kestrel 3000 wind meter (Nielsen-Kellerman Co., Boothwyn, PA, USA). We conducted repeat surveys at each point 5 times during each field season. Thus, annual survey effort for Elephant Mountain WMA and Davis MP was 150 surveys (30 sites \times 5 visits) each. Annual survey effort was 100 surveys (20 sites \times 5 visits) for DRR and 125 surveys (25 sites \times 5 visits) for UVR. The ability to detect Montezuma quail could vary throughout the day; therefore, we conducted call-back surveys at different times of the day during the repeated visits. We partitioned the daylight period into 2 categories: morning (0700–1100 hr) and evening (1600–2000 hr). We randomly chose points to be surveyed for a given time period with the stipulation that all survey points had to be surveyed before an individual point was sampled again.

Weather.—We obtained daily and monthly precipitation and temperature data for Elephant Mountain WMA and Davis MP during May–August 2007 and 2008 using PRISM (Parameter-elevation Relationships on Independent Slopes Model, Oregon State University; <http://www.prism.oregonstate.edu/>). We selected the center-most $4 \times 4\text{-km}$ PRISM grid cell that fell within the boundary of each site and used the interpolation option to allow values to be adjusted for surrounding cells. We did not obtain weather data for DRR and UVR because these routes were not contained within a delineated study area but rather distributed across ≈ 480 km of roads throughout the ecoregion. Thus, survey points were spaced too far apart for a meaningful regional, interpolation of weather.

Vegetation Sampling

Microhabitat.—We quantified 2 broad categories comprising microhabitat (i.e., structure and food resources) at survey points at Elephant Mountain WMA and Davis MP. We did not measure microhabitat at survey points comprising DRR and UVR because these points occurred along public county roads that were bordered by private property, and thus we had restricted access. Variables quantifying vegetation structure consisted of percent herbaceous coverage (percent litter, forb, grass, and bare ground), vegetation height, and visual obstruction that were measured using a Daubenmire frame (Bonham et al. 2004), Robel pole (Robel 1969), and vegetation profile board (Nudds 1977), respectively.

We established 4 30-m transects at each point radiating in the 4 cardinal directions. We measured vegetation structure at the 10-m, 20-m, and 30-m mark along each transect. For herbaceous coverage, we visually estimated percent litter, forb, grass, and bare ground using a Daubenmire frame (20 cm \times 50 cm). We obtained vegetation height readings using a Robel pole from a 4-m distance at 1-m height in each of the 4 cardinal directions (Robel 1969). In addition, we estimated visual obstruction for each of 4-dm strata (0–10, 10–20, 20–30, 30–40) using a profile board following the protocol used for vegetation height (4-m distance, 1-m height, 4 cardinal directions; Nudds 1977). We determined food-plant density using a $1 \times 1\text{-m}$ frame at 10-m, 20-m, and 30-m plots along each transect. We recorded the number of individual plants of *Allium* spp., *Oxalis* spp., and *Cyperus* spp., and calculated

food-plant density from these data (Hernández et al. 2006b).

Macrohabitat.—We measured macrohabitat variables such as aspect, elevation, slope, and vegetation type at survey points at all 4 sites. We determined aspect and elevation using ArcGIS[®] 9.2. Aspect was given a north, east, south, or west direction depending on the direction the mountain slope faced. Elevation (m) data were collected from ArcGIS[™] Digital Elevation Model at a 1-km resolution from the Universal Transverse Mercator projected coordinate WGS 1984 UTM ZONE 14. We determined slope (°) using a Suunto[®] KB-14 clinometer (Shreveport, LA, USA). For areas to which we did not have access (i.e., roadside survey points), we obtained slope using ArcGIS[™] 3D[™] analyst, which is a three-dimensional visualization, topographic analysis, and surface creation. We also classified each point into a habitat-type category based on the Vegetation Types of Texas map of Texas Parks and Wildlife Department (Texas Parks and Wildlife Department 2007b). The study area encompassed 13 vegetation types. We consolidated these 13 vegetation types into 3 habitat-category types (high, moderate, and low) in order to reduce the number of covariates used in habitat modeling. Categorization was based on our field experience and knowledge of these vegetation communities to serve as Montezuma quail habitat and the degree of similarity between the vegetation characteristics associated with a particular vegetation type and known characteristics of Montezuma quail habitat (Brown 1978, Harveson et al. 2007). Habitat-category high consisted of the following vegetation types: 1) gray oak (*Q. grisea*)–pinyon pine (*Pinus edulis*)–alligator juniper (*J. deppeana*) parks and woods, and 2) live oak (*Q. wislizeni*)–ashe juniper (*J. ashei*) parks. Habitat-category moderate consisted of the following vegetation types: 1) cenizo–blackbrush–creosote bush, 2) creosotebush–lechugilla shrub, 3) live oak–juniper woods, 4) live oak–mesquite–ashe juniper, 5) mesquite–juniper shrub, and 6) mesquite–juniper–live oak brush. Finally, habitat-category low consisted of the following vegetation types: 1) creosote–mesquite shrub, 2) creosote–tarbush shrub, 3) mesquite–blackbrush brush, 4) tobosa–black grama grassland, and 5) yucca–ocotillo (*Fouquieria splendens*) shrub.

Statistical Analysis

Calling phenology.—Montezuma quail calling is closely tied with precipitation, with calling generally peaking within a few days following rainfall and rapidly declining thereafter (Brown 1978, Harveson et al. 2007). In addition, high summer temperatures can have suppressive effects on calling. Thus, we calculated mean weekly calling rates (no. of birds calling per point per week) to correlate with mean weekly precipitation or mean maximum temperature. We defined weeks as follows: 1 (24 Jun–30 Jun), 2 (1 Jul–7 Jul), 3 (8 Jul–14 Jul), 4 (15 Jul–21 Jul), 5 (22 Jul–28 Jul), 6 (29 Jul–4 Aug), 7 (5 Aug–11 Aug), 8 (12 Aug–18 Aug), and 9 (19 Aug–25 Aug) for 2007 and 2008. We partitioned precipitation and temperature data into these same weekly periods. We conducted

a Pearson Correlation analysis in Program SAS between mean weekly calling rates (no. birds calling per point per week) and either mean weekly precipitation (mm) or mean maximum daily temperature (° C).

Occupancy and detection probability.—Prior to conducting any analysis in Program MARK (White and Burnham 1999), we conducted a Pearson Correlation Matrix in Program SAS on all explanatory variables (i.e., 13 microhabitat variables and 4 macrohabitat variables). For variable pairs that were highly correlated ($r \geq 0.60$), we kept the most biologically relevant (i.e., greatest relevance to the species from an ecological or management perspective) variable and eliminated the other from the data set. From this reduced set of explanatory variables, we then built a set of 29 *a priori* models with biological relevance to evaluate the influence of habitat structure, food resource, and year on occupancy and detection probability. Specifically, these models evaluated occupancy as a function of year, herbaceous cover, vegetation height, and food-plant density, and evaluated detection probability as a function of year, survey number, time of day, and vegetation height. In this analysis, we only used points for which we had data for both 2007 and 2008 (i.e., points sampled in both years; $n = 24$ points) because our objective was to document how occupancy fluctuated through time over a common area. We modeled occupancy and probability of detection simultaneously (P. Doherty, Colorado State University, personal communication); that is, we modeled a particular detection model with each possible occupancy model. We used Akaike's Information Criterion (AIC_c) to identify the best model ($\Delta AIC_c < 2$) and calculated a pseudo- R^2 statistic for each model to assess how much variation was explained (Nakagawa and Schielzeth 2013).

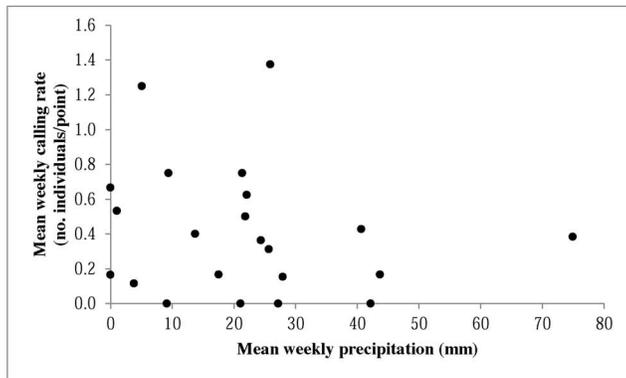
Predictive distribution map.—We developed 9 *a priori* models to evaluate the influence of macrohabitat on occupancy for development of a probability of occupancy map. These models evaluated occupancy as a function of aspect, slope, elevation, and habitat-category type. We used data from all 4 sites collected during July–August 2008 for this analysis: Elephant Mountain WMA ($n = 30$ survey points), Davis MP ($n = 30$ survey points), UVR ($n = 25$ survey points), and DRR ($n = 20$ survey points). We used Akaike's Information Criterion (AIC_c) to identify the best model and calculated a pseudo- R^2 statistics for each model to assess how much variation was explained (Nakagawa and Schielzeth 2013). We then used the best model to develop a predictive occupancy map using ArcGIS[®] 9.3 and ERDAS[®] Imagine Model Maker (Hexagon Geospatial, Madison, AL, USA).

RESULTS

Weather and Calling Behavior

General weather conditions were relatively drier and hotter at Elephant Mountain WMA compared with Davis MP, an expected observation given the higher elevation of Davis MP. Mean monthly rainfall was lower at Elephant Mountain WMA during May–July 2007 (range = 33–72 mm) and May–July 2008 (range = 19–57 mm) compared

A)



B)

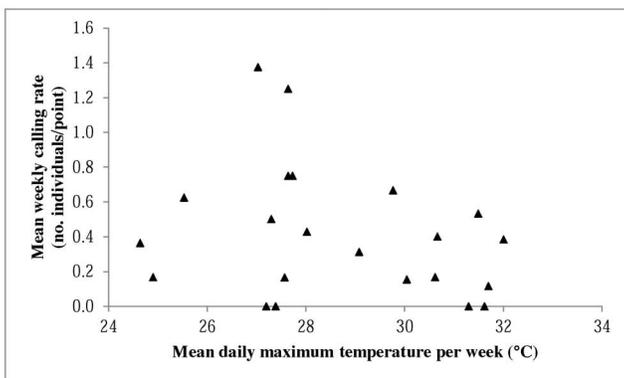


Fig. 1. Scatterplot of mean weekly calling rate (no. of individuals heard per point) of Montezuma quail and (A) mean weekly precipitation (mm), and (B) mean maximum daily temperature per week ($^{\circ}$ C), Brewster and Jeff Davis counties, Texas, USA, June–August 2007 and 2008.

with Davis MP (range = 64–98 mm and 6–149 mm, respectively). Mean maximum daily temperature was higher at Elephant Mountain WMA during May–July 2007 (range = 23–26 $^{\circ}$ C) and May–July 2008 (range = 25–30 $^{\circ}$ C) compared with Davis MP (range = 17–21 $^{\circ}$ C and 19–24 $^{\circ}$ C, respectively). Weather conditions tended to be drier and hotter during the second year. Mean monthly precipitation (May–Jul) decreased from 2007 to 2008 at both Elephant Mountain WMA (54 mm vs. 35 mm, respectively) and Davis MP (82 mm vs. 71 mm, respectively). Mean maximum daily temperature (May–Jul) increased from 2007 to 2008 at both Elephant Mountain WMA (25 $^{\circ}$ C vs. 27 $^{\circ}$ C, respectively) and Davis MP (19 $^{\circ}$ C vs. 21 $^{\circ}$ C, respectively).

The change to more xeric conditions during the second year of study was reflected in a corresponding decrease in calling rates. Mean weekly calling rates decreased by 50% from 2007 (0.4 ± 0.1 birds calling/point) to 2008 (0.2 ± 0.1 birds calling/point) at Elephant Mountain WMA. We also observed a 66% decrease in mean weekly calling rates from 2007 (0.6 ± 0.1 birds calling/point) to 2008 (0.2 ± 0.1 birds calling/point) at Davis MP. However, when we evaluated whether mean

weekly calling rate closely tracked mean weekly precipitation within a given year, we observed no correlation during 2007 ($r = -0.04$, $P = 0.88$) or 2008 ($r = 0.14$, $P = 0.71$; Fig. 1A). Similarly, mean weekly calling rate and mean maximum daily temperature were not correlated during 2007 ($r = -0.55$, $P = 0.07$) or 2008 ($r = -0.27$, $P = 0.46$), although the relationship approached significance during 2007 (Fig. 1B).

Occupancy and Probability of Detection

We evaluated 29 *a priori* microhabitat models using AIC_c to assess the influence of 1) habitat structure and food resources on occupancy, and 2) habitat structure and survey characteristics on detection probability. The most parsimonious model ($\Delta AIC_c < 2$; Nagelkerke's $R^2 = 0.46$) suggested occupancy was influenced primarily (but minimally) by year ($\beta_{Year} = -59.7$, 95% CI = -179.0–59.6) and vegetation-height ($\beta_{VH} = 67.7$, 95% CI = -71.9–207.4), whereas detection probability was influenced by year ($\beta_{Year} = 0.91$, 95% CI = 0.24–1.57; Table 1). Occupancy rates decreased from 2007 (1.00) to 2008 (0.72; 95% CI = 0.00–1.00), although the precision of occupancy estimates decreased considerably during the second year. In addition, vegetation height positively influence probability of occupancy, with a greater threshold value for vegetation height required for occupancy during 2008 (Fig. 2). Detection probability decreased from 2007 (0.40; 95% CI = 0.31–0.49) to 2008 (0.21; 95% CI = 0.14–0.32).

Predictive Distribution Map

We evaluated 9 *a priori* macrohabitat models using AIC_c to develop a predictive map of occupancy. These models evaluated occupancy as a function of aspect, slope, elevation, and habitat-category type. The most parsimonious model ($\Delta AIC_c < 2$; Nagelkerke's $R^2 = 0.20$) suggested occupancy was positively influenced by elevation ($\beta_{Elevation} = 1.11$, 95% CI = 0.0 ± 2.23) and habitat-category type (Table 1). Increasing elevation increased the probability of occupancy within all habitat-category types (Fig. 3). We used this model to construct a probability of occupancy map to include areas that were adjacent to the historical or known Montezuma quail distributions (Fig. 4). The map generally coincided with our field knowledge of Montezuma quail distribution but there were a few counties where the probability of occupancy appeared relatively higher (Maverick and Zavala) or lower (northern Edwards) than field knowledge indicated.

DISCUSSION

We documented that calling activity, occupancy, and probability of detection of Montezuma quail decreased as weather conditions changed from wet (2007) to dry (2008). We also documented that occupancy was influenced by vegetation height and year at a local level and elevation and habitat-category at a regional scale. Below we discuss the ecological relevance of these

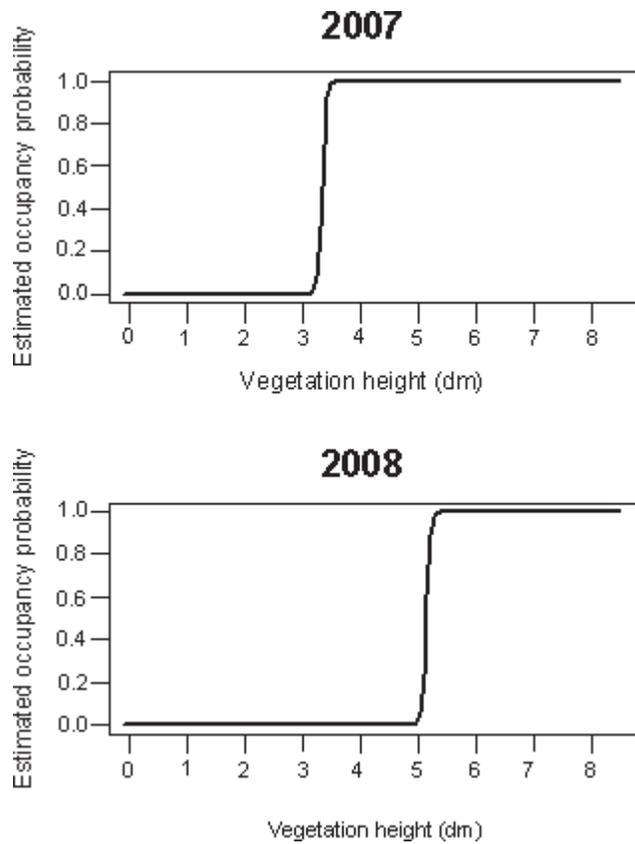


Fig. 2. Predicted probability of occupancy of Montezuma quail as a function of vegetation height (dm), Brewster and Jeff Davis counties, Texas, USA, June–August 2007 and 2008.

findings and how they may be used to develop a monitoring technique for Montezuma quail.

Weather and Calling Behavior

We observed that a transition to more xeric conditions during our study negatively impacted calling behavior of Montezuma quail. Environmental conditions became hotter and drier from 2007 to 2008 and calling

activity decreased correspondingly. These findings are consistent with past research documenting the general phenomenon of the suppressive effects of droughty conditions on quail behavior and populations (Heffelfinger et al. 1999, Guthery et al. 2002, Lusk et al. 2002). In contrast, although we observed a general relationship between dry conditions and calling behavior between years, we did not document a correlation between weekly calling rate and weekly precipitation or temperature within a given year. This finding is inconsistent with what has been reported for Montezuma quail and other quail species. Precipitation is known to be associated with reproductive behavior (e.g., calling, breeding, and nesting) of Montezuma quail (Stromberg 2000). For example, Brown (1979) stated a positive correlation existed between summer precipitation and Montezuma quail harvest. Stromberg (1990) reported that nesting occurred after rains in July and August that resulted in green vegetation. Moreover, Bishop and Hungerford (1965) noted that the herbaceous plants that provide the major winter food items for Montezuma quail, (e.g., *Allium* spp., *Oxalis* spp., and *Cyperus* spp.) are products of summer precipitation. The lack of an apparent relationship between weekly calling and weekly measures of weather in our study may have resulted from weather data being collected at a coarse resolution. The weather data we used for the analysis was obtained from PRISM, which predicts precipitation and temperature values using climate–elevation regression models and incorporates factors such as location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain (Daly et al. 2008). Thus, actual weather at our study sites and those predicted by PRISM may have differed, resulting in low correlation between weather and calling activity of Montezuma quail on a weekly temporal scale.

Occupancy and Probability of Detection

Occupancy and probability of detection also decreased from 2007 to 2008 with increasing xeric conditions. Occupancy appeared to be influenced primar-

Table 1. Top ranked models for occupancy and probability of detection of Montezuma quail based on micro- and macrohabitat characteristics, Brewster and Jeff Davis counties, Texas, USA, June–August, 2007 and 2008. Criterion corrected for sample size (AIC_c), number of model parameters (K), difference in AIC_c relative to best model (ΔAIC_c), model likelihood, model weight (w), and Nagelkerke’s pseudo- F^2 values are shown.

Variable model	K	AIC_c	ΔAIC_c	w	Pseudo F^2
Microhabitat					
$\Psi(\text{year} + \text{vegetation height}), p(\text{year})$	5	241.13	0.00	0.60	0.46
$\Psi(\text{year} + \text{grass cover}), p(\text{year} + \text{vegetation height})$	6	244.72	3.60	0.10	0.44
$\Psi(\text{year} + \text{vegetation height} + \text{food-plant density}), p(\text{year} + \text{survey})$	7	244.77	3.64	0.10	0.47
$\Psi(\text{year} + \text{grass cover}), p(\text{year})$	5	245.74	4.62	0.06	0.40
$\Psi(\text{year} + \text{grass cover}), p(\text{year} + \text{survey} + \text{vegetation height})$	7	246.38	5.25	0.04	0.45
Macrohabitat					
$\Psi(\text{elevation} + \text{habitat category}), p(.)$	5	221.32	0.00	0.41	0.20
$\Psi(\text{elevation} + \text{aspect} + \text{habitat category}), p(.)$	6	221.60	0.28	0.36	0.21
$\Psi(\text{elevation} + \text{slope} + \text{habitat category}), p(.)$	6	223.31	2.00	0.15	0.20
$\Psi(\text{habitat category}), p(.)$	4	226.72	5.40	0.03	0.13
$\Psi(\text{slope} + \text{habitat category}), p(.)$	5	227.01	5.70	0.02	0.15

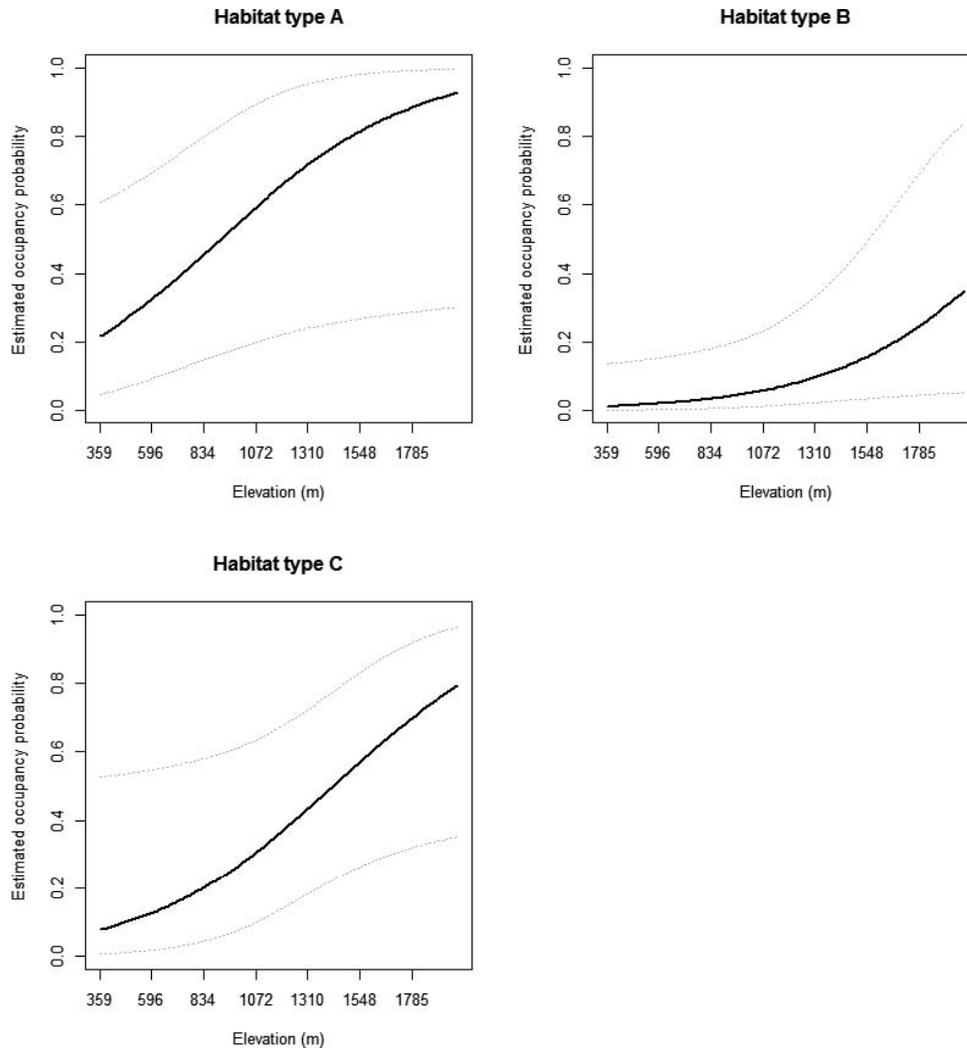


Fig. 3. Predicted probability of occupancy of Montezuma quail as a function of elevation and habitat-category type in western Texas based on presence–absence data collected in Brewster, Edwards, Jeff Davis, Pecos, Real, Terrell, Uvalde, and Val Verde counties, Texas, USA, June–August 2008.

ily (but minimally) by year and vegetation height, whereas detection probability appeared to be influenced by year. Our observation of a positive influence of vegetation height on occupancy is consistent with the ecology of the species. The importance of herbaceous cover for Montezuma quail is well-established (Leopold and McCabe 1957; Bishop 1964; Brown 1978, 1982). Bristow and Ockenfels (2004) noted that cover availability is an important factor affecting Montezuma quail distribution and density and that factors that reduce this cover such as livestock overgrazing detrimentally impact the species. Albers and Gehlbach (1990) also documented that large amounts of tallgrass cover predicted feeding habitat of Montezuma quail on both grazed and nongrazed areas and were most important during the summer months, the time of our study. Furthermore, Bristow and Ockenfels (2002, 2004) reported that vegetation richness, visual obstruction, and cover affected habitat selection during the brood season.

One general finding of ecological interest is that we documented relatively high occupancy at both Elephant

Mountain WMA and Davis MP, 2 study sites that vary considerably in vegetation structure. The vegetation community at Elephant Mountain proper consists primarily of a blue grama–dominated grassland with brush cover limited to the edges of the mesa along steep slopes and ravines. In contrast, the Davis MP is the quintessential habitat of Montezuma quail and consists of pinyon–juniper woodlands and forests (Sanders 2012). This finding of high occupancy at these 2 sites suggests that Montezuma quail may have wide habitat-suitability bounds given that the 2 study areas are markedly different in plant-species composition and structure (Sanders 2012). In general, Elephant Mountain WMA tended to have a less forb cover (6%), lower vegetation height (2 dm), but more grass cover (41%) compared with Davis MP (13%, 4 dm, and 33%, respectively; Sanders 2012). Bristow and Ockenfels (2004) reported that Montezuma quail prefer oak–woodland communities with $\geq 26\%$ tree canopy cover and 51–75% grass cover but can exist in areas with relatively few oak trees, although quail densities are often lower than typical in oak–woodland

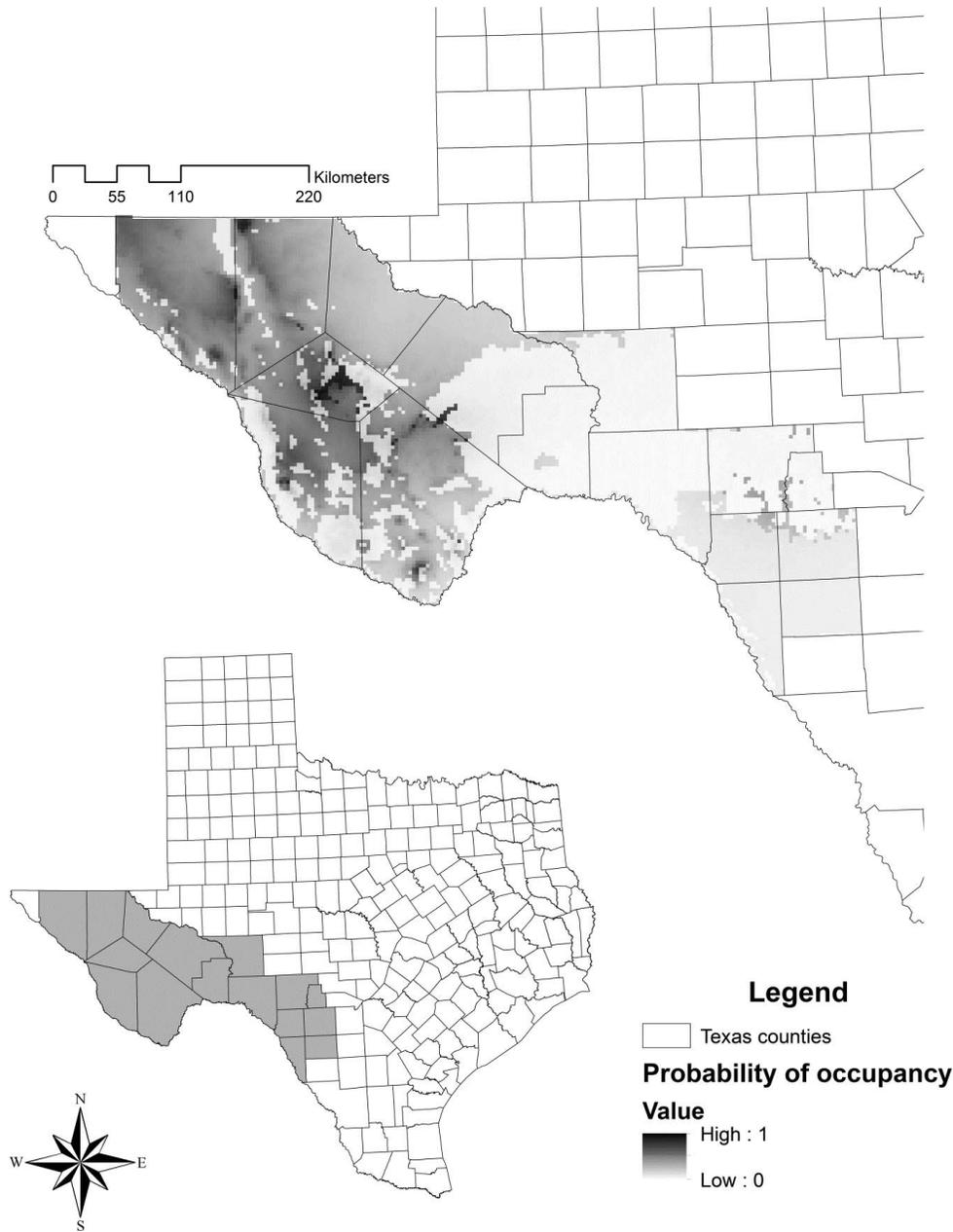


Fig. 4. Map of probability of occupancy of Montezuma quail for western Texas based on presence-absence data collected in Brewster, Edwards, Jeff Davis, Pecos, Real, Terrell, Uvalde, and Val Verde counties, Texas, USA, June-August 2008.

habitat. Thus, although occupancy of Montezuma quail was high at both Elephant Mountain WMA and Davis MP, density still may have differed between the 2 areas. Nevertheless, it appears that habitat structure near ground level may be more important than habitat structure of the overstory or general plant-species composition in determining habitat suitability for Montezuma quail. Hernández et al. (2006b) believed that general plant-species richness and diversity did not adequately characterize foraging habitat for Montezuma quail because of their specialized diets. On our study area, Sanders (2012) documented that Montezuma quail were found in areas with $\geq 6.5\%$ forb cover and ≈ 2.7 food plants/m². Collectively, these findings suggest that areas varying in

overstory habitat structure and general plant-species diversity may be capable of supporting Montezuma quail populations if sufficient grass cover and their key food-plant species (e.g., *Allium* spp., *Oxalis* spp., *Cyperus* spp.) are present.

Predictive Distribution Map

We documented that elevation and habitat-category type (high, moderate, or low) influenced probability of occupancy at a regional scale in our exploratory analysis. The elevation of survey points at Elephant Mountain WMA ranged from 1,596 to 1,896 m in 2007 and from 1,325 to 1,896 m in 2008. At Davis MP, the elevation of

survey points ranged from 1,770 to 2,012 m in 2007 and from 1,144 to 1,992 m in 2008. Elevation varied between years because survey points changed between field seasons with the expansion of our study area to include suboptimum habitat within these 2 sites. The importance of elevation for presence of Montezuma quail has been noted by various researchers. For example, Garza (2007) reported that elevations of Montezuma quail sightings at the Davis MP were most common from 1,738 to 1,838 m. Leopold and McCabe (1957) documented sightings at 1,554 to 2,286 m, while Stromberg (2000) documented nests at elevations from 1,520 to 1,920 m. Hernández et al. (2006b) found Montezuma quail at elevations of approximately 1,900 m. Naturally, it is not likely that elevation *per se* determines Montezuma quail presence but rather the influence of elevation as exerted on climate and vegetation communities that result in favorable habitat for the species.

Regarding the relative accuracy of the predictive distribution map, the map generally coincided with field knowledge and known occurrence of Montezuma quail, although some discrepancies were present. Areas of high probability of occupancy corresponded to areas near Elephant WMA, Davis MP, and Presidio, Texas. These regions of high probability of occupancy coincided closely with the current distribution map reported by Harveson et al. (2007). However, there were a few locations where the probability of occupancy appeared relatively higher (Maverick and Zavala counties) or lower (northern Edwards County) than current field knowledge indicated. The incongruence may have resulted from survey data for these areas being collected along roads and/or a low sampling intensity. Although roadside surveys occurred in remote areas with low-traffic roads, the data of roadside surveys may have differed from data collected within large interior tracts of habitat. Another possibility is that the sampling intensity of survey points within each of the 16 vegetation types (5 survey points/vegetation type) was not sufficient to adequately capture variation in occupancy. In addition, we had to consolidate these diverse vegetation types into a smaller subset (3 habitat-category types) for statistical analysis. Such pooling not only reduced the level of precision possible for a probability of occupancy map developed using presence-absence data from all 16 vegetation communities, but it also introduced nuisances associated with pooling. For example, the yucca-ocotillo shrub vegetation community generally is characterized by a hot, arid environment and thus is not considered typical Montezuma habitat. Thus, we categorized this vegetation type as habitat-category low. However, this vegetation type at Elephant Mountain WMA occurs at relatively high elevation and adjacent to the mountain proper where Montezuma quail habitat exists. At this site, Montezuma quail on the mountain proper often venture to the slopes and foothills and sometimes are found in the yucca-ocotillo shrub vegetation type. Thus, in general, the yucca-ocotillo shrub vegetation type would be classified as habitat-category low but is a habitat-category moderate at Elephant Mountain WMA because of its elevation and location adjacent to Montezuma habitat. These fine-level

considerations on a site by site basis would need to be considered and incorporated to increase the accuracy of a probability of occupancy map on region-wide scale, which would be a plausible but time-consuming task.

We emphasize that the habitat-occupancy relationships developed both at the micro- and macrohabitat scale represent an exploratory analysis and should be interpreted as such. These relationships are limited by low precision of occupancy rates and relatively low sampling intensity of vegetation characteristics. In addition, a mismatch of scale exists between microhabitat variables (collected within 30 m of survey points) and occupancy (estimated within 800 m of survey points). Thus, although the findings of these exploratory analyses closely align with the ecology of the species, these results should be viewed as preliminary and further research is necessary to refine the habitat-occupancy relationships.

Survey Potential

We observed that occupancy fluctuated through time in accordance with environmental conditions. Such fluctuations are similar to the population fluctuations observed for other quail species that are indexed via roadside counts conducted by state agencies (DeMaso et al. 2002). This suggests that is possible for general population trends of Montezuma quail to be tracked via occupancy estimation through time. However, although this certainly is encouraging, we also observed that the precision of occupancy estimates varied depending on environmental conditions. We observed relatively high precision of occupancy during a relatively mesic year (2007), but poor precision during a more xeric year (2008). This limitation of decreased precision during dry years would need to be addressed for development of meaningful population trends, a limitation that could be remediated by increasing survey effort. Using probability laws and an average probability of calling of 0.30, it was determined that surveys would have to be repeated ≥ 4 times in order to have a 0.90 overall probability of detecting a Montezuma quail given the species is present. However, whether such sampling effort is logistically possible for an agency depends on the size of area to be surveyed and the time, personnel, and resource budget of the agency.

MANAGEMENT IMPLICATIONS

This study represents a first attempt to evaluate a monitoring technique for Montezuma quail in western Texas using presence-absence data obtained with callback surveys. In general, this a presence-absence approach holds promise as a plausible and practical approach to monitor Montezuma quail in western Texas, particularly if a continued refinement of a probability of occupancy map occurs resulting from continued sampling of all vegetation communities. An improved probability of occupancy map would allow for efficient allocation of survey points and a more informed selection of a survey route.

Below we present a general survey protocol for Montezuma quail based on our findings. The protocol entails the following:

- *Establishment of survey points.* If monitoring is to occur within a specified, limited area and this area is reasonably accessible, then we recommend that an 800 × 800-m² grid be used to establish survey points because a grid of this size appears sufficient to minimize the probability of double counting given our experience. Alternatively, survey points may be established along a route with a spacing of ≥2 km and allocated in such a manner as to obtain a diverse representation of the different vegetation communities.
- *Conducting call-back surveys.* Call back surveys should be conducted during the breeding season, preferably to coincide during peak calling and the monsoon rains (e.g., Jun–Aug). Call-back surveys may be conducted either within the morning (0700–1100 hr) and/or evening hours (1500–1900 hr; Gonzalez 2012) and consist of playing the Montezuma quail call recording for approximately 1.5 minutes and then pausing to listen for a Montezuma quail response, repeating the process for 5 minutes. Each monitoring site will need to be visited ≥4 times during the field season.

Developing a practical monitoring approach for Montezuma quail will permit a better understanding of the species ecology. A presence–absence survey that provides occupancy estimates through time could be used to evaluate the influence of factors such as weather, habitat changes, land-use practices on the species. Furthermore, occupancy estimates would permit a better understanding of the species' conservation status and changes to its spatial distribution. Thus, a refinement of such a presence–absence survey through continued research is warranted for improved management and conservation of the species.

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