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ESTIMATES OF DENSITY, DETECTION PROBABILITY, AND FACTORS INFLUENCING DETECTION OF BURROWING OWLS IN THE MOJAVE DESERT

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ABSTRACT.—We estimated relative abundance and density of Western Burrowing Owls (*Athene cunicularia hypugaea*) at two sites in the Mojave Desert (2003–04). We made modifications to previously established Burrowing Owl survey techniques for use in desert shrublands and evaluated several factors that might influence the detection of owls. We tested the effectiveness of the call-broadcast technique for surveying this species, the efficiency of this technique at early and late breeding stages, and the effectiveness of various numbers of vocalization intervals during broadcasting sessions. Only 1 (3%) of 31 initial (new) owl responses was detected during passive-listening sessions. We found that surveying early in the nesting season was more likely to produce new owl detections compared to surveying later in the nesting season. New owls detected during each of the three vocalization intervals (each consisting of 30 sec of vocalizations followed by 30 sec of silence) of our broadcasting session were similar (37%, 40%, and 23%; $n = 30$). We used a combination of detection trials (sighting probability) and double-observer method to estimate the components of detection probability, i.e., availability and perception. Availability for all sites and years, as determined by detection trials, ranged from 46.1%–58.2%. Relative abundance, measured as frequency of occurrence and defined as the proportion of surveys with at least one owl, ranged from 19.2%–32.0% for both sites and years. Density at our eastern Mojave Desert site was estimated at 0.09 ± 0.01 (SE) owl territories/km^2 and 0.16 ± 0.02 (SE) owl territories/km^2 during 2003 and 2004, respectively. In our southern Mojave Desert site, density estimates were 0.09 ± 0.02 (SE) owl territories/km^2 and 0.08 ± 0.02 (SE) owl territories/km^2 during 2004 and 2005, respectively.

KEY WORDS: *Western Burrowing Owl*; Athene cunicularia hypugaea; *California*; *detection probability*; *Mojave Desert*; *Nevada*; *survey methods*.

ESTIMADOS DE DENSIDAD, PROBABILIDAD DE DETECCIÓN Y FACTORES QUE INFLUENCIAN LA DETECCIÓN DE *ATHENE CUNICULARIA* EN EL DESIERTO DE MOJAVE

RESUMEN.—Estimamos la abundancia y la densidad relativa de *Athene cunicularia hypugaea* en dos sitios en el Desierto de Mojave (2003–04). Modificamos técnicas de muestreo previamente establecidas para *Athene cunicularia hypugaea* con el fin de usarlas en arbustales de desierto y evaluamos varios factores que podrían influenciar la detección de las lechuzas. Evaluamos la efectividad de la técnica de emisión de llamados para monitorear esta especie, la eficiencia de esta técnica en estadios de cría tempranos y tardíos, y la efectividad de varios números de intervalos de vocalización durante las sesiones de emisión. Sólo una (3%) de las 31 respuestas iniciales (nuevas) de las lechuzas fue detectada durante las sesiones de escucha pasiva. Encon-

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tramos que los muestreos realizados a principios de la estación de anidación arrojaron una mayor probabilidad de detectar nuevas lechuzas en comparación con los muestreos realizados al final de la estación de anidación. Las nuevas lechuzas detectadas durante cada uno de los tres intervalos de vocalización (cada uno consistiendo en 30 s de vocalizaciones seguidos de 30 s de silencio) de nuestra sesión de emisión fueron similares (37%, 40% y 23%; $n = 30$). Empleamos una combinación de sesiones de detección (probabilidad de observación) y un método de observador doble para estimar los componentes de la probabilidad de detección, i.e., disponibilidad y percepción. La disponibilidad para todos los sitios y los años, determinada a partir de las sesiones de detección, variaron entre 46.1% y 58.2%. La abundancia relativa, medida como la frecuencia de ocurrencia y definida como la proporción de muestreos con al menos una lechuza, variaron entre 19.2% y 32.0% para ambos sitios y años. La densidad en nuestro sitio al este del Desierto de Mojave fue estimada en 0.09 ± 0.01 (EE) territorios de lechuza por km² y 0.16 ± 0.02 (EE) territorios de lechuzas por km² durante los años 2003 y 2004, respectivamente. En nuestro sitio del sur del Desierto de Mojave, los estimados de densidad fueron 0.09 ± 0.02 (EE) territorios de lechuza por km² y 0.08 ± 0.02 (EE) territorios de lechuzas por km² durante 2004 y 2005, respectivamente.

[Traducción del equipo editorial]

Western Burrowing Owls (*Athene cunicularia hypugaea*) occur in a variety of open habitats that are generally characterized by short vegetation and bare ground (Haug et al. 1993, Johnsgard 2002). Population estimates are relatively well known for many habitats (e.g., grasslands, Desmond and Savidge 1996; agricultural areas, Rosenberg and Haley 2004; and urban environments, Trulio 1997), but little is known about Western Burrowing Owl populations in deserts. A systematic, rangewide survey of Burrowing Owl populations has been consistently recommended as important for the conservation and management of this species (James and Espie 1997, Holroyd et al. 2001).

Standardized survey protocols specific to Burrowing Owls have been used in grassland habitats, agricultural landscapes, and urban areas (Haug and Didiuk 1993, Trulio 1997, Desmond et al. 2000, Shyry et al. 2001, Conway and Simon 2003, Rosenberg and Haley 2004). However, no single survey method has been used for all habitat types or land-use patterns in which Burrowing Owls occur (Conway and Simon 2003, Rosenburg and Haley 2004). An accurate and efficient survey protocol, with modifications specific to desert shrublands and consistent with methods used in existing protocols, is important for determining the distribution and abundance of owls inhabiting deserts. Here, we present modifications to existing survey protocols (Duxbury and Holroyd 1998, Conway and Simon 2003) to estimate relative abundance and density of Burrowing Owls inhabiting desert shrublands.

Methods presently used for surveying Burrowing Owls appear to be dictated primarily by habitat, land-use patterns, and owl behavior. Visual survey methods, including the use of call-broadcasts, are commonly used in habitats consisting of open areas with low vegetative structure such as prairie dog (*Cynomys* spp.) towns in grasslands, margins of agricultural areas, and empty lots in urban environments (Martell et al. 1997, Trulio 1997, Duxbury and Holroyd 1998, Desmond et al. 2000, Shyry et al. 2001, Conway and Simon 2003). Within these habitats, owls often occur in relatively small patches of appropriate habitat within a larger landscape matrix. Breeding-season surveys frequently are conducted during the brood-rearing and fledgling-dependency stages, as family groups are more readily detected than single owls. Most visual surveys are conducted during crepuscular hours when owls are more likely found aboveground. However, visual surveys are of limited use where vegetation obstructs detection of owls. In these locations, aural detections may be more effective than visual detections. Broadcasting of recorded conspecific songs and calls has been used in both diurnal and nocturnal surveys to increase detection rates of many raptor species (Mosher et al. 1990, Gerhardt 1991), including Western Burrowing Owls (Haug and Didiuk 1993).

Reliable estimates of relative abundance and density depend on an accurate estimate of detection probability (Thompson 2002, Pollock et al. 2004). Development of the most effective methods to address detection probability has been and continues to be an active area of biometric research (Otis et al. 1978, Pollock and Kendall 1987, Marsh and Sinclair 1989, Nichols et al. 2000, Buckland et al. 2001, Farnsworth et al. 2002, Rosenstock et al. 2002). Methods of estimating detectability vary in their effectiveness depending on the influence of confounding factors such as species behavior and habitat characteristics (Thompson 2004, Andersen 2007). The proportion of individuals present but

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not detected, is unknown and is variable across time and space. In addition, surveying for species that occur in low densities and exhibit secretive behavior can result in a high proportion of zero counts (nondetections) for sampling units, making it difficult to find appropriate techniques for determining the components of detection probability. This is of particular concern for the Burrowing Owl.

We evaluated several factors that might influence the detection of Burrowing Owls while conducting surveys at two sites in the Mojave Desert. We tested (1) the effectiveness of the call-broadcast technique for this species; (2) the efficiency of nocturnal call-broadcast surveys at various stages of the breeding cycle; and 3) the effectiveness of various numbers of vocalization intervals during call-broadcast sessions. These factors were evaluated to determine if the likelihood of detection would increase by changing certain aspects of survey protocols. We used a combination of techniques to estimate detection probability. We used sighting probability methods to estimate availability, and used a double-observer method to estimate perception. We used the modified protocol to obtain estimates of the relative abundance and density of Burrowing Owls at two sites in the eastern and southern Mojave Desert.

METHODS

Study Area. We surveyed for Burrowing Owls at two sites in the Mojave Desert: Lake Mead National Recreation Area (Lake Mead NRA; 36°0.6′N, 114°47.8′W) and the Marine Corps Air Ground Combat Center at Twentynine Palms (MCAGCC; 34°12.6′N, 116°3.2′W). Lake Mead NRA is located in southern Nevada within the eastern Mojave Desert region of the Basin and Range physiographic province where the Great Basin and Mexican Highland sections meet (Eaton 1982). Our study site included the Nevada portion of Lake Mead NRA, which encompasses 1470 km². Local topography varies from steep mountain ranges with deep washes to rolling and gently inclined alluvial fans. Elevation ranges from 160 m to 2100 m. MCAGCC is located in the southern Mojave Desert within the Morongo Basin of southern California. MCAGCC encompasses 2415 km². Topography consists of steeply sloping mountain ranges with intervening basins and valleys. Elevation ranges from approximately 190 m to 1430 m. At both sites, the most widespread and dominant vegetation type is the Mojave creosote bush-bursage shrubland association (*Larrea tridentata–Ambrosia dumosa*; Turner 1982). This association occurs on basin floors and bajada slopes and contains low perennial species diversity and a high diversity of annual species that germinate in years of abundant moisture. In areas where soils are heavier and salt content >0.2%, creosote-bursage is replaced by saltbush species such as *Atriplex polycarpa*, *A. confertifolia*, and *A. hymenelytra*.

Survey Methods. During 2002, we conducted pilot roadside surveys at Lake Mead NRA; 49% of the surveys were diurnal and 51% were nocturnal. We incorporated recorded conspecific songs and calls into surveys to increase detection rates (Mosher et al. 1990, Gerhardt 1991, Haug and Didiuk 1993). We used a three-interval call-broadcast session as suggested for Burrowing Owls by Conway and Simon (2003). We surveyed during the brood-rearing and fledgling-dependency stages from mid-April through June. We found that during diurnal surveys, owls in creosote habitat were difficult to detect using established protocols (i.e., vegetation obstructed view beyond 50 m). To accommodate the greater height and/or density of vegetation in deserts, compared with habitats with shorter vegetation, we adjusted survey methods for the following years by conducting only nocturnal surveys and focusing on aural detections. Owls exhibit calling behavior primarily during nocturnal hours (Johnsgard 2002). We expanded the timing of surveys to include not only brood-rearing and fledgling-dependency stages, but also territory-establishment, pair-formation, egg- laying, and incubation stages, when owls vocalize more frequently (Palmer 1987, Clark and Anderson 1997). To include the entire breeding season for our study area, we conducted transects from late February until the end of July.

Our sampling frame for surveying Burrowing Owls consisted of a simple random selection of sampling units within the defined boundary of each study area (Thompson 1992, Lancia et al. 2005, Pollock et al. 2002). We used Geographic Information System (GIS) software (ArcView 3.2, ArcMap 9.1; Environmental Systems Research Institute, Redlands, California 1998) to generate random 3.2-km transects within the study area, spatially enforcing a minimum distance of 3.2 km between transects. We further constrained transects to areas of slopes less than 25% (Haug et al. 1993). Observers were trained in owl surveying and detection techniques prior to conducting transects. Training included studying CDs of Burrowing Owl vocalizations, visiting known occupied burrows, and conducting transects with an experienced observer prior to in-

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dependent surveying. Sampling units consisted of transects conducted as nocturnal walking surveys. Each 3.2-km transect consisted of five point-count stations located 0.8 km apart. Transects began within 0.5 hr of dusk and continued for approximately 3–4 hr (between 1900–2400 H). At each station, point counts consisted of a 3-min passive-listening session followed by a 3-min broadcasting session. Each broadcasting session consisted of an interval of 30-sec owl vocalization followed by 30 sec of silence, repeated three times in succession. The three intervals of vocalization included two intervals of male primary song (*coo-coo*) followed by one interval of alarm calls (*quick-quick-quick*; see Conway and Simon 2003). We used owl vocalizations provided by the Cornell Laboratory of Ornithology (2002) recorded from locations in the western U.S. (Arizona for male primary song and Utah for alarm calls). We used a portable cassette player to broadcast vocalization intervals. The cassette player was held approximately 2 m above the ground and rotated in the four cardinal directions during broadcasting. Broadcast volume was adjusted between 80–90 dB at 1 m from the cassette speaker using a sound-level meter set on slow response and C weighting (Fuller and Mosher 1987). During each passive-listening and broadcasting session, observers faced in the four cardinal directions listening for a vocal response. Surveys were not conducted during inclement weather (moderate to heavy rain or average wind speeds >19 km/hr).

Detection Factors. While conducting owl transects at Lake Mead NRA (2003–04) and MCAGCC (2004), we evaluated three factors used in our point-count protocol. Transects conducted during 2005 at MCAGCC were not used to test protocol components because these surveys did not extend over the entire breeding season. We tested the effectiveness (increase in detection rate) of the call-broadcast technique by determining the occurrence of spontaneous owl vocalizations using a passive-listening session prior to each broadcasting session. Passive-listening and broadcasting sessions were of equal duration to facilitate comparison between the two sessions (Farnsworth et al. 2002, Conway and Gibbs 2005). We evaluated the response rate to broadcasting sessions throughout the entire breeding season (i.e., from territory establishment through the fledgling-dependency stage) by conducting transects from late February through the end of July. We used nest observations and the aging of emergent young to identify the last two weeks of April as the approximate time of hatching for the Mojave Desert, then divided the breeding season into early (<1 May) and late stages (≥1 May). We tested use of the three vocalization intervals by assigning the detection of each owl to the interval during which it was first detected.

Effective Area Sampled. To estimate effective area sampled, we determined the average detection threshold distance for Burrowing Owls at our study sites (Emlen and DeJong 1981). Detection threshold distance is the maximum distance, on average, that a singing male was detected. When a continually singing male was identified during transects and detection trials, observers estimated the distance at which the owl could no longer be heard by walking away from the owl, then stopping at 100-m increments to listen for vocalizations. When the singing male could no longer be heard, the observer reversed direction and moved slowly toward the owl until it could be heard again. Singing males were used to determine detection threshold distance because male primary song can be heard at a greater distance than any other Burrowing Owl vocalization. We used GIS tools (ArcView 3.2, ArcMap 9.1) to generate the effective area sampled, which consisted of 5 overlapping circles of radius 752 m (average detection threshold distance) centered 0.8 km apart for each transect.

Detection Probability. We estimated the two components of detection probability, the availability of individuals for detection and the perception of individuals given their availability (Pollock et al. 2002, Thompson 2002, Pollock et al. 2004). We incorporated detection trials, a variation of sighting probability methods, into our point-count protocol to estimate availability at both study sites (Samuel et al. 1987, Marsh and Sinclair 1989). At the MCAGCC site, we used the double-observer method to estimate perception.

We conducted detection trials to determine the variability in response by owls to the call-broadcast technique (Kennedy and Stahlecker 1993, McLeod and Andersen 1998, Proudfoot et al. 2002). Availability was determined as the proportion of detection trials during which an owl response was detected. A detection trial consisted of the same 3-min broadcasting session used during transects. We conducted trials at known owl territories, defined as those occupied burrows defended by either a single male or an owl pair, during the same breeding-season timing as transects. Trials were not conducted at a detection distance (i.e., distance between the ob-

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server and an occupied burrow) greater than the average detection threshold distance. Following each trial, the owl territory was revisited to verify occupancy. Territories were considered occupied when one or more adult owls were observed at a burrow. We estimated availability for each individual territory and then calculated an average availability (P_a) which we used in our density estimates. We assumed that owl responses to detection trials from known occupied territories found during random transects were representative of owl responses to the call-broadcast technique for the study site populations. Trials at Lake Mead NRA were conducted at 21 territories in 2003 and 19 territories in 2004. At MCAGCC, trials were conducted at 11 and 15 territories during 2004 and 2005, respectively.

After each owl was detected, observers estimated the compass bearing and distance from the point-count station. Observers then moved toward the responding owl and either immediately located its burrow or estimated the response location and returned the following day to search for the occupied burrow. Burrowing Owls nested in tortoise (*Gopherus agassizii*) or kit fox (*Vulpes macrotis*) burrows. We determined territorial and breeding status of owls found during transects by observation of occupied burrows. Observations were conducted using a portable blind and spotting scope placed at 50–115 m from the occupied burrow.

At MCAGCC, we used a double-observer approach to adjust for observer variability in perception (Nichols et al. 2000). Only one observer conducted transects at Lake Mead NRA. The double-observer approach estimates the proportion of individual owls detected by different observers given that the owls were available. Both observers listened for responding owls simultaneously. To avoid detection bias, observers stood at least 10 m apart and did not communicate with each other. Observers alternated broadcasting duties. Assumptions of the double-observer method included independence of observers and equal probability of availability for each observer (Pollock and Kendall 1987, Thompson 2002). Using double-observer and detection-trial methods allowed estimation of both components of detection probability for the MCAGCC site.

Relative Abundance and Density. We estimated relative abundance measured as the frequency of occurrence, which consisted of the proportion of transects where at least one owl was detected. For our density estimate, we converted detections of owl pairs and single males into territory counts (i.e., occupied territories). Density estimates (D) were calculated using the equation (Lancia et al. 2005, Williams et al. 2002),

$$D = C / P_a P_p A,$$

where C is territory count (i.e., the number of owl territories detected in the effective area sampled), P_a is the estimate of availability, P_p is the estimate of perception, and A is the estimated effective area sampled by the survey method. Owl detections outside the average detection threshold distance and migrant owls were not included in the density estimates. We defined a migrant as an owl detected at a particular station during February and March but not detected there during burrow observations or detection trials later in the breeding season.

Statistical Analyses. We tested the number of owls responding to broadcasting sessions by breeding stage and the number of owls responding to passive-listening versus broadcast sessions using Fisher's exact tests for small sample sizes. Pearson chi-square (χ^2) was used to test for differences in owl detections among the three broadcasting intervals. We tested differences in availability between sites and years using a two-sample t-test. Proportions were transformed using the arcsine transformation. We combined results from Lake Mead NRA and MCAGCC for our detection-factor testing to increase sample size. Significance levels were set at $P < 0.05$. We used SYSTAT 11.0 (SYSTAT Software Inc., Richmond, CA, 2004) for analyses. Wintering/migratory owls were not included in analyses. Standard errors for adjusted territory count and density were calculated using the delta method (Williams et al. 2002). Standard error equations for adjusted territory count, $C_{adj} = C/(P_a P_p)$, and density, D, are provided below:

$$SE(C_{adj}) = \frac{C}{P_a P_p} \sqrt{\left(\frac{SE(P_a)}{P_a}\right)^2 + \left(\frac{SE(P_p)}{P_p}\right)^2}$$

$$SE(D) = \frac{C}{P_a P_p A} \sqrt{\left(\frac{SE(P_a)}{P_a}\right)^2 + \left(\frac{SE(P_p)}{P_p}\right)^2 + \left(\frac{SE(A)}{A}\right)^2}$$

RESULTS

We conducted 92 surveys, at a total of 73 transect sites, surveying 467 km² of Mojave Desert habitat. Surveys were conducted at Lake Mead NRA from

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Table 1. Number (and percent) of transects with owl detections (at least one owl) and nondetections (no owls heard or seen) recorded during nocturnal surveys using call-broadcast methods conducted at Lake Mead National Recreation Area (Lake Mead), 2003–04, and Marine Corps Air Ground Combat Center (MCAGCC), 2004. We divided the breeding season into early (<1 May) and late breeding stages (≥1 May). Early breeding stages included territory establishment, pair formation, egg-laying and incubation. Late breeding stages included nestling, fledgling, and fledgling dependency. Detections were of known territorial/breeding owls; detections from migrants were not included in the analysis.

Breeding Stages	Lake Mead 2003 Detections $n = 6$	Lake Mead 2004 Detections $n = 8$	MCAGCC 2004[a] Detections $n = 9$	Total Nondetections $n = 58$	Total Detections $n = 23$
Early	4 (67)	7 (87)	6 (67)	28 (48)	17 (74)
Late	2 (33)	1 (13)	3 (33)	30 (52)	6 (26)

[a] Surveys conducted during 2005 at MCAGCC were not used to test survey components because these surveys did not extend over the entire breeding season.

12 March to 19 July 2003 (26 transects) and from 1 March to 25 July 2004 (25 transects). At MCAGCC, surveying was conducted from 24 February to 28 July 2004 (24 transects) and 1 March to 26 May 2005 (15 transects). At Lake Mead NRA, 80% of transects surveyed in 2003 were resurveyed during 2004; no transects were resurveyed at MCAGCC.

Detectability Factors. We found a difference in the number of initial owl (subsequently referred to as new owls) detections between passive-listening and broadcasting sessions (Fisher's exact test: $P < 0.001$; $n = 31$). Only 1 (3%) of 31 new owl detections occurred during the passive-listening session of our surveys. Early breeding stages had a significantly greater number of transects with owl detections than later breeding stages (Fisher's exact test: $P = 0.048$; $n = 81$; Table 1). We found no difference among vocalization intervals, indicating that the response rate of new owls for each additional interval was similar (Pearson $\chi^2 = 1.400$, df = 2, $P = 0.497$; $n = 30$; Table 2).

Effective Area Sampled. We estimated an average detection threshold distance of singing males from an observer at 752 m ± 20 m ($n = 21$). Owls at distances ≤752 m were easily detected in desert habitat (i.e., limited vegetation and little external noise). Owls became more difficult at distances >1000 m. Using this average detection threshold distance, we calculated that the effective area sampled for Lake Mead NRA was 165 km² for 2003 and 159 km² for 2004. At MCAGCC, effective area sampled was 152 km² and 95 km² during 2004 and 2005, respectively.

Detection Probability. The availability component of detection probability at Lake Mead NRA, determined from detection trials, was estimated at 58.2% ± 8.4% ($n = 21$) in 2003 and 55.6% ± 6.5% ($n = 21$) in 2004. At MCAGCC, availability was estimated at 48.9% ± 7.6% ($n = 11$) and 46.1% ± 7.8% ($n = 15$) during 2004 and 2005, respectively. We found no difference in availability between the two years for either site (Lake Mead NRA *t*-test: $P = 0.931$ and MCAGCC *t*-test: $P = 0.814$) or between the two sites

Table 2. Number (and percent) of owls detected during each of the three call-broadcast intervals recorded during transects conducted at Lake Mead National Recreation Area (Lake Mead), 2003–04, and Marine Corps Air Ground Combat Center (MCAGCC), 2004. Total response is the number and percent of initial owl detections for all study sites and years combined. Detections were of known territorial/breeding owls; detections from migrants were not included in the analysis.

Vocalization Interval	Lake Mead 2003 $n = 10$	Lake Mead 2004 $n = 13$	MCAGCC 2004[a] $n = 7$	Total Response $n = 30$
First (male song)	2 (20)	6 (46)	3 (43)	11 (37)
Second (male song)	5 (50)	5 (38)	2 (29)	12 (40)
Third (alarm call)	3 (30)	2 (15)	2 (29)	7 (23)

[a] Surveys conducted during 2005 at MCAGCC were not used to test survey components because these surveys did not extend over the entire breeding season.

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Table 3. Densities of Burrowing Owls reported from previous studies within several habitat types. Nest sites, pairs, and territories were considered equivalent parameters with the added caveat that <10% of territories consisted of unmated males (Conway and Simon 2003, this study).

LOCATION	HABITAT TYPE	DENSITY
Oklahoma, Nebraska[a]	Perennial grassland	1.5–26.3 pairs/km^2
Coastal California[b]	Urban	5.7–24.7 pairs/km^2
Southern California[c]	Agricultural	2.0–8.3 pairs/km^2
Central California[d]	Annual grassland	0.21 pairs/km^2
Nevada, California[e]	Mojave Desert	0.08–0.16 territories/km^2
Eastern Wyoming[f]	Grassland and agricultural	0.074 nest sites/km^2
Southeastern Idaho[g]	Sagebrush-steppe	0.02 pairs/km^2

[a] Butts and Lewis 1982, Desmond and Savidge 1996 (prairie dog towns).
[b] Thomsen 1971, Trulio 1997.
[c] Coulombe 1971, DeSante et al. 2004, Rosenberg and Haley 2004 (Imperial Valley).
[d] Rosenberg and Haley 2004 (Carrizo Plain).
[e] This study (Lake Mead National Recreation Area, Twentynine Palms Marine Corps Air Ground Combat Center).
[f] Conway and Simon 2003.
[g] Gleason and Johnson 1985.

during 2004 when both sites were surveyed (t-test: $P = 0.529$). Estimates of perception were not available for the Lake Mead NRA surveys. No observer variation was documented during double-observer surveys conducted at MCAGCC; both observers recorded each of the 11 owls detected during the two years of the study.

Relative Abundance. At Lake Mead NRA, we estimated the frequency of occurrence of Burrowing Owls at 19.2% ± 7.9% ($n = 26$) and 32.0% ± 9.5% ($n = 25$) for transects conducted during 2003 and 2004, respectively. At MCAGCC, we detected Burrowing Owls on 25.0% ± 9.0% ($n = 24$) and 26.7% ± 11.8% ($n = 15$) of transects conducted during 2004 and 2005, respectively.

Density. At Lake Mead NRA, we documented eight territories during 2003 and 14 during 2004. We documented seven and four territories at MCAGCC during 2004 and 2005, respectively. Only owls (pairs and single males) detected within the average detection threshold distance were used in determining territory count. After adjusting the observed territory count for detectability, the number of territories was estimated at 13.8 ± 2.0 and 25.2 ± 3.0 at Lake Mead NRA and 14.3 ± 2.2 and 8.7 ± 1.5 at MCAGCC. We estimated density at Lake Mead NRA as 0.09 ± 0.01 owl territories/km^2 or 1 owl territory per 11.54 ± 0.21 km^2 and 0.16 ± 0.02 owl territories/km^2 or 1 owl territory per 6.30 ± 0.05 km^2 during 2003 and 2004, respectively. At MCAGCC, density was estimated at 0.09 ± 0.02 owl territories/km^2 or 1 owl territory per 11.09 ± 0.25 km^2 and 0.08 ± 0.02 owl territories/km^2 or 1 owl territory per 10.98 ± 0.46 km^2 during 2004 and 2005, respectively.

DISCUSSION

We obtained estimates of relative abundance and density of Burrowing Owls at two sites in the Mojave Desert using a survey protocol modified specifically for desert shrublands. Critical estimates of detection probability, both availability and perception, were integrated into our protocol. Our modifications may be useful in other habitats with low visibility and where owls are sparsely distributed across the landscape (e.g., shrub-steppe).

Density estimates across the species range are widely variable and generally reflect availability of resources in each habitat type. At Lake Mead NRA, owl density during 2004 was double that of 2003. Reasons for this were unknown, but the differences may have been related to rainfall patterns and the resulting increase in prey abundance and Burrowing Owl productivity (Butts 1973, Wellicome 1997). During 2002, annual rainfall was well below average, which may have negatively affected the owl population. However, annual rainfall was average during 2003 and 2004 (National Oceanic and Atmospheric Administration 2008), which may have contributed to a higher population density in 2004.

Breeding density estimates for Lake Mead NRA and MCAGCC were among the lowest reported densities (Table 3). This may be characteristic of desert ecosystems. Density estimates across the owl's range

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varied from a high of 26 pairs/km^2 for prairie dog towns in the perennial grasslands of Oklahoma (Butts and Lewis 1982), to a low of 0.02 pairs/km^2 in the sagebrush steppe of southeastern Idaho (Gleason and Johnson 1985). Highest densities occurred in habitats where owls and their burrows were concentrated into smaller habitat patches (e.g., prairie dog towns, edges of agricultural landscapes). In these habitats, Burrowing Owls are clustered, with their nests crowded close together, but they forage well outside of the nesting habitat (Haug and Oliphant 1990, Sissons et al. 2001). Lowest densities occurred where owls were widely distributed across vast landscapes. Results from several of these studies included smaller habitat patches without including the larger surrounding matrix, making density estimates difficult to compare (Desmond and Savidge 1996, Trulio 1997). However, Rosenberg and Haley (2004) provided estimates of crude density (1.1 pairs/km^2), which included the larger surrounding agricultural matrix, and ecological density (5.2 pairs/km^2), representing small habitat patches, for Burrowing Owls in the Imperial Valley, California. Our density estimates represented owl occurrence across a large landscape and thus are not comparable to estimates from small habitat patches. Our study provides reliable density estimates for a Burrowing Owl population in the eastern and southern Mojave Desert, but whether these densities extend throughout the Mojave Desert is unknown.

We altered several components of established survey designs to adapt to conditions specific to desert ecosystems, because owls were difficult to observe due to the spatial pattern of owl distribution and vegetative structure characteristic of the desert landscape. By focusing on aural detections and using call-broadcast techniques, we increased the likelihood of detection and thereby reduced variability between sampling units. Because few spontaneous owl vocalizations (non-elicited vocalizations) were detected during passive sessions, owl detections were strongly dependent on use of the call-broadcast technique. Although nuisance variables (e.g., variation in broadcast volume) have been associated with the use of call-broadcast methods (Mosher et al. 1990, Conway and Simon 2003), our results suggested that detection probability increased significantly with use of the call-broadcast technique.

In areas with limited visibility due to vegetation structure or when owls are widely distributed (e.g., desert shrubland, sagebrush steppe), we recommend conducting nocturnal surveys during territory establishment, pair formation, egg-laying, and incubation stages of breeding. Our results suggested that detection probability is highest during early breeding season stages when young are not present. During this time, adult owls appear to respond with greater frequency to the broadcasting of conspecific calls. Surveys conducted during territory establishment, pair formation, egg-laying, and incubation should result in a higher rate of detections per survey effort, thus lowering the variability in response rate and, consequently, increasing the power of the survey design (Lancia et al. 2005).

Reliable estimates of abundance and density depend on reliable estimates of detection probability (Thompson et al. 1998, Nichols et al. 2000, Rosenstock et al. 2002). When methods for determining detectability are incorporated into survey techniques, then estimated changes in population size (i.e., number of occupied territories) reflect true changes and not differences in detectability. The combination of double-observer and detection trials allowed us to provide estimates of both availability and perception for the MCAGCC site. Many factors affect detectability (e.g., breeding season timing, weather, bird behavior; see Andersen 2007) and we found that the ability to adjust the number of detection trials was essential for establishing greater precision in our availability estimates.

We assumed that detection trials conducted at known territories were representative of the owl population at each study site but these surveys may sample only the portion of the population that responds to call-broadcasting techniques. It is unknown whether a subset of owls exists that rarely respond to broadcasting. Use of the double-sampling technique may be a potential method of determining whether detection trials provide reliable availability estimates (Cochran 1977, Bart and Earnst 2002).

In our double-observer results, the three sets of paired observers all detected the same owls. This suggests that observers with good detection skills (e.g., experience, training, attentiveness) and similar physical fitness exhibit comparable abilities for detecting Burrowing Owl vocalizations. This similarity in detection may also be the result of detection conditions in desert habitats: observers were detecting isolated responses approximately once every three to five surveys, under conditions of limited background noise with few additional bird vocalizations (see Simons et al. 2007). Although our data showed no discernable observer variability (observed $P_p = 1$), it is possible that both observers may have failed to detect an avail-

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able owl. This may be a rare occurrence, but would result in underestimating owl numbers.

Our average detection threshold distance suggested that point-count stations spaced 0.8 km apart are not independent. If stations are placed less than 1.6 km apart, we recommend locating each nest burrow/territory to prevent double counting of owls at adjacent stations. Changing the spacing of stations to include our estimate of independence is consistent with other owl-monitoring methods that use multiples of 0.8 km for spacing of stations (Fuller and Mosher 1987, Takats et al. 2001). Using transects with multiple point-count stations instead of single point-count stations would increase the effective area sampled per sampling unit, thus potentially increasing detection of available owls and, in turn, decreasing the number of zero counts in sampling units.

Many factors, such as vegetative structure and land-use patterns, determine the effectiveness of survey protocols in different habitat types. Survey design should be modified to accommodate those differences to increase detection rates. A single survey protocol for Burrowing Owls is the goal for range-wide assessments (James and Espie 1997, Holroyd et al. 2001). However, present survey methods using habitat-specific techniques that increase detection of Burrowing Owls could be incorporated into a reliable range-wide population survey. To be effective in desert habitats, the protocol should include use of call-broadcast and nocturnal surveys conducted during early breeding stages.

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