AN EVALUATION OF A PRESENCE-ABSENCE SURVEY TO MONITOR MONTEZUMA QUAIL IN WESTERN TEXAS

A Thesis

by

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ABSTRACT

An Evaluation of a Presence-Absence Survey to Monitor Montezuma Quail in Western Texas

(August 2012)

Cristela Gonzalez Sanders, B.S., Texas A&M University-Kingsville

Chairman of Advisory Committee: Dr. Fidel Hernández

Developing an effective monitoring program for Montezuma quail *(Cyrtonyx montezumae)* is a challenge because the technique must be practical for surveying vast landscapes and provide reliable population trends while accounting for its low detectability. I used a presence-absence approach to estimate occupancy (i.e., proportion of sites occupied) and detection probability of Montezuma quail at Elephant Mountain Wildlife Management Area (Elephant Mountain WMA; Brewster County) and the Davis Mountains Preserve (Davis MP; Jeff Davis County) in Texas, July–August 2007 and June–August 2008. In 2008, I also sampled a Del Rio Route (DRR; Val Verde, Terrell, Pecos, and Brewster Counties) and an Uvalde Route (UVR; Uvalde, Real, Edwards, and Val Verde Counties). Four microhabitat (% bare ground, food-plant density, vegetation height, and visual obstruction) and 4 macrohabitat variables (vegetation type, elevation, aspect, and slope) were quantified at each survey point for use in development of resource-selection functions. Microhabitat points could only be sampled at Elephant Mountain WMA and Davis MP because of access. Occupancy rates were high in 2007 (Elephant Mountain WMA [95% CI: 98–100%] and Davis MP [95% CI: 94–100%]). In

2008, occupancy rates for both Elephant Mountain WMA and Davis MP ranged between [95% CI: 37%–48%]. These results indicated that surveys for Montezuma quail have to be repeated multiple times (4–5) in order to ensure at least 90% detection at a point, given a Montezuma quail is present. The survey protocol that was used in this study can help us better understand Montezuma quail populations in west Texas by determining their distribution and allowing us to establish a conservation status for Montezuma quail. Once the distribution of Montezuma quail is determined conducting yearly surveys will allow us to monitor their population distribution.

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CHAPTER I

BACKGROUND ON MONTEZUMA QUAIL

Literature Review on Life History and Ecology

Movements.—Montezuma quail populations are found in suitable habitats in Arizona, New Mexico, and Texas south along Sierra Madre woodlands of Mexico to Oaxaca (Stromberg 2000). During the breeding season (Feb–Sep) pairs will generally remain well spaced over the habitat usually distanced 100–200 m apart (Stromberg 2000). During nesting season and winter (Aug–Jan), adults with young remain in coveys, often feeding, walking, and resting within a few square meters of each other (Stromberg 2000). The size of the covey's home range varies depending on the size of the covey and the number of coveys in an area but on average it is about 5.67–6.07 ha (Brown 1976). No seasonal migrations in elevations or long-distance movements have been documented with data from band recoveries or observations of individually marked birds (Stromberg 2000).

Food habits.—Montezuma quail forage primarily by digging for underground plant organs, such as rhizomes and tubers of flatsedges (*Cyperus* spp.) and corms of woodsorrels (*Oxalis* spp.) (Bristow and Ockenfels 2000). Food selection changes seasonally with roots and tubers eaten year-round. Acorns (*Quercus* spp.) may be taken during the dry season when available, and with monsoonal rains, insects become the dominant food source (Stromberg 2000). Insects consumed during the summer are grasshoppers (*Orthoptera*), ants (*Formicidae*), and beetles (*Coleoptera*) (Bishop1964, Bishop and Hungerford 1965, Brown 1978). During the fall, a variety of seeds such as panic grass (*Panicum* spp.), morning glory (*Ipomoea* spp.), nightshade (*Solanum* spp.),

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brodiaea (*Brodiaea* spp.), yucca (*Yucca* spp), and lupine (*Lupinus* spp.) are consumed, this reflects the abundance of food items available (Stromberg 2000). Montezuma quail do not need to drink free standing water (Stromberg 2000). Adults rarely drink water, but chicks drink more often (Stromberg 2000). Underground plant organs consumed by Montezuma quail contain high water content and probably represent an important source of water for this bird (Holdermann and Holdermann 1998).

Habitat.—Bristow and Ockenfels (2004) found that during the pairing season (Apr–Jun), Montezuma quail prefer oak (*Quercus* spp.) -woodland habitats that contain a minimum tree canopy of 26% and grass canopy of 51–75% cover at 20-cm height to provide optimum cover availability. Montezuma quail can exist in areas with relatively few oak trees, although quail densities are often lower than typical in oak-woodland habitat (Bristow and Ockenfels 2000). Montezuma quail are dependent upon perennial bunch grasses for escape, thermal cover, and for nest construction (Wallmo 1954, Leopold and McCabe 1957, Bishop 1964, Brown 1978). Livestock grazing and cover availability are considered important factors affecting Montezuma quail distribution and density (Bristow and Ockenfels 2004).

Population Estimation Techniques

Auditory counts.—Audio playback techniques have been successful in luring, capturing, and surveying a variety of birds (Johnson et al. 1981). Sorola (1986) stated that auditory playbacks may be suitable for presence-absence surveys for Montezuma quail. Females produce a musical descending call that is owl-like, or a quavering series of metallic whistles with an average of 9 separate notes slowly descending in pitch which is referred to as the flock assembly call (Fuentes 1903, Swarth 1909, Leopold and

McCabe 1957, Levy et al. 1966, Brown 1976). This call is much louder and lower-pitched during breeding season (Bishop 1964). Buzz calls are only produced by males; it is an “insect-like” descending whistle combined with a buzz that has an intangible quavering quality (Bishop 1964, Stromberg 2000). Buzz calls can be heard up to 200 m in quiet, calm conditions (Bishop 1964, Brown 1976). Bishop (1964) and Levy et al. (1966) found that females produce descending calls in early mornings and evenings. Males within 200–300 m respond with a buzz call and approach the calling female (Stromberg 2000). During monsoons of July–September, females and males call throughout the day (Levy et al. 1966, Brown 1976). Males return buzz calls when recordings are played; individual males reveal their location as they respond to playback of previously recorded buzz calls (Levy et al. 1966).

Line and point transects.—Due to the Montezuma quail’s cryptic plumage coloration and “freeze” behavior, it is almost impossible to conduct any type of line transects or point transects to survey this species. Males have bright, contrasting plumage; however, they are almost always invisible in their grassland habitats (Stromberg 2000). Individuals often are first detected as they leap straight up from the observer’s feet (Stromberg 2000). One can hike for days in suitable habitat and never observe these quail, unknowingly walking past many coveys (Stromberg 2000). Thus, traditional survey methods used for other quail species such as Gambel’s quail (*Callipepla gambelii*) and scaled quail (*C. squamata*) do not perform well when used on Montezuma quail (Bristow and Ockenfels 2000).

Trapping and bird dogs.—Some of the trapping techniques for Montezuma quail were compared by Hernández et al. (2006) in the Chihuahuan Desert. Funnel traps, modified funnel traps, and feeding stations were evaluated for capturing Montezuma quail. However, they were unable to capture Montezuma quail using funnel traps or modified funnel traps despite seeing Montezuma quail in the immediate region. Pre-baiting had no significant effect in trapability (Hernández et al. 2006). Stromberg (1990) on the other hand was able to trap Montezuma quail using funnel traps but reported a low capture success (0.008–0.012 birds/trap-day). Brown (1976) used dogs for surveying and capturing Montezuma quail. Other researchers have implemented modifications to Brown's technique for determining distribution and abundance of Montezuma quail (Holdermann 1992, Bristow and Ockenfels 2000). Survey methods, such as mark-recapture and using indirect scratch signs, also proved unsuccessful for Montezuma quail (Bristow and Ockenfels 2000).

Occupancy modeling.—The use of presence-absence information to monitor spatial and temporal changes in wildlife populations has a long history; however, until recently, its application has been limited (Vojta 2005). Presence-absence information has been difficult to interpret because animal detectability is not constant in time or space (Vojta 2005). Geissler and Fuller (1987) were the first to propose that detection probabilities could be estimated from repeated surveys at the same sites. Azuma et al. (1990) showed that trials across a randomized sample of sites could be used to estimate the proportion of sites occupied by a species while adjusting for imperfect detection. Zielinski and Stauffer (1996) incorporated home-range size into sampling unit distribution and used a simulation model to estimate the sample sizes needed to observe specified levels of decline in populations for fishers (*Martes pennanti*) and American martens (*M. americana*) (Vojta 2005). Nichols and Karanth (2002) recommended treating sites as individual animals. The detection-nondetection history became equivalent to capture-recapture data in the model. MacKenzie et al. (2002) made a major contribution to presence-absence information by demonstrating that detection histories could be incorporated directly into a maximum likelihood estimation model resulting in the simultaneous estimate of detection probabilities and occupancy rates.

Recent developments in presence-absence monitoring approaches may provide an effective method for monitoring Montezuma quail populations. In a monitoring context, using the presence-absence technique, the proportion of monitoring sites (i.e., habitat patches or quadrants) within a region where species is present can be used as an index for population size or species abundance. This is particularly true at large scales, for cryptic, low-density and/or territorial species (MacKenzie 2005). The ability to estimate changes in occupancy between two time periods has implications for exploring metapopulation dynamics (Vojta 2005). Rates of colonization and local extinction can now be estimated and relationships can be formally tested between colonization rates and isolation of landscape patches, and between extinction rates and patch sizes (Vojta 2005).

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CHAPTER II

AN EVALUATION OF PRESENCE-ABSENCE SURVEYS TO MONITOR MONTEZUMA QUAIL IN WESTERN TEXAS

INTRODUCTION

The secretive nature and cryptic plumage of Montezuma quail (*Cyrtonyx montezumae*) makes obtaining basic ecological information on this species difficult. Very little data currently exist on the ecology or population status of Montezuma quail in Texas (Hernández et al. 2006*a*, Harveson et al. 2007). This lack of knowledge is problematic because the range and population size of Montezuma quail have declined over the past century (Oberholser 1974, Gehlbach 1981).

Several challenges have impeded the development of an effective population monitoring program for Montezuma quail such as their occurrence on vast, inaccessible landscapes, relatively low densities, and low detectability. Researchers have attempted to develop monitoring techniques for the species but have had limited success (Brown 1976, Bristow and Ockenfels 2000, Robles et al. 2002, Hernández et al. 2006*b*). These have included call counts, dig counts, maps of foraging signs, line drive techniques, radio telemetry, and mark-recapture (Brown 1976, Bristow and Ockenfels 2000, Stromberg 2000, Robles et al. 2002, Harveson et al. 2006, Hernández et al. 2006*b*,).

Recent advancements in monitoring techniques involving the use and application of presence-absence information can provide a practical solution for reliably monitoring rare or elusive species over large scales (Thompson 2004, MacKenzie et al. 2005). Geissler and Fuller (1987) proposed that data from repeated surveys to the same sites could be used to estimate detection probabilities, and Azuma et al. (1990) demonstrated

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that repeat site visits could also be used to estimate occupancy (i.e., proportion of sites occupied by a species) while accounting for imperfect detection. The ability to obtain unbiased occupancy estimates has implications from a monitoring perspective because occupancy can be used as a surrogate for population size, particularly for cryptic or low-density species at large scales (MacKenzie 2005, Vojta 2005). In addition, occupancy estimation permits proper characterization of habitat models and resource selection functions (Vojta 2005, MacKenzie 2006).

Given recent theoretical developments of presence-absence surveys, the use of occupancy estimation for monitoring Montezuma quail populations' warrants evaluation. The purpose of my research was to use a presence-absence approach to estimate occupancy and detection probability of Montezuma quail in Texas. If the call-back surveys are conducted during June–August, then, they can be used as a tool to monitor Montezuma quail distributions. Specifically, the main objectives were to:

1. Estimate occupancy rate and detection probability of Montezuma quail using presence-absence information obtained via repeated, call-back surveys;
2. Evaluate relationships between calling rate of Montezuma quail with precipitation; and
3. Develop a distribution map based on resource-selection functions for Montezuma quail that describe the probability of occupancy as a function of habitat characteristics.

STUDY AREA

My study was conducted on 4 study areas: 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 I called the Uvalde route (UVR; Uvalde, Real, Edwards, and Val Verde counties), and 4) a second survey road route I called the Del Rio route (DRR; Val Verde, Terrell, Pecos, and Brewster counties).

Elephant Mountain Wildlife Management Area (Elephant Mountain WMA) is a 9,300 ha Texas Parks and Wildlife Department holding located approximately 40 km south of Alpine, Brewster County, Texas, USA (Hughes 1993, Hernández et al. 2006*b*) (Figure 1). Elephant Mountain WMA has an approximate elevation of 1,900 m and rises about 609 m above the surrounding lowlands (Hughes 1993). Mean annual precipitation ranges from 38–51 cm with most of the precipitation occurring during July–August. Soils vary in texture, and are 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 is dominated by desert grassland vegetation. The mesa drops off sharply along steep slopes, cliffs and ledges to the surrounding lowlands. Vegetation on Elephant Mountain WMA consists of alpine grasslands dominated by native grasses including sideoats grama (*Bouteloua curtinpendula*), black grama (*Bouteloua eriopoda*), tobosa grass (*Pleuraphis mutica*), and bristlegrass (*Setaria* spp.) (Figure 2). Woody vegetation is characterized by sparse patches of small shrubs including oak (*Quercus* spp.), mountain laurel (*Sophora secundiflora*), and fragrant

Figure 1. Elephant Mountain Wildlife Management Area (TX) terrain, 18 July 2008**.**

Figure 2. Alpine grasslands dominated by native grasses on plateau at Elephant Mountain Wildlife Management Area (TX), 15 July 2008.

sumac (*Rhus trilobata*) (note: these are mostly associated with steep slopes, ravines, and the edges of exposed bedrock and talus) (Hernández et al. 2006*b*).

The Davis Mountain Preserve (Davis MP) is an 11,500-ha privately owned nature preserve 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 ecoregion (Warshal 1995, DeBano and Ffolliott 2005). The Davis Mountains Preserve contains Mount Livermore, the second tallest peak in Texas at 2,225 m. Annual precipitation ranges from 28.2–56.9 cm occurring mainly during the monsoon season (Jun–Sep). Soils are drained, hilly to steep, loamy, shallow to deep, and non-calcareous (Soil Conservation Service 1977). Dominant vegetation types are perennial grasslands, evergreen oak, oak-conifer woodlands, and oak-conifer forests (Figure 3). The Davis MP is comprised of a continuous extensive habitat for Montezuma quail; whereas, Elephant Mountain WMA is a small island habitat. Perennial flowing drainages are common with alluvial soils and mountainous peaks that range in elevation from 1,500–2,200 m (King 2003). The Davis MP has not been grazed by livestock since its purchase in the early 1990s, but some herbivores include elk (*Cervus elaphus*) and deer (*Odocoileus* spp.). The Davis MP has reintroduced fire to the Davis Mountains ecosystem to reduce unnatural fuel loads and catastrophic wildfire threats and to mimic natural ecosystem processes (The Nature Conservancy 2006).

The Uvalde Route (UVR) included the following counties; Uvalde, Real, Edwards, and Val Verde. The UVR began outside of Leaky on Ranch Road 337 due

Figure 3. Woody and grassland vegetation at Davis Mountains Preserve (TX), 6 August 2007.

west to Campwood. It continued north along Ranch Road 55 to Rocksprings where it joins Ranch Road 337 to Carta Valley. Upon reaching Highway 227, it continued due south on Highway 227 until reaching Del Rio, Texas (Figure 4). The area surveyed included counties that are known as sheep-goat-cattle operations (Albers and Gehlbach 1990). The Edwards Plateau is 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 2007*a*). The Edward Plateau region was comprised primarily of grassland savanna with shrubs and low trees along rocky slopes and drainages (Correll and Johnston 1970; Stanford 1976; Weniger 1988; Hatch, Gandhi, and Brown 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). European settlement brought fences, cows, sheep, goats, and control of fire (Baccus and Eitniear 2007). Livestock continuously grazed in fenced pastures, disrupting the natural movement patterns of native grazing animals that allowed plants to rest and recover from grazing (Baccus and Eitniear 2007). When Bailey and Oberholser surveyed the plateau, most of the area had already been overgrazed by cattle, goats, and sheep, and most of the grasses had been depleted and replaced by less desirable woody shrubs (Schmidly 2002). Many of the plants found in the Edwards Plateau include oaks (*Quercus* spp.), ashe and redberry juniper (*Juniperus* spp.), mesquite (*Prosopis* spp.), lotebush (*Zizyphus obtusifolia*), yucca (*Yucca* spp.), pricklypear (*Opuntia* spp.), persimmon (*Diospyros* spp.), hackberry (*Celtis* spp.), catclaw (*Acacia* spp.), pricklyash

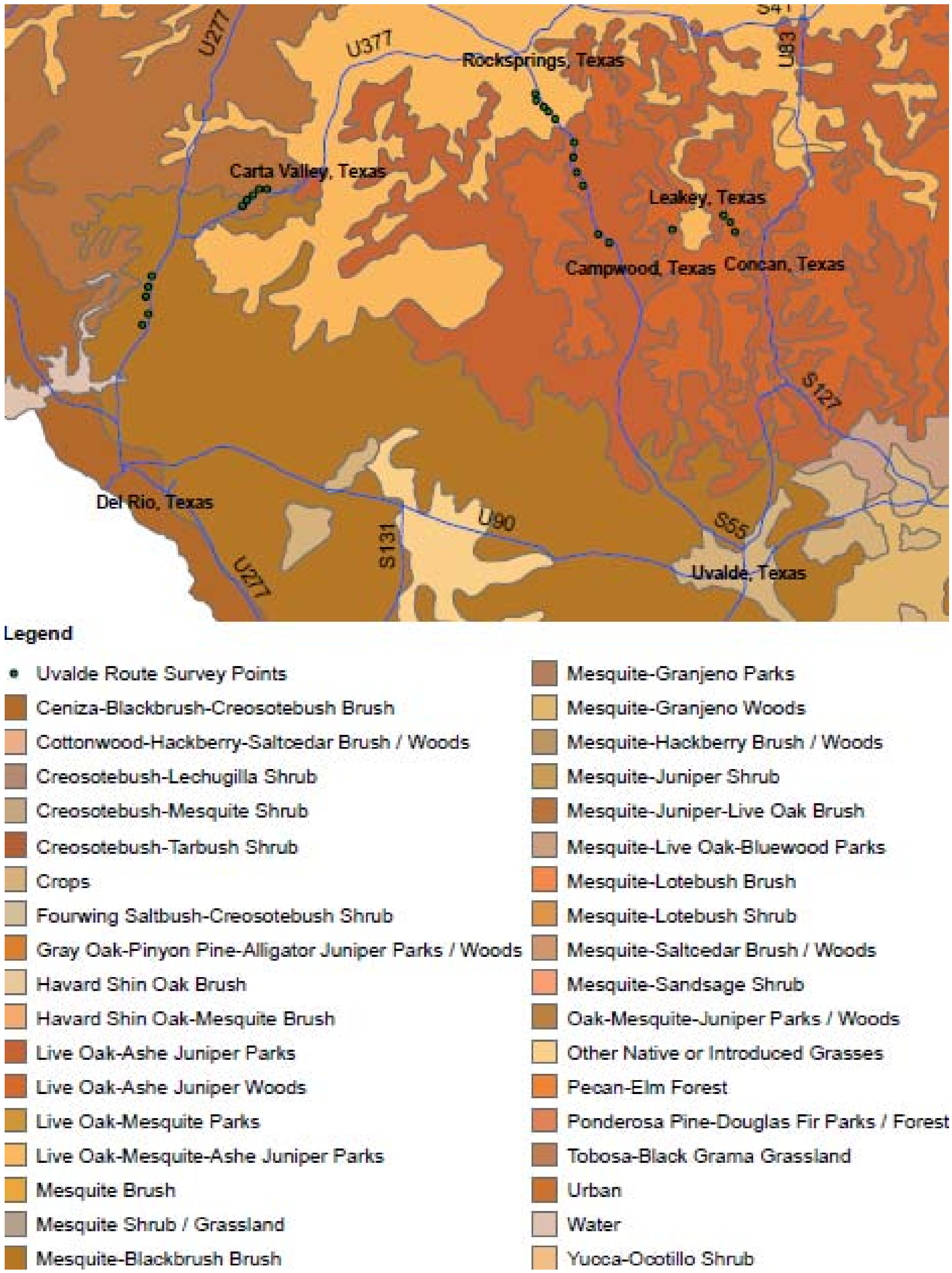


Figure 4. Uvalde Route (TX) (n = 25 survey points), where callback surveys were conducted during July–August 2008.

(Zanthoxylum spp.*)*, and sumac species *(Rhus* spp.*)*, that contribute to habitat for many wildlife species as food and cover (Texas Parks and Wildlife Department 2007*a*).

The Del Rio Route (DRR) is an important area that was surveyed because this route includes the transition from the Edwards Plateau into the Trans-Pecos ecoregion. The DRR consisted of a stretch of road on Highway 90 from Alpine (TX) to Del Rio (TX). The Trans-Pecos region is the only part of Texas where mountain and desert habitats are found, this unique combination contributes to the tremendous vegetation diversity in the region, which includes at least 268 grass species and 447 species of woody plants (Texas Parks and Wildlife Department 2007*c*). However, the vegetation and wildlife has changed more rapidly in composition, abundance, and distribution over the past 120 years than at any other time in recorded history, the major influences behind these dramatic changes were and continue to be livestock grazing and the suppression of fire combined with frequent drought (Texas Parks and Wildlife Department 2007*c*). Prominent invaders of the low elevation desert grasslands include creosotebush *(Larrea tridentata),* tarbush (*Flourensia cernua*), whitethorn acacia *(Acacia constricta)*, mesquite *(Prosopis* spp.*)*, and cacti *(Opuntia* spp.*)*. Prominent invaders of the higher elevation plains grasslands include catclaw *(Acacia greggii)*, sacahuista *(Nolina microcarpa)*, cane cholla *(Cylindropuntia imbricata)*, perennial broomweed (*Gutierrezia sarothrae*), and prickly pear species *(Opuntia* spp.*)* (Texas Parks and Wildlife Department 2007*c*). Healthy grassland savannas exist today on certain sites where wildfires or prescribed burnings have occurred and on certain ranches that have been conservatively grazed and properly managed for decades (Texas Parks and Wildlife Department 2007*c*). Specific areas surveyed were categorized by the vegetation types of Texas as creosotebush (*L.*

tridentata)-tarbush (*F. cernua*) shrub, creosotebush (*L. tridentata*)-mesquite (*Prosopis* spp.) shrub, creosotebush(*L. tridentata*)-lechuguilla (*Agave lechuguilla*), or cenizo (*Leucophyllum frutescens*) blackbrush (*Acacia rigidula*)-creosotebush (*L. tridentata*) (Texas Parks and Wildlife Department 2007 *c*).

These study areas were chosen based on the documented consistent occurrence of Montezuma quail in each area (Oberholser 1974, Sorola 1986, Albers and Gehlbach 1990, Hernàndez et al. 2006*a*, Hernàndez et al. 2006*b*)

METHODS

Occupancy and Probability of Detection

Survey points.—I conducted call-back surveys during July–August 2007 and June–August 2008 at Elephant Mountain WMA and Davis MP. In June–August 2008, I also conducted call-back surveys at UVR and DRR. This time of survey was chosen because these months represented the approximate occurrence of the monsoon rains in the Trans-Pecos and Edwards Plateau ecoregion and corresponded to the period of peak calling by Montezuma quail (D. Holdermann, Texas Parks and Wildlife Department, unpublished report).

I 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 (Figure 5). I chose a $400 \times 400\text{-m}^2$ grid based on literature which stated that the approximate radius of audibility of a male buzz call was about 200 m (Bishop 1964). Each grid was given a numbered centroid, and I randomly selected 30 survey points using Microsoft Office Excel 2003®. In 2008, I increased the grid size ($800 \times 800\text{-m}^2$) in order to minimize the probability of

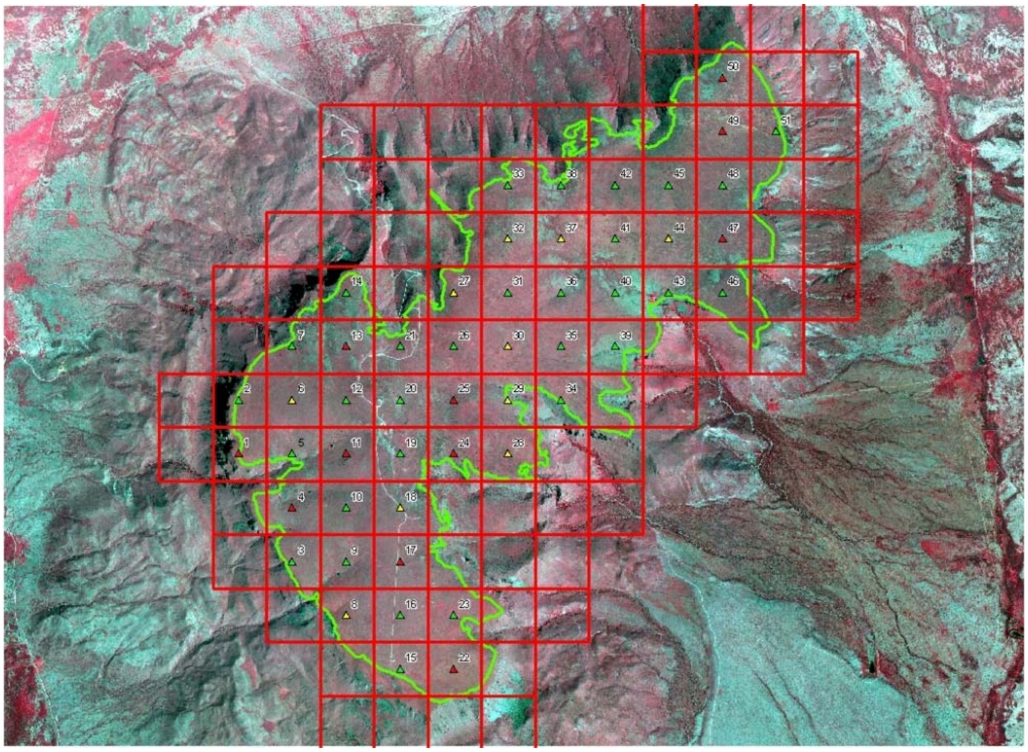


Figure 5. Aerial map of Elephant Mountain Wildlife Management Area that was used for callback surveys and vegetation sampling during July–August 2007.

double counting. This increase in grid size resulted in fewer points occurring within the original monitoring area. Because first year results indicated high occupancy within my original monitoring area, I placed the "extra" points in new, surrounding areas to include sub-optimal habitat. This would increase the variability of the habitats surveyed and provide better data for resource-selection functions. I was able to retain 14 of the original 30 points at Elephant Mountain WMA resulting in 16 points being placed in sub-optimal habitat still within Elephant Mountain WMA. At Davis MP, I was able to retain 10 of the original 30 survey points; the other 20 points had to be placed in areas outside of Davis MP (Figure 6). Eight of these new points were located on Highway 118 north between Alpine (TX) and Fort Davis (TX). 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. At these new survey points for Davis MP, only call-back surveys were conducted (and not including vegetation sampling; see below) due to access restrictions. On the Del Rio Route (DRR) I selected survey points along Highway 90 based on vegetation types of Texas map from Texas Parks and Wildlife. I tried to include as many different vegetation types as possible as long as there was a safe and accessible area along the roadside. I included 5 survey points per vegetation type as each survey point was surveyed ≥ 5 times. As was the case with the survey points located along highways for Davis MP, I only conducted call-back surveys ($n = 20$ survey points) on the DRR (Figure 7).

Survey points for Uvalde Route (UVR) ($n = 25$ survey points) were chosen based on a vegetation map from Texas Parks and Wildlife. I tried to include as many vegetation types as possible as long as there was a safe and accessible area along the

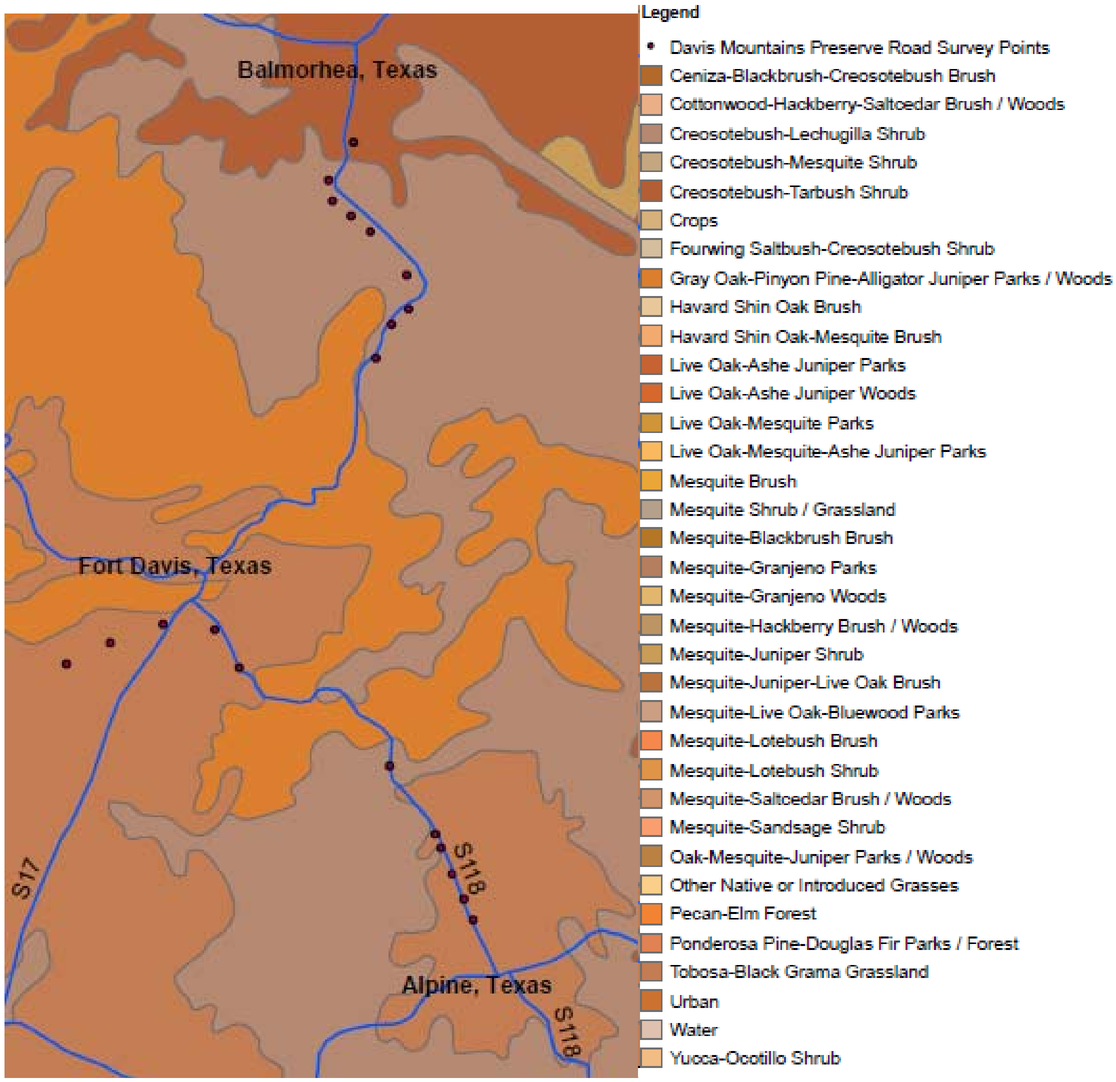


Figure 6. Davis Mountains Preserve (n = 20 survey points), there were additional points on the Davis Mountains Preserve (n = 10) not shown on this map. Callback surveys were conducted during July–August 2008 in different vegetation communities.

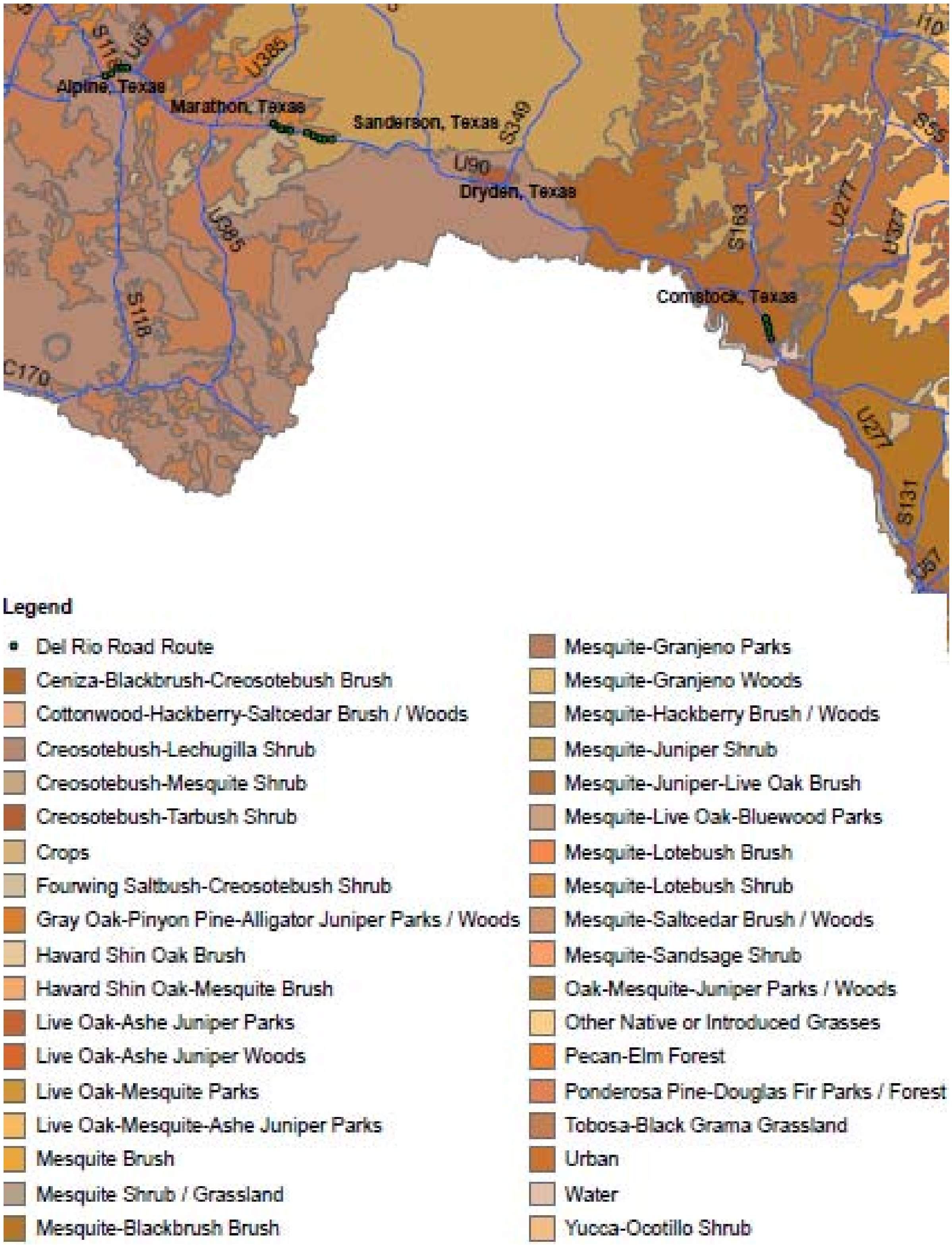


Figure 7. Del Rio Road Route (TX) (n = 20 survey points), callback surveys were conducted during July–August 2008.

roadside. I included 5 survey points per vegetation type as each survey point was surveyed ≥ 5 times.

Call-back surveys.—I used a playback recording of a male buzz call or combination of a male buzz call and a covey-assembly call to detect presence. This playback recording was made by Sylvestre "Junie" Sorola whom is a retired Wildlife Biologist for the Texas Parks and Wildlife Department. Call-back surveys consisted of playing the recording for about 1.5 minute (min) with a 30 second (sec) pause to listen for a Montezuma quail response, if no calls were heard, I continued to play the call for about 30 sec more followed by a 30 sec pause; this was done for a total of 5 minutes. A value of 1 was recorded when Montezuma quail presence was detected (visual or auditory) and a 0 otherwise. I visited each monitoring site 5 times during each field season; thus yearly total survey effort for Elephant Mountain WMA, and Davis MP was 150 surveys (30 sites × 5 visits) each. Total survey effort for DRR was 100 surveys (20 sites × 5 visits) while at the UVR the total survey effort was 125 surveys (25 sites × 5 visits). The ability to detect Montezuma quail may vary throughout the day, thus, I conducted my call-back surveys at different times of the day during the repeated visits. I partitioned the daylight period into 3 categories: morning (0700–1100 hrs), afternoon (1100–1500 hrs), and evening (1600–2000 hrs). Survey points were chosen at random by picking out the numbers from a bag, and each survey point must have been completed once before it could be surveyed again. I separated each partition of the day, counting the morning and evening hours separate. Call-back surveys were conducted during the morning and evening hours, while vegetation sampling took place in the afternoon hours (see below).

I recorded the number of individuals calling and total calls heard for each survey. I used this information to calculate mean number of birds calling (no. birds calling/point/week) and mean calls (no. calls/point/week). Weeks were defined 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), 9 (19 Aug–25 Aug) for 2007 and 2008.

Weather.—I recorded time of day, temperature, humidity, and wind speed during each survey. Temperature, humidity and wind speed were measured using a Kestrel 3000 wind meter (Nielsen-Kellerman Co. Boothwyn, PA).

Precipitation data for Elephant Mountain WMA was obtained from the National Oceanic and Atmospheric Administration (NOAA; http://www.weather.gov/climate /index.php?wfo=alp) center from the Alpine-Casparis Municipal weather station for July–August 2007 and June–August 2008. Precipitation data for Davis MP was obtained from the National Oceanic and Atmospheric Administration (NOAA; http://www.weather.gov/ climate/index.php?wfo=mid) center from Midland/Odessa weather station for Fort Davis for July–August 2007 and June–August 2008. I partitioned precipitation data into the same weekly periods that were used for mean weekly calling rates that were previously defined.

Vegetation Sampling

Microhabitat.—I quantified 2 habitat characteristics (vegetation structure and food-plant density) at survey points at Elephant Mountain WMA and Davis MP for subsequent use in resource-selection functions. 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.

I established 4 30-m transects at each point radiating in the 4 cardinal directions. I measured vegetation structure at 10 m, 20 m, and 30 m plot along each transect. For herbaceous coverage, I visually estimated % litter, % forb, % grass, and % bare ground using a Daubenmire frame. I obtained vegetation height readings using a Robel pole (Figure 8) from a 4 m distance at 1 m height in each of the 4 cardinal directions (Robel 1969). In addition, I 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) (Nudds1977). Food-plant density was determined using a 1- × 1-m frame at 10 m, 20 m, and 30 m plot along each transect. I recorded the number of individual plants of *Allium* spp. (Figure 9A–B), *Oxalis* spp. (Figure 10), and *Cyperus* spp. (Figure 11) and calculated food-plant density from this data.

Macrohabitat.—The macro-scale variables measured at all survey points included aspect, elevation, slope, and vegetation type. I 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 was collected from ArcGIS™ Digital Elevation Model (DEM) at a 1 km resolution from the UTM projected coordinate WGS 1984 UTM ZONE 14. I used the Vegetation types of Texas map as a reference that was originally made by Texas Parks and Wildlife Department (Figure 12: TPWD 2007*c*).

Figure 8. Example how profile board and Robel pole measurements were conducted at Davis Mountains Preserve (TX), 5 August 2008.

A)

B)

Figure 9. A) *Allium* sp. with flower found at Davis Mountain Preserve (TX), 15 April 2007. B) *Allium* sp. without flower found at Elephant Mountain Wildlife Management Area (TX), 28 July 2007.

Figure 10. *Oxalis* sp. found at Davis Mountains Preserve (TX), 4 August 2007.

Figure 11. *Cyperus* sp. found at Davis Mountains Preserve (TX), 29 July 2007.

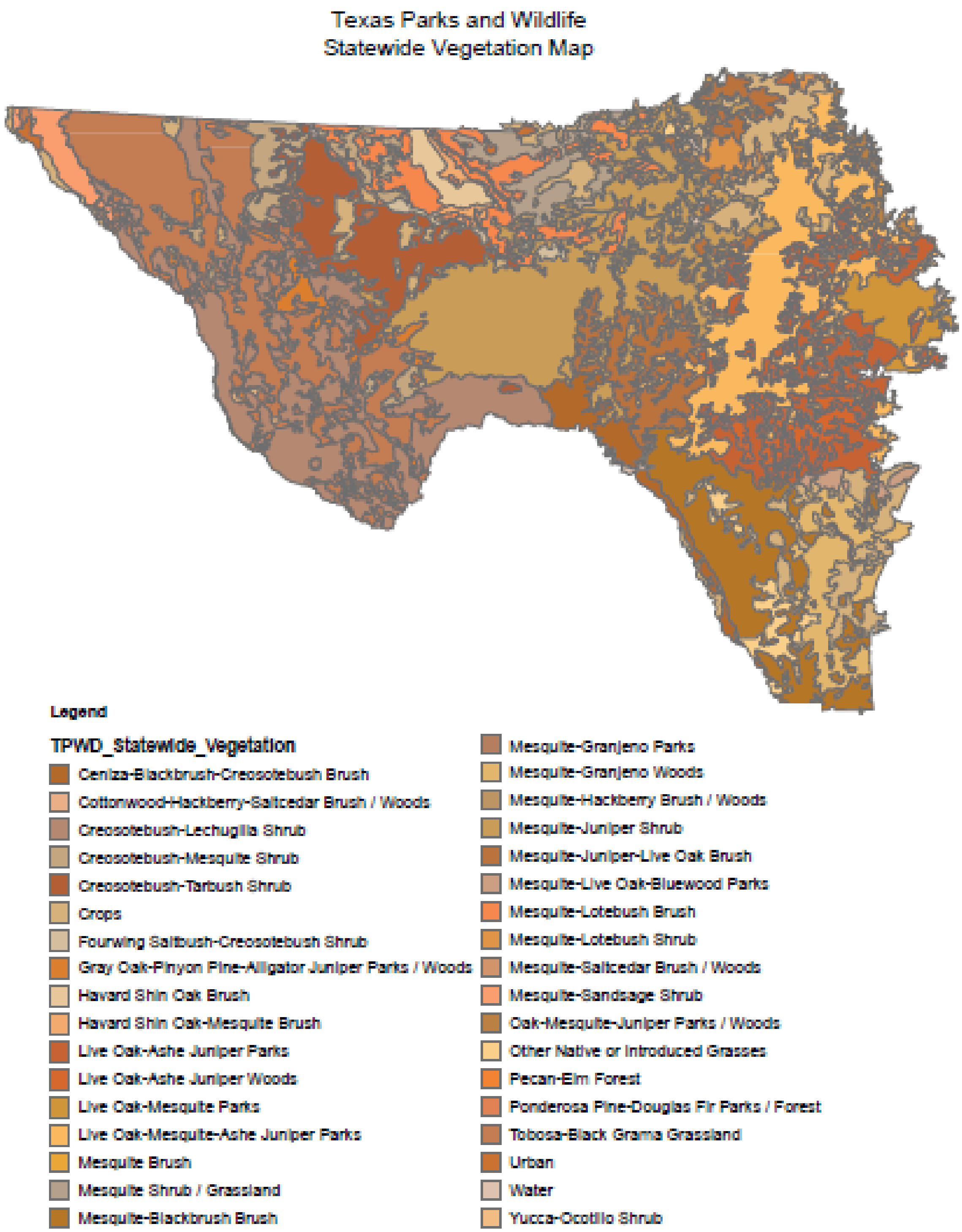


Figure 12. Texas Parks and Wildlife Department Vegetation types of Texas used to distinguish vegetation types for callback surveys in 2008 survey season (TPWD 2000*c*).

Slope was determined using a Suunto® KB-14 clinometer (Shreveport, LA). To estimate slope, I first marked my eye level on the profile board, stepped 15 m down slope from the profile board and measured slope by viewing my eye level through the clinometer. Slope was collected in degrees. For areas that I did not have access to, slope was obtained using ArcGIS™ 3D™ analyst which is a three-dimensional visualization, topographic analysis, and surface creation.

My study area encompassed 13 vegetation types. Since the number of survey points ranged considerably within each vegetation type, I grouped these initial 13 vegetation types into 4 habitat-suitability categories (high, moderate, low, and none) in order to reduce the number of covariates. Categorization was based on the percentage of survey points in each habitat type sampled with Montezuma quail detections, information from prior studies, or observation. High suitability consisted of >50% of survey points with detections, moderate with at least 26–50% of survey points with detections, low with 11–25% of survey points with detections, and none with 0–10% of survey points with detections. For vegetation types not surveyed, I categorized areas as "low" or "none" depending if areas were sympatric or allopatric to historical or known Montezuma quail distributions. Sympatric areas were considered "low" and allopatric areas "none".

Statistical Analysis

Calling rates and precipitation.—I conducted a Pearson Correlation analysis in Program SAS on weekly calling rates (calls/survey) and weekly precipitation (mm). I partitioned weekly calling rates (calls/survey) and precipitation (mm) data into the same weekly periods that were previously defined. This analysis was conducted for Elephant

Mountain WMA and Davis MP separately for each year, pooled across sites for each year, and pooled across sites and years. Analysis for UVR and DRR was not possible since the survey points were too spaced out that not any one weather station would have given a good representation of the precipitation from the area that survey call-back surveys were conducted.

Occupancy and detection probability.—Prior to conducting any analysis in Program PRESENCE, I ran a Pearson Correlation Matrix in Program SAS on all of the variables I had measured throughout my field season. There was a total of 13 micro-scale habitat variables, 4 weather variables, and 19 macro-scale habitat variables (Table 1). By using the correlation matrix I was able to reduce the number of variables that were used in the 3 different analyses ran in Program PRESENCE. Table 1 shows a summary of the variables measured throughout the field season in 2007 and 2008 with the rationale and indication as to whether they were removed from my analysis. Using biologically meaningful variables and a correlation coefficient value of ≥0.60 helped determine which variables of the set were to remain in the subsequent analysis.

I conducted 3 different analyses in Program PRESENCE. These different analyses were necessary because not all points had microhabitat data and not all points were surveyed in both years. Analysis 1 was designed to evaluate the influence of microhabitat on occupancy and the influence of weather and vegetation height on probability of detection (*Psi* [micro-scale], *P* [weather + vegetation height]). Data for this analysis was a subset from 2008 (n = 30 survey points from Elephant Mountain WMA; n = 10 survey points from Davis MP). Not all of 2008 data could be used in this

Table 1. Habitat variables measured during survey season 2007 and 2008 at Elephant Mountain Wildlife Management area and Davis Mountains Preserve with indication of whether they were removed from the analysis.

Scale Initial variable	Removed	Reason:
Micro-scale		
Habitat		
%Grass cover		Has biological importance due to food or for predator concealment.
%Forb cover		Has biological importance due to food or for predator concealment.
%Bare ground cover		Percent bare ground affects Montezuma quail movements and cover.
%Litter	X	Percent litter was correlated with %bare ground in 2007, %litter was the least biologically important.
Allium spp. density	X	I thought it would be better if I added up the three important plant species (food-plant density) that I measured because Montezuma quail consume all three plant species in their diets.
Oxalis spp. density	X	I thought it would be better if I added up the three important plant species (food-plant density) that I measured because Montezuma quail consume all three plant species in their diets.
Cyperus spp. density	X	I thought it would be better if I added up the three important plant species (food-plant density) that I measured because Montezuma quail consume all three plant species in their diets.
Food-plant density		Food-plant density was kept because it was the sum of 3 plant species measured (*Allium* pp., *Oxalis* spp., and *Cyperus* spp.) instead of each plant species individually. It reduced my variables by 3.

Table 1 Continued.

Scale Initial variable	Removed	Reason:
Micro-scale		
Habitat continued		
Vegetation height (dm)		Vegetation height was kept because it was highly correlated with Strata 1–4, and it helped reduce my variables by removing the 4 stratas.
S1	X	Strata 1–4 was highly correlated (95% CI: r= >0.9), by removing strata 1–4 I reduced my variables by 4.
S2	X	Strata 1–4 was highly correlated (95% CI: r= >0.9), by removing strata 1–4 I reduced my variables by 4.
S3	X	Strata 1–4 was highly correlated (95% CI: r= >0.9), by removing strata 1–4 I reduced my variables by 4.
S4	X	Strata 1–4 was highly correlated (95% CI: r= >0.9), by removing strata 1–4 I reduced my variables by 4.
Weather		
Temperature(°F)		Temperature was kept since we took out humidity and they were both highly correlated.
Humidity (%)	X	Percent humidity was highly correlated with temperature in 2007 and 2008 at both sites(r > 0.7). I decided temperature was easier for people to measure, and therefore more important in use for management implications
Time (AM/PM)		Time was kept because I want to see if detection varies by the time of day I did the survey, either in the morning or the evening.
Wind (mph)		Wind was kept because wind affects my ability to detect the bird when calling.

Table 1 Continued.

Scale Initial variable	Removed	Reason:
Macro-scale		
Slope (°)		I wanted to see if occupancy varies by the degree of slope.
Elevation (m)		I wanted to see if occupancy varies at different elevations.
Aspect (N, E, S, W)	X	Aspect did not help explain occupancy or probability of detection so I removed it since I thought it was the one with least biological importance. It reduced my covariates by 4.
Vegetation type		13 vegetation types were categorized into 4 different habitat suitability types (high, moderate, low, and none) based on calling rates.

analysis because there were some survey points within these study areas for which I did not have access to (i.e., call-back surveys were conducted from the side of the road) and therefore no microhabitat data. A *priori* models for the influence of habitat on occupancy at the micro-scale were constructed based on the knowledge of needs of Montezuma quail for food, concealment from predators, and movement (Table 2). A *priori* models for probability of detection were built on the knowledge of their calling phenology, weather, and concealment from predators (Table 3). I modeled occupancy and probability of detection simultaneously (P. Doherty, Colorado State University, personal communication). That is, I modeled a particular detection model with each possible occupancy model.

Analysis 2 represented an additional assessment of the influence of weather and vegetation height on probability of detection. This analysis used data from 2007 (Elephant Mountain WMA [n = 30 survey points]; Davis MP [n = 30 survey points]). I modeled occupancy as constant (1) because occupancy rates were almost 1.0 for both study sites in 2007 indicating that all points were located in optimum habitat. A *priori* models for probability of detection were analyzed based on knowledge Montezuma quail calling phenology, influence of weather, and need for concealment from predators (Table 4).

Analysis 3 was designed to evaluate the influence of macrohabitat variables on occupancy in order to develop a predictive occupancy map and assess the influence of weather on probability of detection. Data used for the macrohabitat models were from Elephant Mountain WMA (n = 30 survey points), Davis MP (n = 30 survey points), UVR

Table 2. Analysis 1 a *priori* occupancy models for Program PRESENCE based on micro-scale habitat characteristics. All model combinations for analysis are shown.

Variable	Model	Basis	Explanation
0	ψ (.)	No influence	Constant occupancy
1	ψ (food density)	Food	Presence influenced by primary food plants
	ψ (grass cover)	Concealment (horizontal)	Presence influenced by predation vulnerability
	ψ (vegetation height)	Concealment (vertical)	Presence influenced by predation vulnerability
2	ψ (food density + grass cover)	Food + Concealment (horizontal)	
	ψ (food density + vegetation height)	Food + Concealment (vertical)	
3	ψ (food density + grass cover + vegetation height)		

Table 3. Analysis 1 a *priori* detection models for Program PRESENCE at a micro-scale based on weather variables and vegetation height. All model combinations for analysis are shown.

Variable	Model	Basis	Explanation
0	p(.)	No influence	Constant detection
1	p(survey)	Calling phenology	Calling varies through season
	p(time)	Calling phenology	Calling varies through day
	p(temperature)	Weather	Activity varies with heat
	p(wind)	Weather	Audiblity varies with wind
	p(vegetation height)	Habitat	Visual detectability varies with cover
2	p(survey + time)	Calling phenology	
	p(survey + temperature)	Calling phenology + Weather	
	p(survey + wind)	Calling phenology + Weather	
	p(survey + vegetationheight)	Calling phenology + Habitat	
	p(time + temperature)	Calling phenology + Weather	
	p(time + wind)	Calling phenology + Weather	
	p(time + vegetation height)	Calling phenology + Habitat	
	p(temperature + wind)	Weather	
	p(temperature + vegetation height)	Weather + Habitat	
	p(wind + vegetation height)	Weather + Habitat	
3	p(survey + time + temperature)	Calling phenology + Weather	
	p(survey + time + wind)	Calling phenology + Weather	
	p(survey + time + vegetation height)	Calling phenology + Habitat	
	p(survey + temperature + wind)	Calling phenology + Weather	
	p(survey + temperature + vegetation height)	Calling phenology + Weather + Habitat	

Table 3 Continued.

Variable	Model	Basis	Explanation
3	p(survey +wind + vegetation height)	Calling phenology + Weather + Habitat	
	p(time + temperature + wind)	Calling phenology + Weather	
	p(time + temperature + vegetation height)	Calling phenology + Weather + Habitat	
	p(time + wind + vegetation height)	Calling phenology + Weather + Habitat	
	p(temperature + wind + vegetation height)	Weather + Habitat	
4	p(survey + time + temperature + wind)	Calling Phenology + Weather	
	p(survey + time + temperature + vegetation height)	Calling phenology + Weather + Habitat	
	p(survey + temperature + wind + vegetation height)	Calling phenology + Weather + Habitat	
	p(survey + time + wind + vegetation height)	Calling phenology + Weather + Habitat	
	p(time + temperature + wind + vegetation height)	Calling phenology + Weather + Habitat	
5	p(survey + time + temperature + wind + vegetation height)	Calling phenology + Weather + Habitat	

Table 4. Analysis 2 a *priori* detection models for Program PRESENCE at a micro-scale based on weather variables and vegetation height. All model combinations for analysis are shown.

Variable	Model	Basis	Explanation
0	p(.)	No influence	Constant detection
1	p(survey)	Calling phenology	Calling varies through season
	p(time)	Calling phenology	Calling varies through day
	p(temperature)	Weather	Activity varies with heat
	p(wind)	Weather	Audibility varies with wind
	p(vegetation height)	Habitat	Visual detectability varies with cover
	p(humidity)	Weather	
2	p(survey + time)	Calling phenology	
	p(survey + temperature)	Calling phenology + Weather	
	p(survey + wind)	Calling phenology + Weather	
	p(survey + vegetation height)	Calling phenology + Habitat	
	(survey + humidity)		
	p(time + temperature)	Calling phenology + Weather	
	p(time + wind)	Calling phenology + Weather	
	p(time + vegetation height)	Calling phenology + Habitat	
	(time + humidity)		
	p(temperature + wind)	Weather	
	p(temperature + vegetation height)	Weather + Habitat	
	(temperature + humidity		
	p(wind + vegetation height)	Weather + Habitat	
	wind + humidity		
	vght + humidity		

Table 4 Continued.

Variable	Model	Basis	Explanation
3	p(survey + time + temperature)	Calling phenology + Weather	
	p(survey + time + wind)	Calling phenology + Weather	
	p(survey + time + vegetation height)	Calling phenology + Habitat	
	survey time humidity		
	p(survey + temperature + wind)	Calling phenology + Weather	
	p(survey + temperature + vegetation height)	Calling phenology + Weather + Habitat	
	survey temperature humidity		
	p(survey +wind + vegetation height)	Calling phenology + Weather + Habitat	
	survey wind humidity		
	p(time + temperature + wind)	Calling phenology + Weather	
	p(time + temperature + vegetation height)	Calling phenology + Weather + Habitat	
	time temperature humidity		
	p(time + wind + vegetation height)	Calling phenology + Weather + Habitat	
	time wind humidity		
	p(temperature + wind + vegetation height)	Weather + Habitat	
	temperature wind humidity		
	wind vght humidity		
4	p(survey + time + temperature + wind)	Calling Phenology + Weather	
	p(survey + time + temperature + vegetation height)	Calling phenology + Weather + Habitat	
	survey time temperature humidity		
	p(survey + temperature + wind + vegetation height)	Calling phenology + Weather + Habitat	
	survey temperature wind humidity		
	p(survey + time + wind + vegetation height)	Calling phenology + Weather + Habitat	
	survey time wind humidity		
	p(time + temperature + wind + vegetation height)	Calling phenology + Weather + Habitat	
	time temperature wind humidity		
	temperature wind vght humidity		
5	p(survey + time + temperature + wind + vegetation height)	Calling phenology + Weather + Habitat	

(n = 25 survey points), and DRR (n = 20 survey points) for July–August 2008. I removed points with no detections (n = 25 survey points) from the original dataset (n = 105 survey points) because the analysis was not reaching convergence (D. I. MacKenzie, Proteus Wildlife Research Consultants, personal communication, 2008). A *priori* models for occupancy were built on the knowledge of the needs of Montezuma quail for food, their current and historic distribution, and habitat (Table 5). A *priori* models for probability of detection were built on the knowledge of Montezuma quail's calling phenology and weather (Table 6).

Using the estimates of probability of detection derived from the analyses above, I ran an analysis in Program SAS to estimate the number of times a survey had to be repeated to ensure detection given a Montezuma quail was present. This equation in Program SAS was derived with the help of a statistician (R. Bingham, Caesar Kleberg Wildlife Research Institute, personal communication, 2008) (Appendix 1).

Predictive distribution map.—Based on the results from Analysis 3, I used ArcGIS® 9.3 and ERDAS® Imagine Model Maker to develop the predictive occupancy map based on the best macrohabitat model. I used the following general formula in Program ERDAS® Imagine Model Maker:

Logit Psi = Intercept + (Moderate × –4.10) + (Low × -6.45) + (Elevation × – 2.74)

where

Intercept = 7.24 (calculated by in Program PRESENCE)

Moderate = 1 if habitat-suitability is moderate, else 0

Low = 1 if habitat-suitability is low, else 0

Elevation = (elevation value/1000)

Table 5. Analysis 3 a *priori* occupancy models for Program PRESENCE based on macro-scale habitat characteristics to develop predictive distribution map. All model combinations for analysis are shown

Variable	Model	Basis	Explanation
0	ψ (.)	No influence	Constant detection
1	ψ (slope)	Food	Food plants density may be influenced by slope
	ψ (elevation)	Species Distribution	Occur within an elevation range
	ψ (vegetation type)	Habitat	Influences life history and ecology
2	ψ (slope + vegetation type)		
	ψ (elevation + vegetation type)		
3	ψ (slope + elevation + vegetation type)		

Table 6. Analysis 3 a *priori* detection models for Program PRESENCE based on weather variables. All model combinations for analysis are shown.

Variable	Model	Basis	Explanation
0	p(.)	No influence	Constant detection
1	p(survey)	Calling phenology	Calling varies through season
	p(time)	Calling phenology	Calling varies through day
	p(temperature)	Weather	Activity varies with heat
	p(wind)	Weather	Audibility varies with wind
2	p(survey + time)	Calling phelonogy	
	p(survey + temperature)	Calling phenology + Weather	
	p(survey + wind)	Calling phenology + Weather	
	p(time + temperature)	Calling phenology + Weather	
	p(time + wind)	Calling phenology + Weather	
	p(temperature + wind)	Weather	
3	p(survey + time + temperature)	Calling phenology + Weather	
	p(survey + time + wind)	Calling phenology + Weather	
	p(survey + temperature + wind)	Calling phenology + Weather	
	p(time + temperature + wind)	Calling phenology + Weather	
4	p(survey + time + temperature + wind)	Calling phenology + Weather	

A high-suitability habitat was indicated when the value for Moderate and Low was 0. Elevation was transformed for Program Presence in order for the Program to run the analysis without any problems. If the average value of elevation is considerably greater than zero, then PRESENCE may have not been able to find the true maximum likelihood estimates of the model parameters, which would have resulted in unreliable results or Program warnings (D. I. MacKenzie, Proteus Wildlife Research Consultants, personal communication, 2008).

The equation above was inserted in ERDAS® Imagine Model Maker using object graphics and lines to show the interrelationships among each component. I first inputted the equation that determines the *Logit Psi*, then, from the *Logit Psi*, occupancy (*Psi*) was determined using the equation below.

I then used the following formula to estimate occupancy:

Psi = Exp (Logit Psi)/ 1+(exp Logit Psi)

where

Psi = occupancy

Exp = *e*, base of natural logarithm (≈ 2.72)

Logit Psi = the value found in the formula above

Once both of these formulas were modeled in Program ERDAS® Imagine Model Maker, I then transferred them into ArcGIS® where the software used the digital elevation data and habitat-suitability types to generate the predictive distribution map of Montezuma quail.

RESULTS

General Weather and Habitat Conditions

General weather conditions during surveys appeared similar between Elephant Mountain WMA and Davis MP (Table 7). Ranges of mean monthly temperature and humidity during July–August 2007 were 23.3–25.6 °C and 65.3–61.3% at Elephant Mountain WMA compared to 22.8–24.1 °C and 59.3–61.4% at Davis MP, respectively. However, mean monthly wind speed tended to be numerically greater at Elephant Mountain WMA (range: 6.6–7.1 km/hr) than Davis MP (range: 1.6–2.4 km/hr). This same pattern of similar mean monthly temperature and humidity but greater wind speed at Elephant Mountain WMA was observed during surveys in June–August 2008 (Table 7). Regarding weather conditions between years, weather conditions tended to be drier (greater temperature and lower humidity) in 2008 (Table 7). Ranges of mean monthly temperature and humidity were 29.2–32.9 °C and 23.0–44.1% during June–August 2008 at Elephant Mountain WMA and 29.7–33.3 °F and 37.8–40.7% at Davis MP, respectively.

Elephant Mountain WMA and Davis MP are located in different vegetation zones. Thus, habitat was expected to differ and no statistical analyses were conducted. In general, Elephant Mountain WMA tended to have a lower percent forb cover (95% CI: 4.7 ± 1.6%), percent bare ground (95% CI: 44.7 ± 3.2%), and vegetation height (95% CI: 2.3 ± 0.5 dm) compared to Davis MP (95% CI: 9.1 ± 3.5%, 25.7 ± 3.9%, and 5.4 ± 0.9 dm, respectively) in July–August 2007 (Table 8). Elephant Mountain WMA also tended to have a lower percent forb cover (95% CI: 6.8 ± 3.1%), percent bare ground (95% CI: 39.0 ± 6.2%), and vegetation height (95% CI: 1.4 ± 0.5 dm) compared to Davis MP

Table 7. Monthly mean ($\bar{x}$) weather variables (temperature, wind, and humidity) for Elephant Mountain Wildlife Management Area (Elephant Mountain WMA), Davis Mountains Preserve (Davis MP), Del Rio Route (DRR), and Uvalde Road Route (UVR) for July–August 2007 (N = 150 surveys/study site) and June–August 2008 (N = 150 surveys/study site). Units for temperature are Celsius (°C), wind (km/hr) and humidity (%).

Year Variable Month	Elephant Mountain WMA			Davis MP			DRR			UVR		
	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE
2007												
Temperature												
July	77	73.9	0.9	73	73.1	1.1						
August	73	78.0	1.0	77	75.4	0.9						
Wind												
July	77	4.1	0.3	73	1.0	0.2						
August	73	4.4	2.9	77	1.5	0.2						
Humidity												
July	77	65.0	1.8	73	61.4	2.1						
August	73	61.3	2.2	77	59.3	1.9						

Table 7 Continued.

Year Variable Month	Elephant Mountain WMA			Davis MP			DRR			UVR		
	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE
2008												
Temperature												
June	22	82.1	3.1	16	72.7	1.1						
July	117	84.6	1.0	128	85.4	1.3	57	85.5	1.4	100	86.9	0.9
August	11	91.2	2.2	6	91.9	2.0	43	84.0	2.5	50	90.1	1.4
Wind												
June	22	3.6	0.8	16	1.9	0.3						
July	117	4.5	0.3	128	2.4	0.3	57	3.7	0.3	100	3.0	0.2
August	11	2.4	0.4	6	0.4	0.2	43	3.5	1.6	50	1.7	0.2
Humidity												
June	22	44.3	2.8	16	63.3	3.4						
July	117	44.1	1.7	128	40.7	1.5	57	44.4	2.2	100	51.8	1.8
August	11	23.0	1.0	6	37.8	4.8	43	41.5	2.3	50	49.3	2.6

(95% CI: 16.1 ± 6.2%, 29.3 ± 4.5%, and 2.7 ± 0.6 dm, respectively) in June–August 2008 (Table 8). These results indicate that Montezuma quail may have a wide range of habitat suitability given the 2 study areas are markedly different, particularly in structure

I conducted call-back surveys in 13 different habitat types during my study. Of these 13 habitat types, I grouped them into the following habitat-suitability categories: 2 were high, 2 moderate, 3 low, and 6 none (Table 9). The general pattern for percent forb cover, percent grass cover, and food-plant density decreased from high-suitability habitat to low suitability habitat (Table 10).

Calling Rates

Weekly survey mean number of birds calling per point and mean calls per point both decreased by 82% from 2007 to 2008 at Elephant Mountain WMA (Table 11). I also observed a decrease in mean number of birds calling per point and mean calls per point (88% and 85%, respectively) at Davis MP during this same time period (Table 11). This decrease in calling rate was expected because survey points changed from 2007 to 2008 at both study sites to include areas thought to have low Montezuma quail abundance. Mean weekly calling rate did not track consistently mean weekly precipitation across years and sites (Figures 13–14, Appendix 2–3). I documented that mean weekly calling rate and mean weekly precipitation were highly correlated only in July–August 2007 at Davis MP (r = 0.85, P = 0.07) and in June–August 2008 at Elephant Mountain WMA (r = 0.86; P = 0.03. Mean weekly calling rate and mean weekly precipitation were not correlated pooled across sites and years (r = 0.06, P = 0.80, Table 12).

Mean number of birds calling/pt was 60–95 % greater in high-suitability habitat

Table 8. Comparison of habitat variables (mean ($\bar{x}$) and standard error (SE)) measured at Elephant Mountain Wildlife Management Area (Elephant Mountain WMA; N = 30 survey points) and Davis Mountains Preserve (Davis MP; N = 30 survey points) during July–August 2007 and June–August 2008 (Elephant Mountain WMA; N = 12 survey points: Davis MP; N = 10). Percent Forb, % Grass, % Bare ground, and % Litter were measured using a daubenmire frame. *Alliums* pp, *Oxalis* spp. and *Cyperus* spp. were measured using a 1 × 1 m frame, Food-plant density is a sum of the 3 plant species measured. Strata 1–4 are % obstructed per stratum on a profile board. Vegetation height was collected using a Robel pole®. Slope was measured using a clinometer using ArcGIS™ 3D™ analyst and Suunto® KB-14 clinometer. Elevation was obtained by using ArcGIS™ Digital Elevation Model.

Year	Elephant Mountain WMA			Davis MP		
Variable	N	$\bar{x}$	SE	N	$\bar{x}$	SE
2007						
% Forb	30	4.7	0.8	30	9.1	1.8
% Grass	30	37.2	1.9	30	31.8	2.1
% Bare ground	30	44.7	1.6	30	25.7	2.0
% Litter	30	13.3	1.5	30	32.4	2.7
Allium spp.	30	0.3	0.1	30	0.0	0.0
Oxalis spp.	30	0.0	0.0	30	0.1	0.0
Cyperus spp.	30	0.9	0.6	30	1.9	0.5
Food-plant density	30	1.2	0.6	30	2.0	0.4
Strata 1	30	50.1	3.5	30	60.7	2.3
Strata 2	30	7.9	1.6	30	30.6	2.5
Strata 3	30	1.9	0.8	30	25.5	2.4
Strata 4	30	1.5	0.7	30	30.2	2.7

Table 8 Continued.

Year Variable	EMWMA N	EMWMA $\bar{x}$	EMWMA SE	DMP N	DMP $\bar{x}$	DMP SE
2007 Continued.						
Vegetation height	30	2.3	0.2	30	5.4	0.4
Slope	30	7.2	0.7	30	9.3	1.1
Elevation	30	1765.0	17.0	30	1869.6	11.2
2008						
% Forb	12	6.8	1.6	10	16.1	3.2
% Grass	12	44.7	3.8	10	33.7	3.0
% Bare ground	12	39.0	3.2	10	29.3	2.3
% Litter	12	9.6	1.4	10	20.8	1.6
Allium spp.	12	0.5	0.4	10	0.0	0.0
Oxalis spp.	12	0.0	0.0	10	2.4	2.1
Cyperus spp.	12	0.1	0.1	10	2.7	0.9
Food-plant density	12	0.7	0.4	10	5.0	2.2
Strata 1	12	27.0	5.1	10	45.7	3.1
Strata 2	12	3.3	1.8	10	17.5	2.8
Strata 3	12	1.3	0.9	10	16.5	2.8
Strata 4	12	1.4	1.0	10	21.2	3.3
Vegetation height	12	1.4	0.3	10	2.7	0.3
Slope	12	6.8	1.3	10	8.0	1.4
Elevation	12	1771.2	24.5	10	1872.8	20.4

Table 9. Ranking of habitat types into habitat-suitability categories[a] (high, moderate, low, and none) based on the percentage of survey points with Montezuma quail detections at Elephant Mountain Wildlife Management Area, Davis Mountains Preserve, Uvalde Route, and Del Rio Route in June–August 2008. (*N* = Number of survey points, *D* = Number of survey points with detections, *d* = % of survey points with detections [*D* / *N*]).

Habitat Type	*N*	D	d	Habitat-suitability
Yucca (*Yucca* spp.) Ocotillo (*Fouquieria splendens*)shrub	12	7	58	High
Gray Oak (*Quercus* spp.)-Pinyon Pine (*Pinus cembroides*)-Alligator Juniper (*Juniperus* spp.) Parks / Woods	10	6	60	High
Tobosa (*Pleuraphis mutica*) Black Grama (*Bouteloua eriopoda*) Grassland	18	5	28	Moderate
Live Oak (*Quercus* spp.) Mesquite (*Prosopis* spp.)-Ashe Juniper (*Juniperus* spp.)	5	2	40	Moderate
Creosotebush (*Larrea tridentata*) Lechuguilla (*Agave lechuguilla*) Shrub	20	2	10	Low
Live Oak (*Quercus* spp.) Ashe Juniper (*Juniperus* spp.) woods	5	1	20	Low
Mesquite (*Prosopis* spp.)-Blackbrush (*Acacia rigidula*) brush	5	1	20	Low
Mesquite (*Prosopis* spp.)-Juniper (*Juniperus* spp.)-Live Oak (*Querus* spp.) brush	5	0	0	None
Live Oak (*Quercus* spp.)-Ashe Juniper (*Juniperus* spp.)Parks	5	0	0	None
Creosotebush *(L. tridentata)* -tarbush *(Flourensia cernua)* Shrub	5	0	0	None
Creosotebush *(L. tridentata)* -Mesquite (*Prosopis* spp.) Shrub	5	0	0	None
Mesquite (*Prosopis* spp.)-Juniper (*Juniperus* spp.)Shrub	5	0	0	None
Cenizo *(Leucophyllum frutescens)* -Blackbrush (*Acacia rigidula*) Creosote *(L. tridentata)* bush	5	0	0	None

High = Montezuma quail were detected at >50% of survey points; Moderate = survey points that had at least 25–50% detections per habitat type; Low = survey points that had at least 10–25% detection per habitat type; None = survey points that had 0–10% detection per habitat type.

Table 10. Comparison of habitat variables (mean and standard error) by habitat-suitability[a] type (high, moderate, and low) at Elephant Mountain Wildlife Management Area (*N* = 30 survey points) and Davis Mountains Preserve (*N* = 10 survey points) in June–August 2008.

Year	High			Moderate			Low			Pooled		
Variable	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE
2008												
% Forb	22	11.0	1.9	8	6.8	2.5	10	6.5	2.1	40	9.0	1.3
% Grass	22	39.7	2.7	8	32.5	7.4	10	24.2	6.5	40	34.4	2.8
% Bare ground	22	34.6	2.2	8	44.3	7.0	10	49.8	5.4	40	40.3	2.5
% Litter	22	14.7	1.6	8	16.4	5.4	10	19.5	4.3	40	16.2	1.7
Allium spp.	22	0.3	0.2	8	0.0	0.0	10	0.0	0.0	40	0.2	0.1
Oxalis spp.	22	1.1	1.0	8	0.0	0.0	10	0.0	0.0	40	0.6	0.5
Cyperus spp.	22	1.3	0.5	8	0.0	0.0	10	0.0	0.0	40	0.7	0.3
Food-plant density	22	2.7	1.1	8	0.0	0.0	10	0.0	0.0	40	1.5	0.6
Strata 1	22	35.5	3.7	8	44.8	2.5	10	42.3	5.3	40	39.1	2.5
Strata 2	22	9.8	2.2	8	13.1	3.7	10	16.6	5.2	40	12.1	1.9
Strata 3	22	8.2	2.1	8	7.0	2.7	10	8.4	4.2	40	8.0	1.6
Strata 4	22	10.4	2.6	8	4.7	2.4	10	5.0	3.0	40	7.9	1.7
Vegetation height	22	2.0	0.3	8	2.8	0.3	10	3.1	0.9	40	2.5	0.3
Slope	22	7.3	0.9	8	5.6	2.7	10	5.7	1.9	40	6.6	0.9
Elevation	22	1817.4	19.3	8	1363.3	17.2	10	1411.8	35.0	40	1625.2	36.8

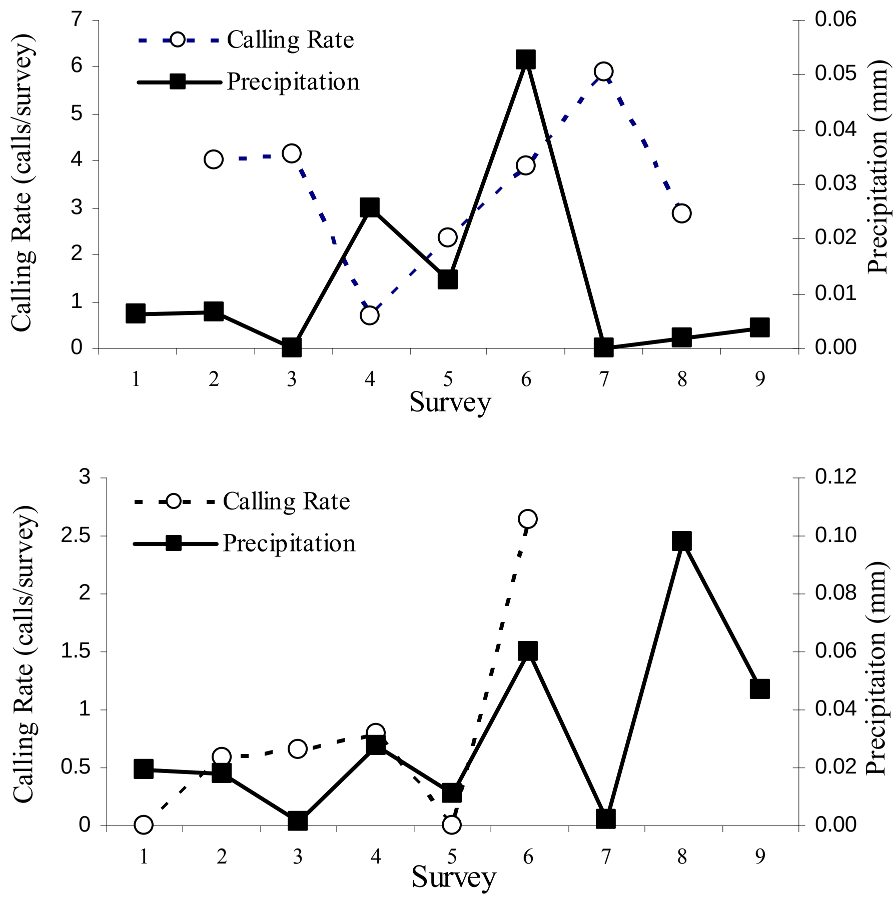
[a]High = Montezuma quail were detected at >50% of survey points, Moderate = survey points that had at least 25–50% detections per habitat type, Low = survey points that had at least 10–25% detection per habitat type.

Table 11. Mean of birds calling/point and mean calls/point of Montezuma quail at Elephant Mountain Wildlife Management Area (EMWMA), Davis Mountains Preserve (DMP), Uvalde Route (UVR), and Del Rio Route (DRR) during July–August, 2007 and June–August 2008. The UVR and DRR were incorporated into the study in 2008. Number of surveys (*N*) remained the same for EMWMA (*N* =150 surveys) and DMP (*N* =150 surveys) for both years; however only a certain number of survey points (*n*) remained the same for EMWMA (*n* =12 survey points, *N* =60 surveys) and DMP (*n* =10 survey points, *N* =50 surveys) in 2008.

Year		Birds calling/point		Calls/point	
Site	N	$\bar{x}$	SE	$\bar{x}$	SE
2007					
EMWMA	150	0.90	0.29	3.56	0.57
DMP	150	0.60	0.07	4.73	0.69
2008					
EMWMA	150	0.16	0.04	0.64	0.21
DMP	150	0.07	0.02	0.70	0.31
UVR	125	0.05	0.02	0.18	0.09
DRR	100	0.01	0.01	0.01	0.01

A)

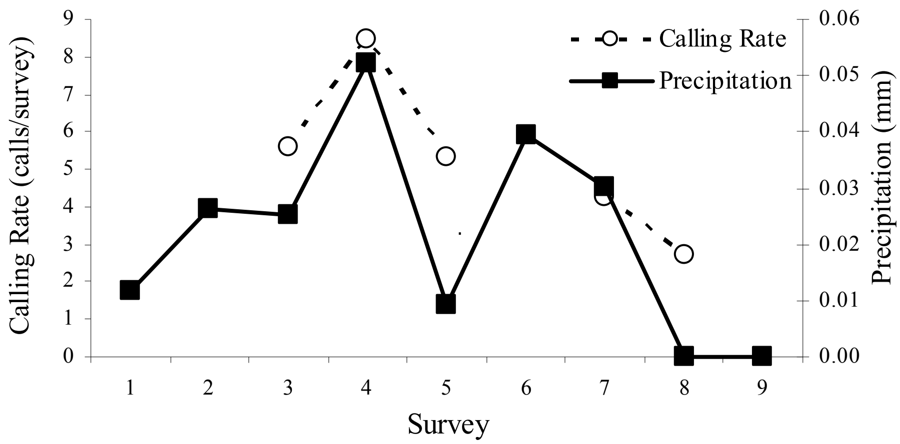
B)



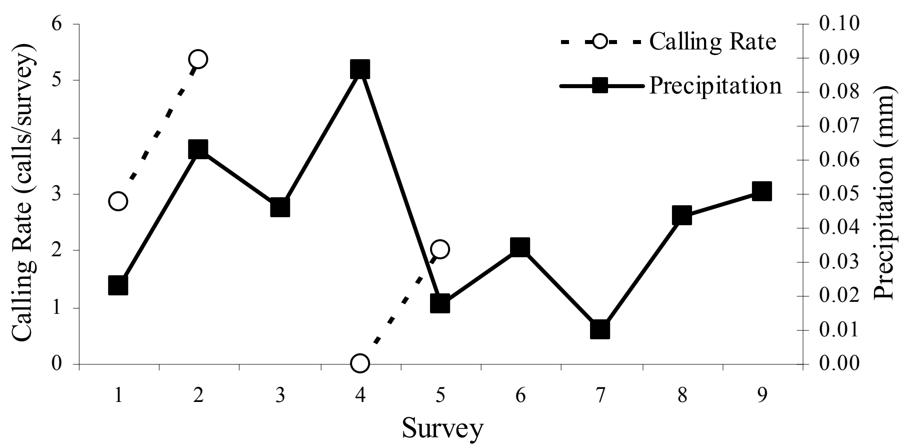
[a] Survey 1 (Jun 24–30), Survey 2 (Jul 1–7), Survey 3 (Jul 8–14), Survey 4 (Jul 15–21), Survey 5 (Jul 22–28), Survey 6 (Jul 29–Aug 4), Survey 7 (Aug 5–11), Survey 8 (Aug 12–18), Survey 9 (Aug 19–25).

Figure 13. Mean weekly calling rates (no. calls/survey/week) of Montezuma quail and mean weekly precipitation (mm) at Elephant Mountain Wildlife Management Area (n = 30 survey points) during A) July–August 2007 and B) June–August 2008. Survey interval[a] equals 1 week.

A)



B)



[a] Survey 1 (Jun 24–30), Survey 2 (Jul 1–7), Survey 3 (Jul 8–14), Survey 4 (Jul 15–21), Survey 5 (Jul 22–28), Survey 6 (Jul 29–Aug 4), Survey 7 (Aug 5–11), Survey 8 (Aug 12–18), Survey 9 (Aug 19–25).

Figure 14. Mean weekly calling rates (no. calls/survey/week) of Montezuma quail and mean weekly precipitation (mm) at Davis Mountains Preserve (*n* = 30 survey points) during A) July–August 2007 and B) June–August 2008. Survey interval[a] equals 1 week.

Table 12. Pearson product-moment correlation between mean weekly calling rate (no. calls/survey/week) and mean weekly precipitation (mm) reported by National Oceanic and Atmospheric Administration at Alpine (TX) for Elephant Mountain Wildlife Management Area (EMWMA) and at Fort Davis (TX) for the Davis Mountains Preserve (DMP), July–August 2007 and June–August 2008. Data are in Appendix 1–2.

Year Site	r	P-value
2007		
EMWMA	-0.29	0.54
DMP	0.85	0.07
Pooled	0.33	0.30
2008		
EMWMA	0.86	0.03
DMP	-0.22	0.78
Pooled	0.33	0.35
2007 & 2008		
Pooled	0.06	0.80

compared to the remaining habitat types in 2008 (Table 13). Mean calls/pt was 79–99% greater in high-suitability habitat compared to the remaining habitat types during 2008 surveys (Table 13).

Occupancy and Probability of Detection

I documented high occupancy at both Elephant Mountain WMA (95% CI: 98–100%) and Davis MP (95% CI: 94–100%) in 2007. Occupancy rates decreased for both Elephant Mountain WMA (95% CI: 47–90%) and Davis MP (95% CI: 79–100%) in 2008. I documented a low probability of detection during individual surveys at Elephant Mountain WMA (95% CI: 30–53%) and Davis MP (95% CI: 30–65%) in 2007. Probability of detection decreased for both Elephant Mountain WMA (95% CI: 14–28%) and Davis MP (95% CI: 0–20%) in 2008. These decreases in occupancy and probability of detection again were expected due to the change in survey points between years. Based on the probability of detection results for each study site and the formula used in Program SAS, I determined that surveys would have to be repeated 4–5 times in order to ensure ≥ 90% probability of detection at a point given a Montezuma quail is present.

Habitat Modeling

I began with 17 *a priori* variables (13 habitat and 4 weather) deemed biologically relevant to Montezuma quail prior to modeling occupancy and probability of detection at the microhabitat scale. I reduced this suite to 8 variables (5 habitat + 3 weather) based on correlation analysis. This decrease in number of variables reduced the number of microhabitat model combinations that needed to be run from more than one trillion models to 4,875. Of these 4,875, I removed an additional 4,651 because I deemed them biologically irrelevant.

Table 13. Mean number of birds calling/point and mean calls/point of Montezuma quail in different habitat-suitability types[a] (High, Moderate, and Low). Habitat suitability types included surveys conducted in Elephant Mountain Wildlife Management Area (N = 150 surveys), Davis Mountains Preserve (N = 150 surveys) in Jun–Aug 2007 and 2008, and for Uvalde Road Route (N = 125 surveys), and Del Rio Route (N = 100 surveys) in June–August 2008.

Year		Birds calling/point		Calls/point	
Habitat	N	$\bar{x}$	SE	$\bar{x}$	SE
2007					
High	300	0.75	0.15	4.15	0.45
2008					
High	110	0.20	0.05	1.55	0.48
Moderate	120	0.08	0.03	0.33	0.15
Low	135	0.04	0.02	0.12	0.07
None	160	0.01	0.01	0.01	0.01

[a]High = Montezuma quail were detected at >50% of survey points, Moderate = survey points that had at least 25–50% detections per habitat type, Low = survey points that had at least 10–25% detection per habitat type, None = survey points that had 0–10% detection per habitat type.

In addition to modeling probability of detection at the micro-scale with the inclusion of vegetation height while occupancy was constant, I began with 5 *a priori* variables (1 habitat and 4 weather) and reduced them to 4 variables (1 habitat, 3 weather) based on correlation analysis. This decrease in number of variables reduced the number of microhabitat models that needed to be run from 325 to 64. Of these 64, I removed an additional 32 models because I deemed them biologically irrelevant.

Regarding modeling of occupancy and probability of detection at the macro-scale, I began with 8 *a priori* variables (4 macrohabitat and 4 weather) and reduced them to 6 variables (2 macrohabitat and 3 weather) based on correlation analysis. This decrease in number of variables reduced the number of macrohabitat model combinations that needed to be run from 635,700 to 4,875. Of these 4,875, I removed an additional 4,747 models because I deemed them biologically irrelevant.

Microhabitat models.—In Analysis 1, I evaluated 224 *a priori* microhabitat models using Akaike's Information Criterion (AIC) (Appendix 4). The best model included food-plant density and percent grass cover (*psi* [1, food + grass], *p* [.]) (Table 14). Summed model weight (*w*) out of the 224 *a priori* microhabitat models for food-plant density (food) was 0.70 and 0.63 for grass cover (grass) indicating food-plant density had a primary influence on occupancy closely followed by grass cover. The best model indicated a constant probability of detection suggesting detection probability did not appear to be influenced by weather or vegetation height

In Analysis 2, I evaluated 33 *a priori* probability of detection models using Akaike's Information Criterion (AIC) (Appendix 5). The model with the lowest AIC

Table 14. Analysis 1 top 10 a *priori* microhabitat models for Montezuma quail evaluated using Akaike's Information Criterion (AIC) in Program PRESENCE 2.3. Models evaluated occupancy (*psi*) as a function of 3 micro- habitat variables (food-plant density [m^2], percent grass cover, and vegetation height [cm]) and probability of detection (*p*) as a function of weather (time, temperature, and wind), survey date, and vegetation height [dm]. The AIC values, relative differences in AIC (*Δ AIC*), AIC model weights (*w*), model likelihood (AIC weight divided by the AIC weight of the best model), and number of parameters (*K*) are given for each model. Models are for Elephant Mountain Wildlife Management Area and Davis Mountains Preserve subset data (*n* = 40 survey points) for June–August, 2007 and July–August 2008.

Model	AIC	Δ AIC	*w*	Model Likelihood	K
psi(1, food+grass),p(.)	149.30	0.00	0.06	1.00	4
psi(1, food+grass),p(time)	150.02	0.72	0.04	0.70	5
psi(grass),p(.)	150.16	0.86	0.04	0.65	2
psi(1, food),p(.)	150.28	0.98	0.04	0.61	3
psi(1, food+grass),p(1, vght)	150.58	1.28	0.03	0.53	5
psi(grass),p(1, time)	151.09	1.79	0.02	0.41	3
psi(1, food),p(1, time)	151.11	1.81	0.02	0.40	4
psi(1, food+grass),p(temp)	151.19	1.89	0.02	0.39	5
psi(1, food+grass),p(1, wind)	151.24	1.94	0.02	0.38	5
psi(1, food+grass+vght),p(.)	151.29	1.99	0.02	0.37	5

Psi (psi) and detection (*p*) were modeled as a constant (.) or as a function of micro habitat, weather, and vegetation height variables.

(psi[.], p[1, vght]) received a model likelihood of 1 (Table 15). Vegetation height (vght, [dm]) model weight is 0.45 out of the top 10 models, and a summed weight of 0.56 out of the total 33 models, which suggests that vegetation height (dm) is an important factor when trying to detect Montezuma Quail. I documented that an inverse relationship between vegetation height (dm) and probability of detection at Elephant Mountain WMA and Davis MP (Figures 15–17). This analysis corroborates the findings of Analysis 1, both of which indicated that weather did not appear to influence probability of detection given our survey protocol.

Macrohabitat models.—I evaluated 128 *a priori* macrohabitat models using Akaike's Information Criterion (AIC) to develop a predictive map of occurrence of Montezuma quail in Texas (Analysis 3). These models evaluated occupancy as a function of habitat-suitability type, slope, and elevation (Table 16). Probability of detection was evaluated as a function of weather (time, temperature, and wind) and survey (Table 16; Appendix 5). The best fit model included habitat-suitability and elevation (psi[1,high moderate low + elevation],p[.]) (Table 16). Summed model weight (*w*) out of the 128 *a priori* macrohabitat models was 0.99 for habitat-suitability type and 0.72 for elevation which suggests that habitat-suitability type and elevation had a major influence on occupancy. Probability of detection was not influenced by weather or survey date.

Predictive distribution map.— The total output area generated from ERDAS® Imagine Model Maker and ArcGIS®, included areas that were close but not in the historical or known Montezuma quail distributions. I felt that the only way to get unbiased results would be to only report areas in which I conducted surveys and had

Table 15. Analysis 2 top 10 a *priori* weather and vegetation height models (Analysis 2) for Montezuma quail evaluated using Akaike's Information Criterion (AIC) in Program PRESENCE 2.3. Models evaluated probability of detection (*p*) as a function of the constant function, survey specific function, and weather (time [am/pm], temperature [°F], wind [mph] and vegetation height [dm]. The AIC values (*AIC*), relative differences in AIC (*Δ AIC*), AIC model weights (*w*), model likelihood (AIC weight divided by the AIC weight of the best model), and the number of parameters (*K*) are given for each model. Models are for Elephant Mountain Wildlife Management Area (*n* = 30 survey points), Davis Mountains Preserve (*n* = 30 survey points) in June–August 2007.

Model	AIC	Δ AIC	*w*	Model Likelihood	K
psi(.),p(1, vght)	410.35	0.00	0.14	1.00	3
1 group, Constant P	410.60	0.25	0.12	0.88	2
psi(.),p(1, temp+vght)	410.87	0.52	0.11	0.77	4
psi(.),p(1, temp)	411.23	0.88	0.09	0.64	3
psi(.),p(1, wind+vght)	411.45	1.10	0.08	0.58	4
psi(.),p(1, time+vght)	412.35	2.00	0.05	0.37	4
psi(.),p(1, wind)	412.42	2.07	0.05	0.36	3
psi(.),p(1, time+temp+vght)	412.49	2.14	0.05	0.34	5
psi(.),p(1, temp+wind+vght)	412.52	2.17	0.05	0.34	5
psi(.),p(1, time)	412.57	2.22	0.05	0.33	3

Psi and detection (*p*) were modeled as a constant (.) or as a function of weather variables and vegetation height.

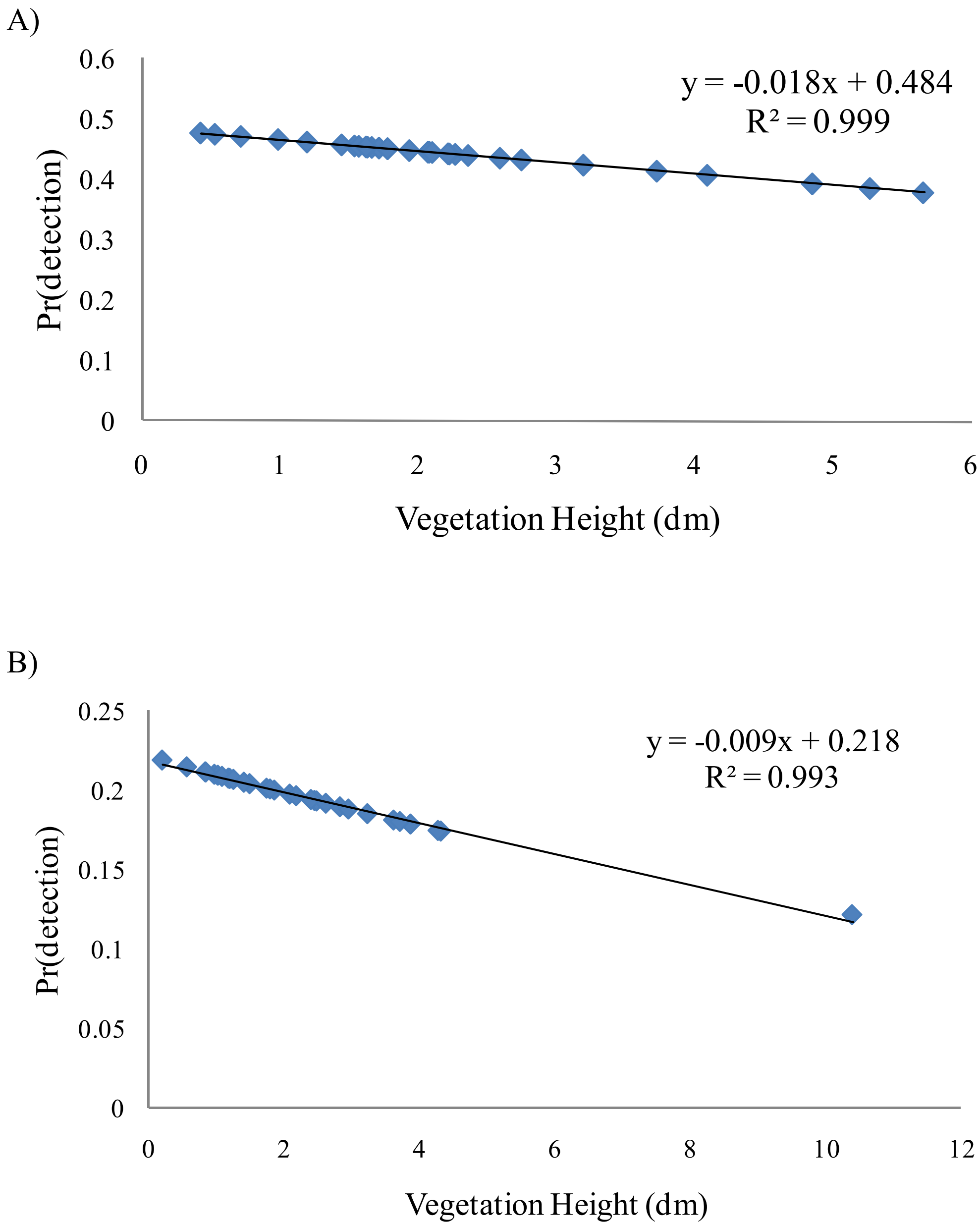


Figure 15. Probability of detection and vegetation height (dm) at Elephant Mountain Wildlife Management Area (*n* = 30 survey points) during A) July–August 2007 and B) June–August 2008.

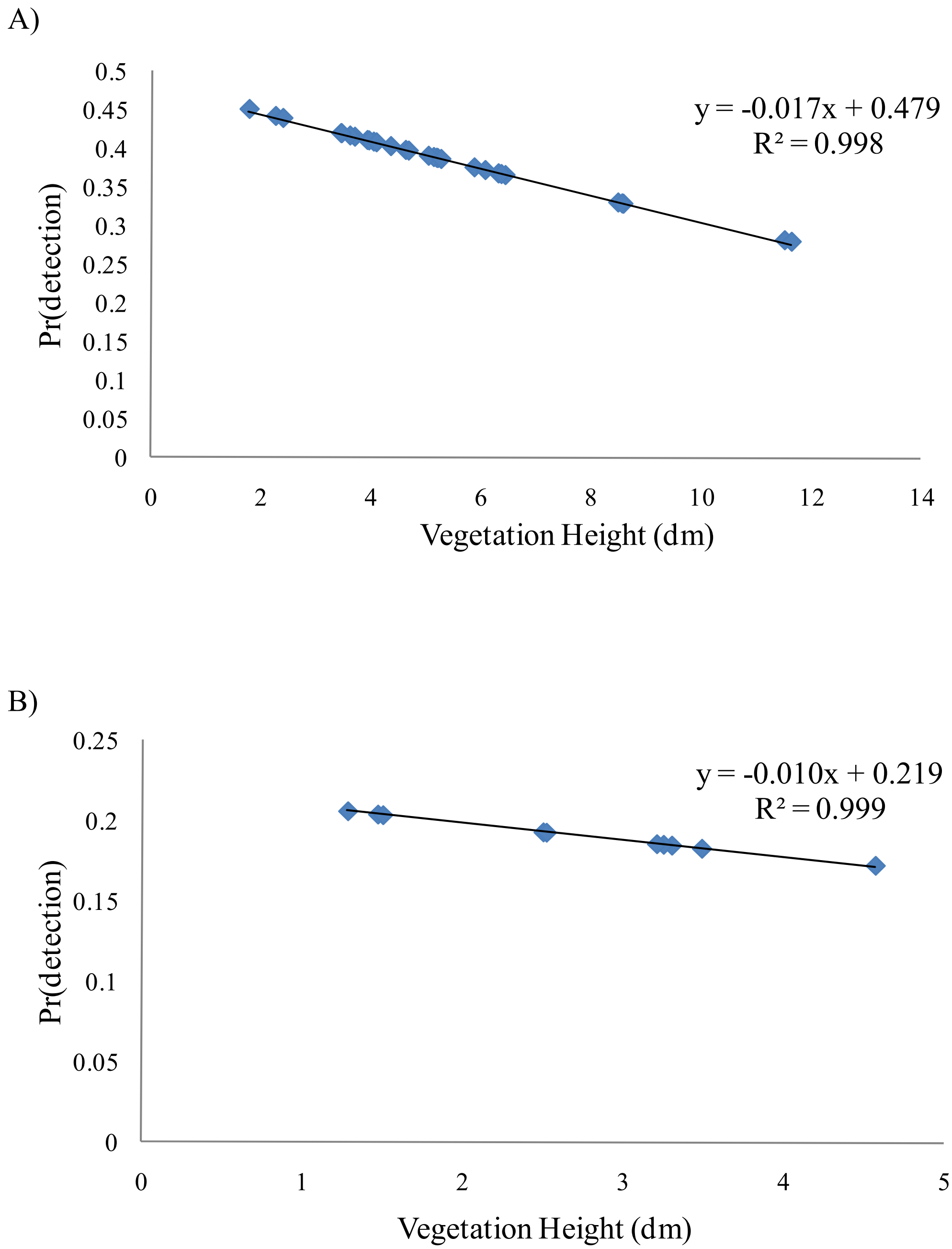
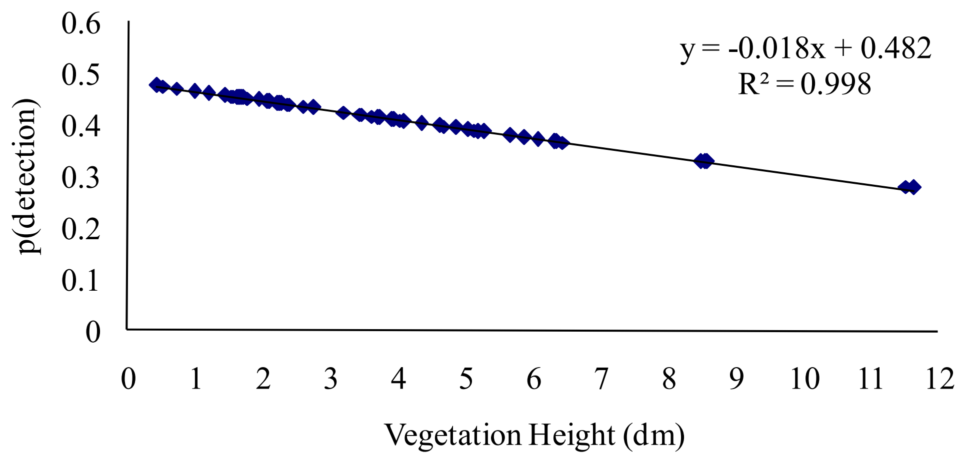


Figure 16. Probability of detection and vegetation height (dm) at Davis Mountains Preserve (n = 30 survey points) during A) July–August 2007 and (n = 10 survey points) during B) June–August 2008.

A)



B)

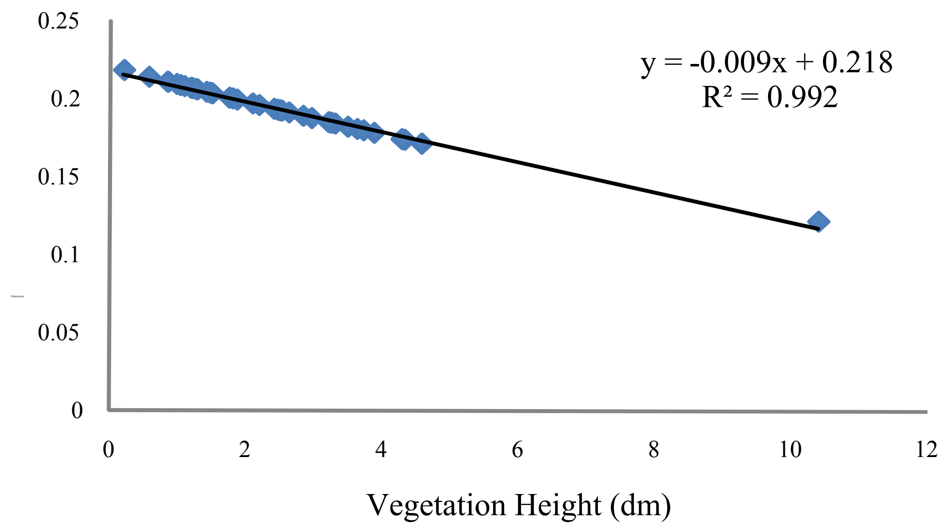


Figure 17. Probability of detection and vegetation height (dm) at Elephant Mountain Wildlife Management Area (*n* = 30 survey points in 2007, and *n* = 30 survey points in 2008) and Davis Mountains Preserve (*n* = 30 survey points in 2007 and *n* = 10 survey points in 2008) during A) July–August 2007 and B) June–August 2008.

Table 16. Analysis 3 top 10 a *priori* macro-models for Montezuma quail evaluated using Akaike's Information Criterion (AIC) in Program PRESENCE 2.3. Models evaluated occupancy (psi) as a function of 5 macrohabitat variables (habitat- suitability type [High, Moderate, or Low], slope [°], and elevation [m]), and probability of detection (p) as a constant function, survey specific function, and weather (time [am/pm], temperature [°F], and wind [mph]). The AIC values (*AIC*), relative differences in AIC (*Δ AIC*), AIC model weights (w), model likelihood (AIC weight divided by the AIC weight of the best model), and the number of parameters (K) are given for each model. Models are for Elephant Mountain Wildlife Management Area (n = 30 survey points), Davis Mountains Preserve (n = 30 survey points), Uvalde Road Route (n = 25 survey points), and Del Rio Route (n = 20 survey points) for July–August 2008. If points within a single habitat type did not have a single detection throughout the 5 surveys, they were removed because analysis was not reaching convergence (n = 25).

Model	AIC	Δ AIC	w	Model Likelihood	K
psi((1, high) moderate low+elevation),p(.)	206.79	0.00	0.15	1.00	5
psi((1, high) moderate low+elevation+elevation^2),p(.)	207.53	0.74	0.10	0.69	6
psi((1, high) moderate low),p(.)	208.41	1.62	0.07	0.44	4
psi((1, high) moderate low+elevation),p(1, time)	208.43	1.64	0.07	0.44	6
psi((1, high) moderate low+slope+elevation),p(.)	208.62	1.83	0.06	0.40	6
psi((1, high) moderate low+elevation),p(1, temp)	208.75	1.96	0.06	0.38	6
psi((1, high) moderate low+elevation),p(1, wind)	208.76	1.97	0.06	0.37	6
psi((1, high) moderate low),p(1, time)	210.05	3.26	0.03	0.20	5
psi((1, high) moderate low+slope),p(.)	210.11	3.32	0.03	0.19	5
psi((1, high) moderate low+slope+elevation),p(1, time)	210.25	3.46	0.03	0.18	7

Psi and detection (p) were modeled as a constant (.) or as a function of macro habitat, and weather variables.

enough data to make reasonable assumptions. Therefore, I excluded areas that had vegetation types that were categorized as “none”. My predictive distribution map of Montezuma quail will only include areas where I conducted call-back surveys (Figure 18).

DISCUSSION

Influence of Rainfall on Calling Behavior

I did not document a consistent, positive correlation between calling behavior and precipitation during my study. Positive correlations were found only in 1 study site in each year. This is in contrast to what is known for Montezuma quail and other quail species. Brown (1979) stated a positive correlation existed between summer precipitation and Montezuma quail harvest, suggesting a link to reproductive success and survival. Stromberg (1990) stated that nesting occurred after rains in July and August that resulted in green vegetation. In addition, 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 (Bishop and Hungerford 1965).

The lack of a relationship between calling and precipitation in my study may have resulted from precipitation data being collected at a coarse resolution. The precipitation data I used for the analysis was collected from the closest National Oceanic and Atmospheric Administration (NOAA) station available which was 47.64 km from Elephant Mountain WMA and 272 km from Davis MP. Thus, weather between the station and my study sites may have differed resulting in low correlation between weather and calling activity of Montezuma quail.

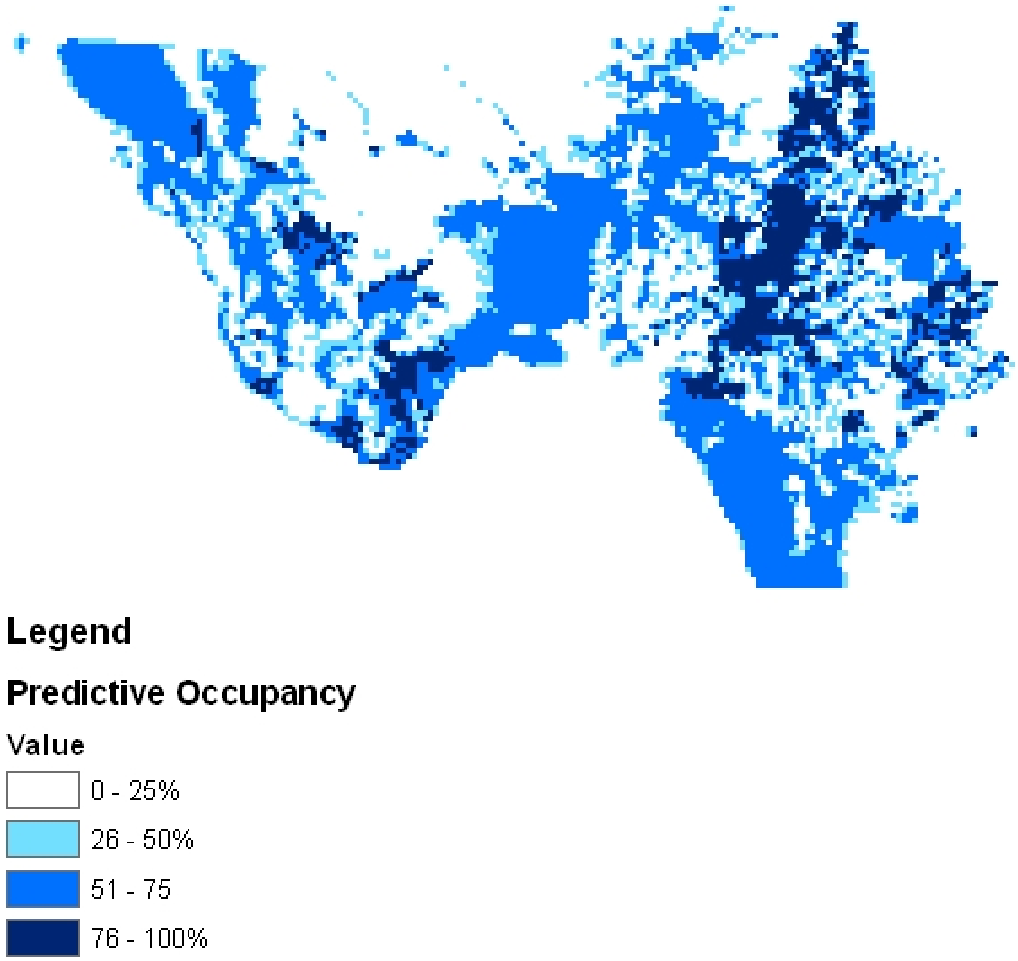


Figure 18. Predictive map of occurrence of Montezuma quail based on vegetation type and elevation in west Texas.

Detection Probability

I found that vegetation height influenced probability of detection of Montezuma quail. I found that as vegetation height increased the probability of detection decreased. In addition, vegetation height was shorter in the high habitat-suitability type than in moderate and low habitat-suitability types. Bristow and Ockenfels (2004) found that livestock grazing and cover availability are considered important factors affecting Montezuma quail distribution and density. They acknowledged that overgrazing by livestock is considered an important factor affecting distribution and abundance of Montezuma quail (Leopold and McCabe 1957, Bishop 1964, Brown 1978, 1982). In addition, Albers and Gehlbach (1990) found high amounts of tall-grass cover predicted feeding habitat on both grazed and ungrazed areas and were most important during the summer months, which coincided during the time of sampling in my study. Bristow and Ockenfels (2002, 2004) found vegetation richness, visual obstruction, and cover affected habitat selection during the brood season. They attributed this to predator avoidance and feeding strategies.

Occupancy

I found that food plant density (*Allium* spp., *Oxalis* spp., *Cyperus* spp.) and percent grass cover highly influenced occupancy. The percent grass cover was higher in the high habitat-suitability type than in moderate or low habitat suitability groups. Interestingly, I documented high occupancy at both Elephant Mountain WMA and Davis MP in optimal habitat despite the fact that habitat structure (e.g., % forb, % grass, % bare ground, vegetation height, and vertical structure) varied considerably between the 2 study areas. The habitat at Elephant Mountain WMA consists mainly of open grassland vegetation with brush and tree species in steep slopes and ravines, while the Davis MP has both open grassland vegetation along with extensive woodlands and forests. These results indicate that Montezuma quail may have a wide range of habitat suitability given the 2 study areas are markedly different, particularly in structure. Bristow and Ockenfels (2004) reported that Montezuma quail prefer oak-woodland habitats that contain a minimum tree canopy of 26% and grass canopy of 51–75% cover at 20-cm height during the pairing season. Structurally, this description is similar to the habitat in my study areas. Bristow and Ockenfels (2004) also stated that Montezuma quail can exist in areas with relatively few oak trees, although quail densities are often lower than typical in oak-woodland habitat. However, sites occupied with Montezuma quail populations seemed to be similar between Elephant Mountain WMA and Davis MP, at least based on occupancy rates.

This finding seems to indicate that habitat structure near ground level may be more important than overstory habitat structure or habitat species composition in determining habitat suitability for Montezuma quail, given the basic needs of the species are met. Hernández et al. (2006*b*) believed that species richness and diversity did not adequately characterize foraging habitat for Montezuma quail because of their specialized diets. I documented that Montezuma quail were found in areas with coverage of at least 6.5% forbs and about 2.7 food plants/m^2. Collectively, these findings indicate that even if 2 areas vary in overstory habitat structure they can both support Montezuma quail populations if they have enough grass for cover and the key plant species (*Allium* spp., *Oxalis* spp., *Cyperus* spp.) that they rely on for their diet. Importantly, these key plant species are found at rock outcrops which allow for fertile soil to collect.

Predictive Distribution Map

I documented that habitat-suitability type (high, moderate, or low) and elevation highly influenced occupancy at a macroscale in my study. Areas that are shown as high habitat-suitability are found in the Elephant WMA, Davis MP, and other small areas close to Presidio. Areas considered high coincide with the current distribution map reported by Harveson et al. (2007). I did not conduct any surveys near Presidio and this may be an area that needs sampling and further research. In my study, I found that the elevation of sites surveyed at Elephant Mountain WMA in 2007 ranged 1,596 m–1,896 m and in 2008 1,325 m–1,896 m with the expansion of study area. At Davis MP the elevation of sites surveyed in 2007 ranged 1,770 m–2,012 m and in 2008 ranged 1,144 m–1,992 m with the expansion in study area. Elevation varied between years because points surveyed changed within years. Garza (2007) found that elevations of Montezuma quail sightings at the Davis MP were most commonly recorded from 1,738 m to 1,838 m. Leopold and McCabe (1957) documented sightings at 1,554 m to 2,286 m. Stromberg (2000) documented nest sightings at elevations that ranged from 1,520 m to 1,920 m and Hernández et al. (2006*b*) found Montezuma quail at elevations of approximately 1,900 m. Albers and Gehlbach (1990) conducted studies at 2 locations in the Edwards Plateau region of Texas where the elevation was 500 m and 550 m. Elevations (1,200 m–2,750 m) with pine (*Pinus* spp.) or oak (*Quercus* spp.) vegetation are where Montezuma quail were flushed most often by surprise in the summer (Swarth 1909, Bent 1932, Miller 1943, Stromberg 2000).

CONCLUSIONS

A presence-absence approach appeared to be an efficient and practical approach to monitor Montezuma quail distributions. Based on my findings, a general survey protocol can be developed for Montezuma quail. The process entails:

- *Establishment of survey points*. An 800 × 800-m^2 grid overlaid onto a map of the area to be sampled may be used to establish survey points. This size grid appears sufficient to minimize the probability of double counting. Alternatively, survey points may be established along a route with a spacing of 2 km in order to get an accurate representation of different vegetation communities. Survey points can be established using geographic information systems (GIS) and ArcGIS® 9.2. If using a grid, each grid then will have to be assigned a numbered centroid for identification purposes. Survey points will need to be sampled randomly. In addition, being knowledgeable of Montezuma quail calls is important along with having a suitable Montezuma quail call recording.
- *Conducting call-back surveys*. Call back surveys should be conducted during the breeding season, preferably June–August. Call-back surveys may be conducted either within the morning (0700–1100 hrs) and-or evening hours (1500–1900 hrs) and consist of playing the Montezuma quail call recording for about 1.5 minutes and then pausing to listen for a Montezuma quail response. This procedure should be followed for a total of 5 minutes. Presence of Montezuma quail should be recorded when detected visually or aurally. Each monitoring site will need to be visited 4–5 times during the

field season. Survey points will need to be chosen at random and each survey point must be surveyed once before it can be done again. Record the number of individual birds calling and the total calls for each survey to calculate the mean number of birds calling for each area surveyed.

By using callback surveys monitoring agencies can possibly get a better understanding of Montezuma quail distributions in areas that haven't been researched since the 1930's. Population trends based on sites occupied could help researchers determine variables affecting Montezuma quail populations.

Montezuma quail are a unique species that warrant further research. It is important to understand the basic ecology and develop effective monitoring programs for the conservation of the species. This information will permit a better understanding of its conservation status and present distribution. It is my hope that my study has contributed toward this knowledge advancement of Montezuma quail.

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APPENDICES

Appendix 1. Statistical Analysis System formula used to determine the number of field visits required for a 95% detection probability, based off of the probability of detection Analysis 3 results.

```
TITLE 'Calculation of # of visits required for detection.';

OPTIONS PS=60 LS=90 CENTER FORMDLIM=' ';

DATA RAWDATA ; P=0.004 ; MAX=0.95 ;
        ADD = P ; TOTAL = P ; n = 1 ;
        in1: ADD = ADD* (1-P) ; n+1;
                TOTAL = TOTAL + ADD;
                IF TOTAL < MAX THEN DO ; OUTPUT ; GO TO IN1 ; END ;
ELSE STOP ;
LABEL P= 'Detection Probability' MAX='Probability Upper Limit'
        Total= 'Overall Detection Probability'
        n= '# of Visits';
PROC PRINT LABEL ; BY P MAX ;
        VAR TOTAL ; ID n ;
RUN ; QUIT ;
```

Appendix 2. Elephant Mountain Wildlife Management Area ($N_{surveys}$ = 150 surveys) Calls (total calls produced), Calling rate (calls/ survey), and precipitation (mm) from A) June (Jun)–August (Aug) 2007 B) June (Jun)–August (Aug) 2008.

A)

Survey	Week	$N_{surveys}$	Calls	Calling Rate	Precipitation
1	24 Jun–30 Jun				0.01
2	1 Jul–7 Jul	12	48	4.00	0.01
3	8 Jul–14 Jul	14	58	4.14	0.00
4	15 Jul–21Jul	15	10	0.67	0.03
5	22 Jul–28 Jul	36	85	2.36	0.01
6	29 Jul–4 Aug	27	105	3.89	0.05
7	5 Aug–11 Aug	33	195	5.91	0.00
8	12 Aug–18 Aug	13	37	2.85	0.00
9	19 Aug–25 Aug				0.00

B)

Survey	Week	$N_{surveys}$	Calls	Calling Rate	Precipitation
1	24 Jun - 30 Jun	22	0	0	0.02
2	1 Jul - 7 Jul	24	14	0.58	0.02
3	8 Jul - 14 Jul	44	29	0.66	0.00
4	15 Jul - 21Jul	30	24	0.80	0.03
5	22 Jul - 28 Jul	19	0	0.00	0.01
6	29 Jul - 4 Aug	11	29	2.64	0.06
7	5 Aug - 11 Aug				0.00
8	12 Aug - 18 Aug				0.10
9	19 Aug - 25 Aug				0.05

Appendix 3. Davis Mountains Preserve ($N_{surveys}$ = 150 surveys) Calls (total calls produced), Calling rate (calls/ survey), and precipitation (mm) from A) June (Jun)–August (Aug) 2007 B) June (Jun)–August (Aug) 2008.

A)

Survey	Week	$N_{surveys}$	Calls	Calling Rate	Precipitation
1	24 Jun–30 Jun				0.01
2	1 Jul–7 Jul				0.03
3	8 Jul–14 Jul	23	129	5.61	0.03
4	15 Jul–21Jul	20	169	8.45	0.05
5	22 Jul–28 Aug	30	160	5.33	0.01
6	29 Jul–4 Aug				0.04
7	5 Aug–11 Aug	32	136	4.25	0.03
8	12 Aug–18 Aug	45	123	2.73	0.00
9	19 Aug–25 Aug				0.00

B)

Survey	Week	$N_{surveys}$	Calls	Calling Rate	Precipitation
1	24 Jun - 30 Jun	7	20	2.86	0.02
2	1 Jul - 7 Jul	11	59	5.36	0.06
3	8 Jul - 14 Jul				0.05
4	15 Jul - 21Jul	20	0	0.00	0.09
5	22 Jul - 28 Aug	12	24	2.00	0.02
6	29 Jul - 4 Aug				0.03
7	5 Aug - 11 Aug				0.01
8	12 Aug - 18 Aug				0.04
9	19 Aug - 25 Aug				0.05

Appendix 4. Analysis 1 *a priori* microhabitat models for Montezuma quail evaluated using Akaike's Information Criterion (AIC) in Program PRESENCE 2.3. Models evaluated occupancy (psi) as a function of 3 microhabitat variables (food-plant density [m^2], grass cover [%], and vegetation height [dm]) and probability of detection (p) as a function of weather (time [am or pm], temperature [°C], and wind [mph]), survey, and vegetation height [dm]. The AIC values, relative differences in AIC (Δ AIC), AIC model weights (*w*), model likelihood (AIC weight divided by the AIC weight of the best model), and number of parameters (*K*) are given for each model. Models are for Elephant Mountain Wildlife Management Area (*n* = 30 survey points) and Davis Mountains Preserve (*n* = 10 survey points) for July–August 2008.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
1	psi(1, food+grass),p(.)	149.30	0.00	0.06	1.00	4
2	psi(1, food+grass),p(time)	150.02	0.72	0.04	0.70	5
3	psi(grass),p(.)	150.16	0.86	0.04	0.65	2
4	psi(1, food),p(.)	150.28	0.98	0.04	0.61	3
5	psi(1, food+grass),p(1, vght)	150.58	1.28	0.03	0.53	5
6	psi(grass),p(1, time)	151.09	1.79	0.02	0.41	3
7	psi(1, food),p(1, time)	151.11	1.81	0.02	0.40	4
8	psi(1, food+grass),p(temp)	151.19	1.89	0.02	0.39	5
9	psi(1, food+grass),p(1, wind)	151.24	1.94	0.02	0.38	5
10	psi(1, food+grass+vght),p(.)	151.29	1.99	0.02	0.37	5
11	psi(1, food+grass),p(1, time+vght)	151.49	2.19	0.02	0.33	6
12	psi(1, food+grass),p(1, time+temp)	151.50	2.20	0.02	0.33	6

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
13	psi(1, food+grass),p(1, time+wind)	151.99	2.69	0.02	0.26	6
14	psi(1, food+grass+vght),p(1, time)	152.00	2.70	0.02	0.26	6
15	psi(1, food+grass+vght),p(1, vght)	152.06	2.76	0.02	0.25	6
16	psi(grass),p(1, temp)	152.08	2.78	0.02	0.25	3
17	psi(grass),p(1, wind)	152.13	2.83	0.01	0.24	3
18	psi(1, food),p(1, temp)	152.15	2.85	0.01	0.24	4
19	psi(1, food+vght),p(.)	152.15	2.85	0.01	0.24	4
20	psi(grass),p(1, vght)	152.16	2.86	0.01	0.24	3
21	psi(1, food+grass+vght),p(1, time+vght)	152.18	2.88	0.01	0.24	7
22	psi(1, food),p(1, vght)	152.19	2.89	0.01	0.24	4
23	psi(1, food),p(1, wind)	152.26	2.96	0.01	0.23	4
24	1 group, Constant P	152.29	2.99	0.01	0.22	2
25	psi(1, food+grass),p(1, temp+vght)	152.39	3.09	0.01	0.21	6
26	psi(1, food),p(1, time+temp)	152.57	3.27	0.01	0.20	5
27	psi(1, food+grass),p(1, wind+vght)	152.58	3.28	0.01	0.19	6
28	psi(grass),p(1, time+temp)	152.74	3.44	0.01	0.18	4
29	psi(1, vght),p(1, vght)	152.79	3.49	0.01	0.17	4
30	psi(1, food),p(1, time+wind)	152.81	3.51	0.01	0.17	5
31	psi(1, food+grass),p(1, time+temp+vght)	152.90	3.60	0.01	0.17	7
32	psi(1, food),p(1, time+vght)	152.94	3.64	0.01	0.16	5
33	psi(1, food+vght),p(1, time)	152.97	3.67	0.01	0.16	5

Appendix 4 Continued

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
34	psi(food+grass+vght),p(1, time+temp)	153.04	3.74	0.01	0.15	6
35	psi(grass),p(1, time+wind)	153.06	3.76	0.01	0.15	4
36	psi(grass),p(1, time+vght)	153.09	3.79	0.01	0.15	4
37	psi(1, food+grass),p(1, temp+wind)	153.09	3.79	0.01	0.15	6
38	psi(1, food+grass+vght),p(1, temp)	153.17	3.87	0.01	0.14	6
39	psi(.),p(1, time)	153.23	3.93	0.01	0.14	3
40	psi(1, food+grass+vght),p(1, wind)	153.24	3.94	0.01	0.14	6
41	psi(1, food+grass),p(1, time+wind+vght)	153.39	4.09	0.01	0.13	7
42	psi(1, grass),p(1, survey)	153.41	4.11	0.01	0.13	7
43	psi(1, food+grass),p(1, time+temp+wind)	153.49	4.19	0.01	0.12	7
44	psi(1, vght),p(1, time+vght)	153.75	4.45	0.01	0.11	5
45	psi(1, food+vght),p(1, vght)	153.81	4.51	0.01	0.10	5
46	psi(1, food+grass+vght),p(1, temp+vght)	153.88	4.58	0.01	0.10	7
47	psi(1, food+grass+vght),p(1, time+wind)	153.96	4.66	0.01	0.10	7
48	psi(grass),p(1, temp+wind)	154.03	4.73	0.01	0.09	4
49	psi(1, food+vght),p(1, temp)	154.03	4.73	0.01	0.09	5
50	psi(1, food+grass+vght),p(1, wind+vght)	154.06	4.76	0.01	0.09	7
51	psi(grass),p(1, temp+vght)	154.08	4.78	0.01	0.09	4
52	psi(1, food),p(1, temp+vght)	154.08	4.78	0.01	0.09	5
53	psi(grass),p(1, wind+vght)	154.13	4.83	0.01	0.09	4
54	psi(1, vght),p(.)	154.14	4.84	0.01	0.09	3

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	w	Model Likelihood	K
55	psi(1, food+vght),p(1, wind)	154.14	4.84	0.01	0.09	5
56	psi(1, food),p(1, temp+wind)	154.14	4.84	0.01	0.09	5
57	psi(.),p(1, vght)	154.16	4.86	0.01	0.09	3
58	psi(1, food),p(1, wind+vght)	154.18	4.88	0.01	0.09	5
59	psi(.),p(1, temp)	154.21	4.91	0.01	0.09	3
60	psi(.),p(1, wind)	154.29	4.99	0.01	0.08	3
61	psi(1, food+grass),p(1, temp+wind+vght)	154.38	5.08	0.00	0.08	7
62	psi(1, food),p(1, time+temp+wind)	154.38	5.08	0.00	0.08	6
63	psi(1, food),p(1, time+temp+vght)	154.44	5.14	0.00	0.08	6
64	psi(1, food+vght),p(1, time+temp)	154.45	5.15	0.00	0.08	6
65	psi(food+grass+vght),p(1, temp+wind)	154.45	5.15	0.00	0.08	6
66	psi(1, food+vght),p(1, time+vght)	154.47	5.17	0.00	0.08	6
67	psi(1, food+grass+vght),p(1, time+temp+vght)	154.49	5.19	0.00	0.07	8
68	psi(1, vght),p(1, wind+vght)	154.53	5.23	0.00	0.07	5
69	psi(1, vght),p(1, temp+vght)	154.66	5.36	0.00	0.07	5
70	psi(1, food),p(1, time+wind+vght)	154.69	5.39	0.00	0.07	6
71	psi(grass),p(1, time+temp+wind)	154.72	5.42	0.00	0.07	5
72	psi(1, food+vght),p(1, time+wind)	154.73	5.43	0.00	0.07	6
73	psi(grass),p(1, time+temp+vght)	154.74	5.44	0.00	0.07	5
74	psi(1, vght),p(1, temp)	154.76	5.46	0.00	0.07	4
75	psi(1, food+grass),p(1, time+temp+wind+vght)	154.82	5.52	0.00	0.06	8

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
76	psi(.),p(1, time+temp)	154.87	5.57	0.00	0.06	4
77	psi(1, food+grass+vght),p(1, time+wind+vght)	154.94	5.64	0.00	0.06	8
78	psi(1, vght),p(1, time+wind+vght)	154.98	5.68	0.00	0.06	6
79	psi(.),p(1, time+vght)	155.04	5.74	0.00	0.06	4
80	psi(food+grass+vght),p(1, time+temp+wind)	155.04	5.74	0.00	0.06	7
81	psi(grass),p(1, time+wind+vght)	155.06	5.76	0.00	0.06	5
82	psi(.),p(1, time+wind)	155.07	5.77	0.00	0.06	4
83	psi(1, vght),p(1, time)	155.08	5.78	0.00	0.06	4
84	psi(1, vght),p(1, time+temp+vght)	155.35	6.05	0.00	0.05	6
85	psi(1, food+vght),p(1, temp+vght)	155.69	6.39	0.00	0.04	6
86	psi(1, food+vght),p(1, wind+vght)	155.75	6.45	0.00	0.04	6
87	psi(1, food+grass+vght),p(1, temp+wind+vght)	155.88	6.58	0.00	0.04	8
88	psi(1, food+vght),p(1, time+temp+vght)	155.97	6.67	0.00	0.04	7
89	psi(1, food+vght),p(1, time+wind+vght)	156.02	6.72	0.00	0.03	7
90	psi(grass),p(1, temp+wind+vght)	156.03	6.73	0.00	0.03	5
91	psi(1, food+vght),p(1, temp+wind)	156.03	6.73	0.00	0.03	6
92	psi(1, food),p(1, temp+wind+vght)	156.08	6.78	0.00	0.03	6
93	psi(.),p(1, temp+vght)	156.10	6.80	0.00	0.03	4
94	psi(1, vght),p(1, wind)	156.14	6.84	0.00	0.03	4
95	psi(.),p(1, wind+vght)	156.16	6.86	0.00	0.03	4
96	psi(.),p(1, temp+wind)	156.21	6.91	0.00	0.03	4

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
97	psi(1, food+grass),p(1, survey)	156.28	6.98	0.00	0.03	8
98	psi(1, food),p(1, time+temp+wind+vght)	156.28	6.98	0.00	0.03	7
99	psi(1, food+vght),p(1, time+temp+wind)	156.30	7.00	0.00	0.03	7
100	psi(1, food+grass+vght),p(1, time+temp+wind+vght)	156.41	7.11	0.00	0.03	9
101	psi(1, vght),p(1, temp+wind+vght)	156.46	7.16	0.00	0.03	6
102	psi(1, vght),p(1, time+temp+wind+vght)	156.70	7.40	0.00	0.02	7
103	psi(.),p(1, time+temp+vght)	156.70	7.40	0.00	0.02	5
104	psi(grass),p(1, time+temp+wind+vght)	156.72	7.42	0.00	0.02	6
105	psi(1, vght),p(1, time+temp)	156.74	7.44	0.00	0.02	5
106	psi(.),p(1, time+temp+wind)	156.76	7.46	0.00	0.02	5
107	psi(.),p(1, time+wind+vght)	156.93	7.63	0.00	0.02	5
108	psi(1, vght),p(1, time+wind)	156.98	7.68	0.00	0.02	5
109	psi(grass),p(1, survey)	157.19	7.89	0.00	0.02	6
110	psi(1, food),p(1, survey)	157.25	7.95	0.00	0.02	7
111	psi(1, food+grass),p(1, survey+time)	157.28	7.98	0.00	0.02	9
112	psi(1, food+grass),p(1, survey+vght)	157.55	8.25	0.00	0.02	9
113	psi(1, food+vght),p(1, time+temp+wind+vght)	157.65	8.35	0.00	0.02	8
114	psi(1, food+vght),p(1, temp+wind+vght)	157.66	8.36	0.00	0.02	7
115	psi(1, vght),p(1, temp+wind)	158.06	8.76	0.00	0.01	5
116	psi(.),p(1, temp+wind+vght)	158.09	8.79	0.00	0.01	5
117	psi(1, food+grass),p(1, survey+temp)	158.10	8.80	0.00	0.01	9

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
118	psi(1, food+grass),p(1, survey+wind)	158.25	8.95	0.00	0.01	9
119	psi(1, food+grass+vght),p(1, survey)	158.26	8.96	0.00	0.01	9
120	psi(1, food),p(1, survey+time)	158.37	9.07	0.00	0.01	8
121	psi(1, food+grass),p(1, survey+time+temp)	158.63	9.33	0.00	0.01	10
122	psi(.),p(1, time+temp+wind+vght)	158.63	9.33	0.00	0.01	6
123	psi(1, vght),p(1, time+temp+wind)	158.67	9.37	0.00	0.01	6
124	psi(food+grass+vght),p(1, survey+time)	158.72	9.42	0.00	0.01	9
125	psi(1, food+grass),p(1, survey+time+vght)	158.73	9.43	0.00	0.01	10
126	psi(1, food),p(1, survey+temp)	159.02	9.72	0.00	0.01	8
127	psi(grass),p(1, survey+temp)	159.05	9.75	0.00	0.01	7
128	psi(1, food+grass+vght),p(1, survey+vght)	159.05	9.75	0.00	0.01	10
129	psi(1, food+vght),p(1, survey)	159.11	9.81	0.00	0.01	8
130	psi(1, food),p(1, survey+vght)	159.16	9.86	0.00	0.01	8
131	psi(1, food),p(1, survey+wind)	159.18	9.88	0.00	0.01	8
132	psi(grass),p(1, survey+wind)	159.18	9.88	0.00	0.01	7
133	psi(grass),p(1, survey+vght)	159.19	9.89	0.00	0.01	7
134	psi(1, food+grass),p(1, survey+time+wind)	159.26	9.96	0.00	0.01	10
135	psi(1, food+grass),p(1, survey+temp+vght)	159.26	9.96	0.00	0.01	10
136	psi(.),p(1, survey)	159.29	9.99	0.00	0.01	6
137	psi(food+grass+vght),p(1, survey+temp)	159.51	10.21	0.00	0.01	9
138	psi(1, food+grass),p(1, survey+wind+vght)	159.55	10.25	0.00	0.01	10

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
139	psi(1, food),p(1, survey+time+temp)	159.71	10.41	0.00	0.01	9
140	psi(1, vght),p(1, survey+vght)	159.83	10.53	0.00	0.01	8
141	psi(grass),p(1, survey+time+temp)	159.88	10.58	0.00	0.01	8
142	psi(1, food+grass),p(1, survey+time+temp+vght)	159.98	10.68	0.00	0.00	11
143	psi(1, food+grass),p(1, survey+temp+wind)	160.02	10.72	0.00	0.00	10
144	psi(1, food),p(1, survey+time+wind)	160.10	10.80	0.00	0.00	9
145	psi(food+grass+vght),p(1, survey+time+temp)	160.16	10.86	0.00	0.00	10
146	psi(1, food),p(1, survey+time+vght)	160.21	10.91	0.00	0.00	9
147	psi(1, food+vght),p(1, survey+time)	160.23	10.93	0.00	0.00	9
148	psi(1, food+grass+vght),p(1, survey+wind)	160.24	10.94	0.00	0.00	10
149	psi(1, food+grass+vght),p(1, survey+time+vght)	160.26	10.96	0.00	0.00	11
150	psi(grass),p(1, survey+time+wind)	160.30	11.00	0.00	0.00	8
151	psi(grass),p(1, survey+time+vght)	160.32	11.02	0.00	0.00	8
152	psi(.),p(1, survey+time)	160.47	11.17	0.00	0.00	7
153	psi(1, food+grass),p(1, survey+time+temp+wind)	160.63	11.33	0.00	0.00	11
154	psi(1, food+grass),p(1, survey+time+wind+vght)	160.65	11.35	0.00	0.00	11
155	psi(1, food+grass+vght),p(1, survey+temp+vght)	160.77	11.47	0.00	0.00	11
156	psi(1, food+vght),p(1, survey+vght)	160.79	11.49	0.00	0.00	9
157	psi(1, food+vght),p(1, survey+temp)	160.91	11.61	0.00	0.00	9
158	psi(1, food),p(1, survey+temp+vght)	160.96	11.66	0.00	0.00	9
159	psi(1, vght),p(1, survey+time+vght)	160.97	11.67	0.00	0.00	9

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
160	psi(grass),p(1, survey+temp+wind)	161.01	11.71	0.00	0.00	8
161	psi(1, food),p(1, survey+temp+wind)	161.01	11.71	0.00	0.00	9
162	psi(grass),p(1, survey+temp+vght)	161.04	11.74	0.00	0.00	8
163	psi(1, food+grass+vght),p(1, survey+wind+vght)	161.04	11.74	0.00	0.00	11
164	psi(1, food+vght),p(1, survey+wind)	161.08	11.78	0.00	0.00	9
165	psi(1, food),p(1, survey+wind+vght)	161.12	11.82	0.00	0.00	9
166	psi(.),p(1, survey+temp)	161.14	11.84	0.00	0.00	7
167	psi(1, vght),p(1, survey)	161.14	11.84	0.00	0.00	7
168	psi(.),p(1, survey+vght)	161.16	11.86	0.00	0.00	7
169	psi(grass),p(1, survey+wind+vght)	161.18	11.88	0.00	0.00	8
170	psi(1, food+grass+vght),p(1, survey+time+wind)	161.24	11.94	0.00	0.00	11
171	psi(1, food+grass),p(1, survey+temp+wind+vght)	161.26	11.96	0.00	0.00	11
172	psi(.),p(1, survey+wind)	161.27	11.97	0.00	0.00	7
173	psi(food+grass+vght),p(1, survey+temp+wind)	161.41	12.11	0.00	0.00	10
174	psi(1, vght),p(1, survey+wind+vght)	161.47	12.17	0.00	0.00	9
175	psi(1, food+grass+vght),p(1, survey+time+temp+vght)	161.55	12.25	0.00	0.00	12
176	psi(1, food),p(1, survey+time+temp+wind)	161.58	12.28	0.00	0.00	10
177	psi(1, food+vght),p(1, survey+time+temp)	161.59	12.29	0.00	0.00	10
178	psi(1, food),p(1, survey+time+temp+vght)	161.60	12.30	0.00	0.00	10
179	psi(1, vght),p(1, survey+temp+vght)	161.60	12.30	0.00	0.00	9
180	psi(1, food+vght),p(1, survey+time+vght)	161.78	12.48	0.00	0.00	10

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
181	psi(grass),p(1, survey+time+temp+wind)	161.87	12.57	0.00	0.00	9
182	psi(grass),p(1, survey+time+temp+vght)	161.88	12.58	0.00	0.00	9
183	psi(1, food+grass),p(1, survey+time+temp+wind+vght)	161.95	12.65	0.00	0.00	12
184	psi(1, food),p(1, survey+time+wind+vght)	162.00	12.70	0.00	0.00	10
185	psi(.),p(1, survey+time+temp)	162.01	12.71	0.00	0.00	8
186	psi(1, food+vght),p(1, survey+time+wind)	162.02	12.72	0.00	0.00	10
187	psi(food+grass+vght),p(1, survey+time+temp+wind)	162.16	12.86	0.00	0.00	11
188	psi(1, food+grass+vght),p(1, survey+time+wind+vght)	162.17	12.87	0.00	0.00	12
189	psi(1, vght),p(1, survey+time+wind+vght)	162.23	12.93	0.00	0.00	10
190	psi(.),p(1, survey+time+vght)	162.29	12.99	0.00	0.00	8
191	psi(grass),p(1, survey+time+wind+vght)	162.30	13.00	0.00	0.00	9
192	psi(1, vght),p(1, survey+time)	162.31	13.01	0.00	0.00	8
193	psi(.),p(1, survey+time+wind)	162.33	13.03	0.00	0.00	8
194	psi(1, vght),p(1, survey+time+temp+vght)	162.49	13.19	0.00	0.00	10
195	psi(1, food+vght),p(1, survey+temp+vght)	162.59	13.29	0.00	0.00	10
196	psi(1, food+vght),p(1, survey+wind+vght)	162.67	13.37	0.00	0.00	10
197	psi(1, food+grass+vght),p(1, survey+temp+wind+vght)	162.77	13.47	0.00	0.00	12
198	psi(1, food+vght),p(1, survey+temp+wind)	162.90	13.60	0.00	0.00	10
199	psi(1, food),p(1, survey+temp+wind+vght)	162.95	13.65	0.00	0.00	10
200	psi(1, vght),p(1, survey+temp)	163.01	13.71	0.00	0.00	8
201	psi(grass),p(1, survey+temp+wind+vght)	163.01	13.71	0.00	0.00	9

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
202	psi(.),p(1, survey+temp+vght)	163.04	13.74	0.00	0.00	8
203	psi(1, vght),p(1, survey+wind)	163.14	13.84	0.00	0.00	8
204	psi(.),p(1, survey+temp+wind)	163.14	13.84	0.00	0.00	8
205	psi(.),p(1, survey+wind+vght)	163.16	13.86	0.00	0.00	8
206	psi(1, food+vght),p(1, survey+time+temp+vght)	163.19	13.89	0.00	0.00	11
207	psi(1, vght),p(1, survey+temp+wind+vght)	163.34	14.04	0.00	0.00	10
208	psi(1, food+vght),p(1, survey+time+wind+vght)	163.36	14.06	0.00	0.00	11
209	psi(1, food),p(1, survey+time+temp+wind+vght)	163.49	14.19	0.00	0.00	11
210	psi(1, food+vght),p(1, survey+time+temp+wind)	163.49	14.19	0.00	0.00	11
211	psi(1,food+grass+vght),p(1,survey+time+temp+wind+vght)	163.51	14.21	0.00	0.00	13
212	psi(.),p(1, survey+time+temp+vght)	163.85	14.55	0.00	0.00	9
213	psi(1, vght),p(1, survey+time+temp)	163.87	14.57	0.00	0.00	9
214	psi(grass),p(1, survey+time+temp+wind+vght)	163.87	14.57	0.00	0.00	10
215	psi(1, vght),p(1, survey+time+temp+wind+vght)	163.88	14.58	0.00	0.00	11
216	psi(.),p(1, survey+time+temp+wind)	163.93	14.63	0.00	0.00	9
217	psi(.),p(1, survey+time+wind+vght)	164.18	14.88	0.00	0.00	9
218	psi(1, vght),p(1, survey+time+wind)	164.23	14.93	0.00	0.00	9
219	psi(1, food+vght),p(1, survey+temp+wind+vght)	164.54	15.24	0.00	0.00	11
220	psi(1, food+vght),p(1, survey+time+temp+wind+vght)	164.94	15.64	0.00	0.00	12
221	psi(1, vght),p(1, survey+temp+wind)	165.01	15.71	0.00	0.00	9
222	psi(.),p(1, survey+temp+wind+vght)	165.04	15.74	0.00	0.00	9

Appendix 4 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
223	psi(.),p(1, survey+time+temp+wind+vght)	165.81	16.51	0.00	0.00	10
224	psi(1, vght),p(1, survey+time+temp+wind)	165.83	16.53	0.00	0.00	10

Psi (*psi*) and detection (*p*) were modeled as a constant (.) or as a function of micro habitat, weather, and vegetation height.

Appendix 5. Analysis 2 *a priori* weather and vegetation height models for Montezuma quail evaluated using Akaike's Information Criterion (AIC) in Program PRESENCE 2.3. Models evaluated probability of detection (p) as a constant function, survey, and weather (time [am/pm], temperature [°C], wind [mph]) and vegetation height [dm]. The AIC values (AIC), relative differences in AIC (Δ AIC), AIC model weights (*w*), model likelihood (AIC weight divided by the AIC weight of the best model), and the number of parameters (*K*) are given for each model. Models are for Elephant Mountain Wildlife Management Area (*n* = 30 survey points), Davis Mountains Preserve (*n* = 30 survey points) in June–August 2007.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
1	psi(.),p(1, vght)	410.35	0	0.14	1.00	3
2	1 group, Constant P	410.60	0.25	0.12	0.88	2
3	psi(.),p(1, temp+vght)	410.87	0.52	0.11	0.77	4
4	psi(.),p(1, temp)	411.23	0.88	0.09	0.64	3
5	psi(.),p(1, wind+vght)	411.45	1.10	0.08	0.58	4
6	psi(.),p(1, time+vght)	412.35	2.00	0.05	0.37	4
7	psi(.),p(1, wind)	412.42	2.07	0.05	0.36	3
8	psi(.),p(1, time+temp+vght)	412.49	2.14	0.05	0.34	5
9	psi(.),p(1, temp+wind+vght)	412.52	2.17	0.05	0.34	5
10	psi(.),p(1, time)	412.57	2.22	0.05	0.33	3
11	psi(.),p(1, time+temp)	413.01	2.66	0.04	0.26	4
12	psi(.),p(1, temp+wind)	413.23	2.88	0.03	0.24	4

Appendix 5 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
13	psi(.),p(1, time+wind+vght)	413.41	3.06	0.03	0.22	5
14	psi(.),p(1, time+temp+wind+vght)	414.03	3.68	0.02	0.16	6
15	psi(.),p(1, time+wind)	414.41	4.06	0.02	0.13	4
16	psi(.),p(1, time+temp+wind)	415.00	4.65	0.01	0.10	5
17	psi(.),p(1,survey+vght)	415.81	5.46	0.01	0.07	7
18	psi(.),p(1,survey+temp+vght)	415.92	5.57	0.01	0.06	8
19	psi(.),p(1,survey)	416.04	5.69	0.01	0.06	6
20	psi(.),p(1,survey+temp)	416.26	5.91	0.01	0.05	7
21	psi(.),p(1,survey+wind+vght)	416.53	6.18	0.01	0.05	8
22	psi(.),p(1,survey+temp+wind+vght)	417.35	7.00	0.00	0.03	9
23	psi(.),p(1,survey+wind)	417.69	7.34	0.00	0.03	7
24	psi(.),p(1,survey+time+temp+vght)	417.69	7.34	0.00	0.03	9
25	psi(.),p(1,survey+time+vght)	417.74	7.39	0.00	0.02	8
26	psi(.),p(1,survey+time)	417.89	7.54	0.00	0.02	7
27	psi(.),p(1,survey+time+temp)	418.15	7.80	0.00	0.02	8
28	psi(.),p(1,survey+temp+wind)	418.22	7.87	0.00	0.02	8
29	psi(.),p(1,survey+time+wind+vght)	418.53	8.18	0.00	0.02	9
30	psi(.),p(1,survey+time+temp+wind+vght)	419.02	8.67	0.00	0.01	10
31	psi(.),p(1,survey+time+wind)	419.62	9.27	0.00	0.01	8
32	psi(.),p(1,survey+time+temp+wind)	420.10	9.75	0.00	0.01	9

Occupancy (ψ) and detection (*p*) were modeled as a constant (.) or as a function of weather variables and vegetation height.

Appendix 6. Analysis 3 *a priori* macro-models for Montezuma quail evaluated using Akaike's Information Criterion (AIC) in Program PRESENCE 2.3. Models evaluated occupancy (psi) as a function of 5 macrohabitat variables (habitat-suitability type [High, Moderate, or Low], slope [°], and elevation [m]), and probability of detection (p) as a constant function, survey, and weather (time [am/pm], temperature [°C], and wind [mph]). The AIC values (AIC), relative differences in AIC (Δ AIC), AIC model weights (*w*), model likelihood (AIC weight divided by the AIC weight of the best model), and the number of parameters (K) are given for each model. Models are for Elephant Mountain Wildlife Management Area (*n* = 30 survey points), Davis Mountains Preserve (*n* = 30 survey points), Uvalde Road Route (*n* = 25 survey points), and Del Rio Route (*n* = 20 survey points) for July–August 2008. If points within a single habitat type did not have a single detection throughout the 5 surveys, they were removed because analysis was not reaching convergence (*n* = 25 survey points).

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
1	psi((1, high) moderate low+elevation),p(.)	206.79	0	0.15	1.00	5
2	psi((1, high) moderate low+elevation+elevation^2),p(.)	207.53	0.74	0.10	0.69	6
3	psi((1, high) moderate low),p(.)	208.41	1.62	0.07	0.44	4
4	psi((1, high) moderate low+elevation),p(1, time)	208.43	1.64	0.07	0.44	6
5	psi((1, high) moderate low+slope+elevation),p(.)	208.62	1.83	0.06	0.40	6
6	psi((1, high) moderate low+elevation),p(1, temp)	208.75	1.96	0.06	0.38	6

Appendix 6 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
7	psi((1, high) moderate low+elevation),p(1, wind)	208.76	1.97	0.06	0.37	6
8	psi((1, high) moderate low),p(1, time)	210.05	3.26	0.03	0.20	5
9	psi((1, high) moderate low+slope),p(.)	210.11	3.32	0.03	0.19	5
10	psi((1, high) moderate low+slope+elevation),p(1, time)	210.25	3.46	0.03	0.18	7
11	psi((1, high) moderate low),p(1, wind)	210.37	3.58	0.03	0.17	5
12	psi((1, high) moderate low),p(1, temp)	210.40	3.61	0.02	0.16	5
13	psi((1, high) moderate low+elevation),p(1, time+temp)	210.43	3.64	0.02	0.16	7
14	psi((1, high) moderate low+elevation),p(1, time+wind)	210.43	3.64	0.02	0.16	7
15	psi((1, high) moderate low+slope+elevation),p(1, wind)	210.57	3.78	0.02	0.15	7
16	psi((1, high) moderate low+slope+elevation),p(1, temp)	210.59	3.80	0.02	0.15	7
17	psi((1, high) moderate low+elevation),p(1, temp+wind)	210.73	3.94	0.02	0.14	7
18	psi((1, high) moderate low+slope),p(1, time)	211.75	4.96	0.01	0.08	6
19	psi((1, high) moderate low),p(1, time+temp)	212.04	5.25	0.01	0.07	6
20	psi((1, high) moderate low),p(1, time+wind)	212.05	5.26	0.01	0.07	6
21	psi((1, high) moderate low+slope),p(1, wind)	212.06	5.27	0.01	0.07	6
22	psi((1, high) moderate low+slope),p(1, temp)	212.10	5.31	0.01	0.07	6
23	psi((1, high) moderate low+slope+elevation),p(1, time+temp)	212.24	5.45	0.01	0.07	8
24	psi((1, high) moderate low+slope+elevation),p(1, time+wind)	212.24	5.45	0.01	0.07	8
25	psi((1, high) moderate low+elevation),p(1, survey)	212.26	5.47	0.01	0.06	9
26	psi((1, high) moderate low),p(1, temp+wind)	212.37	5.58	0.01	0.06	6

Appendix 6 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
27	psi((1, high) moderate low+elevation),p(1, time+temp+wind)	212.43	5.64	0.01	0.06	8
28	psi((1, high) moderate low+slope+elevation),p(1, temp+wind)	212.55	5.76	0.01	0.06	8
29	psi((1, high) moderate low+slope),p(1, time+temp)	213.73	6.94	0.00	0.03	7
30	psi((1, high) moderate low+slope),p(1, time+wind)	213.75	6.96	0.00	0.03	7
31	psi((1, high) moderate low),p(1, survey)	213.91	7.12	0.00	0.03	8
32	psi((1, high) moderate low),p(1, time+temp+wind)	214.04	7.25	0.00	0.03	7
33	psi((1, high) moderate low+slope),p(1, temp+wind)	214.06	7.27	0.00	0.03	7
34	psi((1, high) moderate low+slope+elevation),p(1, survey)	214.12	7.33	0.00	0.03	10
35	psi((1, high) moderate low+elevation),p(1, survey+time)	214.22	7.43	0.00	0.02	10
36	psi((1, high) moderate low+slope+elevation),p(1, time+temp+wind)	214.24	7.45	0.00	0.02	9
37	psi((1, high) moderate low+elevation),p(1, survey+temp)	214.26	7.47	0.00	0.02	10
38	psi((1, high) moderate low+elevation),p(1, survey+wind)	214.26	7.47	0.00	0.02	10
39	psi(1, elevation+elevation^2),p(.)	214.40	7.61	0.00	0.02	4
40	psi((1, high) moderate low+slope),p(1, survey)	215.62	8.83	0.00	0.01	9
41	psi((1, high) moderate low+slope),p(1, time+temp+wind)	215.73	8.94	0.00	0.01	8
42	psi((1, high) moderate low),p(1, survey+time)	215.87	9.08	0.00	0.01	9
43	psi((1, high) moderate low),p(1, survey+wind)	215.90	9.11	0.00	0.01	9
44	psi((1, high) moderate low),p(1, survey+temp)	215.91	9.12	0.00	0.01	9
45	psi(1, elevation+elevation^2),p(1, time)	215.92	9.13	0.00	0.01	5
46	psi((1, high) moderate low+slope+elevation),p(1, survey+time)	216.07	9.28	0.00	0.01	11
47	psi((1, high) moderate low+slope+elevation),p(1, survey+temp)	216.12	9.33	0.00	0.01	11

Appendix 6 Continued.

Model #	Model	AIC	ΔAIC	*w*	Model Likelihood	K
48	psi((1, high) moderate low+slope+elevation),p(1, survey+wind)	216.12	9.33	0.00	0.01	11
49	psi((1, high) moderate low+elevation),p(1, survey+time+wind)	216.21	9.42	0.00	0.01	11
50	psi((1, high) moderate low+elevation),p(1, survey+time+temp)	216.22	9.43	0.00	0.01	11
51	psi((1, high) moderate low+elevation),p(1, survey+temp+wind)	216.26	9.47	0.00	0.01	11
52	psi(1, elevation+elevation^2),p(1, temp)	216.32	9.53	0.00	0.01	5
53	psi(1, elevation+elevation^2),p(1, wind)	216.40	9.61	0.00	0.01	5
54	psi((1, high) moderate low+slope),p(1, survey+time)	217.59	10.80	0.00	0.00	10
55	psi((1, high) moderate low+slope),p(1, survey+temp)	217.62	10.83	0.00	0.00	10
56	psi((1, high) moderate low+slope),p(1, survey+wind)	217.62	10.83	0.00	0.00	10
57	psi((1, high) moderate low),p(1, survey+time+temp)	217.86	11.07	0.00	0.00	10
58	psi((1, high) moderate low),p(1, survey+time+wind)	217.86	11.07	0.00	0.00	10
59	psi((1, high) moderate low),p(1, survey+temp+wind)	217.90	11.11	0.00	0.00	10
60	psi(1, elevation+elevation^2),p(1, time+wind)	217.90	11.11	0.00	0.00	6
61	psi(1, elevation+elevation^2),p(1, time+temp)	217.92	11.13	0.00	0.00	6
62	psi((1, high) moderate low+slope+elevation),p(1, survey+time+temp)	218.06	11.27	0.00	0.00	12
63	psi((1, high) moderate low+slope+elevation),p(1, survey+time+wind)	218.07	11.28	0.00	0.00	12
64	psi((1, high) moderate low+slope+elevation),p(1,survey+temp+wind)	218.12	11.33	0.00	0.00	12
65	psi((1, high) moderate low+elevation),p(1, survey+time+temp+wind)	218.21	11.42	0.00	0.00	12
66	psi(1, elevation+elevation^2),p(1, temp+wind)	218.32	11.53	0.00	0.00	6
67	psi(1, slope),p(.)	218.48	11.69	0.00	0.00	3
68	psi((1, high) moderate low+slope),p(1, survey+time+temp)	219.57	12.78	0.00	0.00	11

Appendix 6 Continued.

Model #	Model	AIC	Δ AIC	*w*	Model Likelihood	K
69	psi((1, high) moderate low+slope),p(1, survey+time+wind)	219.58	12.79	0.00	0.00	11
70	psi((1, high) moderate low+slope),p(1, survey+temp+wind)	219.62	12.83	0.00	0.00	11
71	psi((1, high) moderate low),p(1, survey+time+temp+wind)	219.86	13.07	0.00	0.00	11
72	psi(1, elevation+elevation^2),p(1, time+temp+wind)	219.90	13.11	0.00	0.00	7
73	psi(1, elevation+elevation^2),p(1, survey)	219.94	13.15	0.00	0.00	8
74	psi(1, slope),p(1, temp)	219.96	13.17	0.00	0.00	4
75	psi(1, elevation),p(.)	220.06	13.27	0.00	0.00	3
76	psi((1, high) moderate low+slope+elevation),p(1, survey+time+temp+wind)	220.06	13.27	0.00	0.00	13
77	psi(1, slope),p(1, time)	220.25	13.46	0.00	0.00	4
78	psi(1, slope),p(1, wind)	220.31	13.52	0.00	0.00	4
79	1 group, Constant P	221.28	14.49	0.00	0.00	2
80	psi((1, high) moderate low+slope),p(1, survey+time+temp+wind)	221.57	14.78	0.00	0.00	12
81	psi(1, elevation),p(1, temp)	221.65	14.86	0.00	0.00	4
82	psi(1, slope),p(1, temp+wind)	221.67	14.88	0.00	0.00	5
83	psi(1, elevation),p(1, time)	221.76	14.97	0.00	0.00	4
84	psi(1, elevation+elevation^2),p(1, survey+time)	221.86	15.07	0.00	0.00	9
85	psi(1, slope),p(1, time+temp)	221.89	15.10	0.00	0.00	5
86	psi(1, slope),p(1, time+wind)	221.91	15.12	0.00	0.00	5
87	psi(1, elevation+elevation^2),p(1, survey+wind)	221.92	15.13	0.00	0.00	9
88	psi(1, elevation+elevation^2),p(1, survey+temp)	221.93	15.14	0.00	0.00	9
89	psi(1, elevation),p(1, wind)	222.05	15.26	0.00	0.00	4

Appendix 6 Continued.

Model #	Model	AIC	Δ AIC	*w*	Model Likelihood	K
90	psi(.),p(1, temp)	222.48	15.69	0.00	0.00	3
91	psi(.),p(1, time)	222.98	16.19	0.00	0.00	3
92	psi(.),p(1, wind)	223.24	16.45	0.00	0.00	3
93	psi(1, slope),p(1, time+temp+wind)	223.49	16.70	0.00	0.00	6
94	psi(1, elevation,p(1, time+temp)	223.53	16.74	0.00	0.00	5
95	psi(1, elevation),p(1, temp+wind)	223.59	16.80	0.00	0.00	5
96	psi(1, elevation),p(1, time+wind)	223.67	16.88	0.00	0.00	5
97	psi(1, elevation+elevation^2),p(1, survey+time+wind)	223.80	17.01	0.00	0.00	10
98	psi(1, elevation+elevation^2),p(1, survey+time+temp)	223.86	17.07	0.00	0.00	10
99	psi(1, elevation+elevation^2),p(1, survey+temp+wind)	223.89	17.10	0.00	0.00	10
100	psi(1, slope),p(1, survey)	224.02	17.23	0.00	0.00	7
101	psi(.),p(1, temp+wind)	224.35	17.56	0.00	0.00	4
102	psi(.),p(1, time+temp)	224.42	17.63	0.00	0.00	4
103	psi(.),p(1, time+wind)	224.84	18.05	0.00	0.00	4
104	psi(1, elevation),p(1, time+temp+wind)	225.41	18.62	0.00	0.00	6
105	psi(1, elevation),p(1, survey)	225.54	18.75	0.00	0.00	7
106	psi(1, slope),p(1 survey+wind)	225.64	18.85	0.00	0.00	8
107	psi(1, slope),p(1 survey+temp)	225.71	18.92	0.00	0.00	8
108	psi(1, elevation+elevation^2),p(1, survey+time+temp+wind)	225.80	19.01	0.00	0.00	11

Appendix 6 Continued.

Model #	Model	AIC	Δ AIC	*w*	Model Likelihood	K
109	psi(1, slope),p(1 survey+time)	226.01	19.22	0.00	0.00	8
110	psi(.),p(1, time+temp+wind)	226.23	19.44	0.00	0.00	5
111	psi(.),p(survey)	226.78	19.99	0.00	0.00	6
112	psi(1, slope),p(1 survey+temp+wind)	227.13	20.34	0.00	0.00	9
113	psi(1, elevation),p(1, survey+temp)	227.32	20.53	0.00	0.00	8
114	psi(1, elevation),p(1, survey+wind)	227.42	20.63	0.00	0.00	8
115	psi(1, elevation),p(1 survey+time)	227.51	20.72	0.00	0.00	8
116	psi(1, slope),p(1 survey+time+wind)	227.55	20.76	0.00	0.00	9
117	psi(1, slope),p(1 survey+time+temp)	227.71	20.92	0.00	0.00	9
118	psi(.),p(1 survey+temp)	228.28	21.49	0.00	0.00	7
119	psi(.),p(1 survey+wind)	228.62	21.83	0.00	0.00	7
120	psi(.),p(1 survey+time)	228.74	21.95	0.00	0.00	7
121	psi(1, elevation),p(1, survey+temp+wind)	229.09	22.3	0.00	0.00	9
122	psi(1, elevation),p(1, survey+time+temp)	229.32	22.53	0.00	0.00	9
123	psi(1, elevation),p(1, survey+time+wind)	229.34	22.55	0.00	0.00	9
124	psi(.),p(1 survey+temp+wind)	229.93	23.14	0.00	0.00	8
125	psi(.),p(1 survey+time+temp)	230.27	23.48	0.00	0.00	8
126	psi(.),p(1 survey+time+wind)	230.50	23.71	0.00	0.00	8
127	psi(1, elevation),p(1, survey+time+temp+wind)	231.08	24.29	0.00	0.00	10
128	psi(.),p(1 survey+time+temp+wind)	231.93	25.14	0.00	0.00	9

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