Population Status and Reproductive Ecology of the Western Burrowing Owl (*Athene cunicularia hypugaea*) in Clark County, Nevada

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
WESTERN ECOLOGICAL RESEARCH CENTER

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Executive Summary

The Western Burrowing Owl (*Athene cunicularia hypugaea*) is a small, ground-dwelling owl widely distributed in arid and semi-arid habitats of western North America. Population declines and associated range contractions have been documented for this species in many of the states and provinces of its historic range. Habitat destruction associated with human encroachment has played a major role in these declines (Haug et al. 1993, Trulio 1997, Desmond et al. 2000). As a result, Western Burrowing Owls are currently listed as a species of special concern in many midwestern and western states in the U. S. (Wellicome and Haug 1995, James and Espie 1997, De Smet 1997, Sheffield 1997). Presently, there is a paucity of information about Burrowing Owl populations in desert ecosystems. Evaluation of owl distribution and abundance within desert environs is critical for developing conservation actions throughout the desert southwest. Our objectives for this project were: 1) determining distribution and relative abundance of Western Burrowing Owls in Clark County, southern Nevada; 2) determining the relationship between Western Burrowing Owl reproductive success and nest-site characteristics; and 3) developing a habitat model for Western Burrowing Owls in Clark County.

We surveyed Clark County (2008-2009) using a survey protocol we developed specifically for Western Burrowing Owls in the Mojave Desert. We conducted transect surveys in four habitat types; Sonora-Mojave creosotebush-white bursage (*Larrea tridentata -Ambrosia dumosa*) desert scrub, Mojave mid-elevation mixed desert scrub, Colorado Plateau blackbrush (*Coleogyne ramosissima*), and Great Basin pinyon-juniper (*Pinus-Juniperus*). During 2008 we conducted 61 transects. In 2009, we conducted 34 new transects and repeated 29 transects from 2008 in the two desert scrub habitats; we repeated five transects in blackbrush during 2009. Western Burrowing Owls occurred at low densities throughout desert scrub habitat. No owls were detected in either blackbrush or pinyon-juniper. Several areas in Clark County contained a relatively higher number of owls, including Gold Butte, Piute Valley, the eastern slopes of the El Dorado Valley, and the alluvial fan west of Lake Mojave in Lake Mead National Recreation Area.

Based upon the results of our surveys (n = 95), we determined estimates of relative abundance and density of owls in Clark County. Frequency of occurrence, a measure of relative abundance defined as the proportion of transects with at least one owl detected, was 23% and 29% of transects conducted in 2008 and 2009, respectively. Territory count in the two desert scrub habitats, defined as the number of territories detected on transects, was 12 in 2008 and 25 in 2009. For estimating density, territory count was adjusted using detection probability and effective area sampled. Density estimates for desert scrub were 0.12 owl territories per km^2 for 2008 and 0.12 owl territories per km^2 for 2009. We estimated apparent nest success, defined as the proportion of owl pairs that produce ≥1 young, at 60% in 2008 and 58% in 2009. Productivity, defined as the number of young per pair that reach 21-28 d post-hatch, was 3.1 young produced per nesting attempt in 2008 and 3.3 young per nesting attempt in 2009. Owls selected nest burrows with larger excavated soil mounds and less creosote bush cover in mixed desert scrub and selected for larger excavated soil mounds in desert scrub. None of the nest-site selection characteristics measured was associated with nest success.

Six key elements predicted potential Western Burrowing Owl habitat: elevation, slope, winter precipitation, summer precipitation, yearly variation in summer precipitation, and vegetation cover. Using the derived model results, we constructed a map of potential Western Burrowing Owl habitat. Based on this map, Clark County contains 27.2% (5,476 km^2) habitat with relatively higher probability of owl occurrence, 53.4% (10,731 km^2) habitat with a relatively moderate probability of occurrence, and 19.4% (3,898 km^2) of habitat with a relatively low probability of occurrence.

Introduction

The Western (*Athene cunicularia hypugaea*, hereafter BUOW) is a small, ground-dwelling owl widely distributed throughout arid and semi-arid habitats of southwestern Canada, western United States and Mexico. This species is migratory in the northern part of its range including Canada, northern Great Plains and northern Great Basin (James 1992, Haug et al. 1993). In the desert southwest, Burrowing Owls are both resident and migratory (Haug et al. 1993).

Western Burrowing Owls (hereafter BUOW) inhabit a wide variety of open habitats including grassland, shrub-steppe, and deserts (Johnsgard 1988, Haug et al. 1993). Throughout its range, the BUOW occupies burrows that have been initially excavated and abandoned by fossorial species, including prairie dog (*Cynomys* spp.), ground squirrel (*Spermophilis* spp.), badger (*Taxidea taxus*), skunk (*Mephitis* spp., *Spilogale putorius*), armadillo (*Dasypus novemcinctus*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), kangaroo rat (*Dipodomys* spp.), and tortoise (*Gopherus* spp.) (Grinnell and Miller 1944, Zarn 1974, Haug and Oliphant 1990). BUOW are opportunistic predators, feeding primarily on insects, small mammals, birds, and reptiles (Bent 1961, Johnsguard 2002, Haug et al. 1993 Green 1983, Haug 1985).

BUOW populations have declined throughout much of their range. Although they occupy the majority of their historic range, populations have decreased by greater than 50% in Alberta, British Columbia, California, Nevada, Colorado and New Mexico (DeSante and George 1994). In addition, range contractions have occurred in southern Canada, the eastern Great Plains, western California, and the Pacific Northwest. Range contractions indicate a trend that is often associated with a declining population (Wellicome and Holroyd 2001). Habitat destruction, resulting from human encroachment, eradication of fossorial mammals, and intensive pesticide use near occupied burrows has been pivotal in these declines (Haug et al. 1993, Trulio 1997, Desmond et al. 2000). The open, flat or gently rolling landscapes suitable for BUOW habitat are also lands preferred for agricultural and urban development.

As a result of population declines, BUOW are currently listed as endangered in Canada (1995) and are a species of special concern in many U. S. states within their range (Wellicome and Haug 1995, James and Espie 1997, De Smet 1997, Sheffield 1997). U. S. Fish and Wildlife Service conducted a status review in 1996 and concluded that insufficient information was available to warrant listing under the Endangered Species Act (Klute et al. 2003). At the present time, the BUOW has no federal regulatory designation in the United States but is protected under the Migratory Bird Treaty Act (1918). It is included as a priority species in seven of the Bird Conservation Regions, including the Sonoran and Mojave Deserts region, in the most recent National Birds of Conservation Concern List (U. S. Fish and Wildlife Service 2008).

In the Mojave Desert, little is known about BUOW populations. The only known population estimates are from surveys conducted in the Nevada portion of Lake Mead National Recreation Area (Crowe and Longshore 2010). Obtaining population estimates for species that occur in low densities has been problematic, particularly for investigations of rare and declining species (Thompson 2004). Accurate, habitat-specific productivity and survivorship estimates are critical to understanding BUOW population dynamics and may ultimately be used to develop plans to retain viable populations of this species. Thus, conservation needs of BUOW in Clark County cannot be adequately defined until a better understanding of its distribution and population status in Clark County is developed. Due to the lack of information regarding BUOW in southern Nevada, this species has been listed under the Clark County Multiple Species Habitat

Conservation Plan as a High Priority Evaluation Species (RECON 2000). A change from High Priority Evaluation Species to Covered Species status requires: (1) an assessment of the current distribution and population status of the species; (2) an evaluation of the area necessary to maintain a minimum viable population of BUOW in Clark County; and (3) assurances that the area is managed appropriately to deal with identified threats. Conservation of the BUOW might be adequately dealt with by managing areas of overlap between owl distribution and conservation areas including Desert Wildlife Management Areas (DWMA) and Areas of Critical Environmental Concern (ACEC).

Our goal was to address the first of these requirements. Specific objectives included (1) conducting population surveys with a protocol specific to the Mojave Desert to determine distribution and relative abundance of BUOW; (2) providing estimates of density, detection probability, apparent nest success, and productivity of BUOW in Clark County; 3) relating nest site selection and reproductive success to habitat and environmental variables; and (4) constructing a habitat model for predicting potential habitat of BUOW based upon important landscape-level habitat components using current technology (i.e., GIS software).

Study Site

Clark County is located in the southernmost portion of Nevada and encompasses 20,956 km^2. Local topography varies from steep mountain ranges with deep washes to rolling and gently inclined alluvial fans and valley basins. Elevation ranges from 160 m within the lower Colorado River drainage to 2100 m of Mount Charleston in the Spring Mountains. Mean monthly temperature is 6.8˚C in January and 33.3˚C in July. Rainfall patterns are highly variable both annually and seasonally with an annual bimodal precipitation cycle of <125 mm falling as winter cool-season rain and snowfall (74%) and summer monsoonal thundershowers (26%). Plant diversity and density in the desert shrubland and mountain vegetation communities increases with higher elevations and latitudes and is associated with increasing rainfall and cooler temperatures. Within Clark County, major habitat types include Sonora-Mojave creosote-white bursage (*Larrea tridentata* (D.C.) Cov.-*Ambrosia dumosa* (Gray) Payne) desert scrub and Mojave mid-elevation mixed desert scrub (SWReGAP 2007). At higher elevations, Colorado Plateau blackbrush (*Coleogyne ramosissima* Torr.), Great Basin pinyon-juniper (*Pinus-Juniperus*), and mixed conifer occur as minor habitat types. Blackbrush occurs as the transition between Mojave mid-elevation mixed desert scrub and pinyon-juniper habitats. The most widespread and dominant vegetation is the creosote bush-white bursage association, which includes both Sonora-Mojave creosote-white bursage desert scrub and Mojave mid-elevation mixed desert scrub. This association is found on basin floors and bajada slopes and is characterized by low diversity of perennial species and a high diversity of annual species that germinate during years of abundant moisture (Turner 1982).

Methods

Population Surveys

Survey methods. During 2008-2009, we conducted owl surveys in Clark County, southern Nevada, using a protocol specifically developed for Mojave Desert shrubland (Crowe and Longshore 2010). We used recorded conspecific song and calls to increase detection rates (Mosher et al. 1990, Gerhardt 1991, Haug and Didiuk 1993). To include breeding stages when owls are most vocal, territory establishment to incubation, we conducted transects from late February to mid-May. Our sampling design consisted of a stratified random selection of transect sites within four vegetation communities in the study area (Thompson 1992, Lancia et al. 2005, Pollock et al. 2002). We surveyed in Sonora-Mojave creosote-white bursage desert scrub (designated here as desert scrub), Mojave mid-elevation mixed desert scrub (designated here as mixed scrub), Colorado Plateau blackbrush, and Great Basin pinyon-juniper. We used Geographic Information System (GIS) software (ArcMap 9.3; Environmental Systems Research Institute, Redlands, California 2008) to generate random 3.2-km transects within the study area, spatially enforcing a minimum distance of at least 3.2 km between transects.

Each BUOW transect (sampling unit) consisted of 5 point-count stations located 0.8 km apart. Transects began within 0.5 hr of sunset and continued for approximately 3-4 hours. At each station, a point count included a 3-minute passive-listening session followed by a 3-minute call-broadcast session. Each broadcasting session consisted of 30-sec of owl vocalizations followed by 30-sec of silence, repeated three times in succession. We used a MP3 player, with an attached external speaker, to broadcast owl vocalizations. Observers were trained by observing BUOW (e.g., flight patterns), listening to vocalizations, and participating in surveys with an experienced observer. Transects were not conducted during moderate to heavy rain or average wind speeds >19 km/hr.

Using methods described in Crowe and Longshore (2010) we adjusted for the proportion of individuals present but not detected (i.e., probability of detection < 1), by estimating the two components of detection probability, availability of individuals for detection and the perception of individuals given their availability. Availability of individuals for detection represents the proportion of owls present that vocalized within the effective area sampled. To estimate density, we determined the average detection threshold distance for BUOW defined as the maximum distance a singing owl can be heard, and in turn, we used this distance to estimate an effective area sampled by our transects. We converted owl detections recorded during transects into two relative abundance indices: frequency of occurrence and territory count. We defined frequency of occurrence as the proportion of transects where at least one owl was detected. Territory count was an enumeration (i.e., total number of owls detected on all transects conducted during a season). For our density estimates, we converted detections of single owls and owl pairs 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. Standard errors were calculated using the delta method

(Williams et al. 2002, Crowe and Longshore 2010). Owl detections outside the average detection threshold distance and migrant owls were not included in our estimates. We defined a migrant as an owl detected at a particular station early in the season (i.e., February and March) but not detected there during burrow observations or detection trials later in the breeding season.

Reproductive Success

We collected information for estimating apparent nest success and productivity (i.e., number of young per nesting attempt, number of young per successful nest) of BUOW. We defined apparent nest success as the proportion of successful nests among all identified nesting attempts. We considered a nest as failed for unknown reasons if either adult was not present or young not considered old enough to fledge were not detected at the nest burrow during subsequent visits. We defined a nesting attempt as a burrow occupied by a pair of owls observed on ≥1 visit. We monitored apparent nest success and productivity using an established protocol (Gorman et al. 2003). To determine the number of young, a series of three 30-min watches were conducted when the young were 21-28 days post-hatch; each watch was separated by at least 6 hours. We defined nest success as ≥1 young observed during the brood rearing stage (Steenhof 1987, Rosenberg and Hayley 2004). For each nest, the maximum number of young observed at any one session was used to estimate the average number of young produced per successful nest and average number of young produced per nesting attempt (Gorman et al. 2003, Rosenberg and Haley 2004). Nest observations occurred when young were active above ground, but young enough to remain close to the nest burrow (i.e., 21-28 days post-hatch). Young were aged using descriptions in Haug et al. (1993) and Priest (1997). We observed nests using camouflaged blinds and spotting scopes at a distance of 50-120 m from the nest. We monitored all occupied burrows found during surveying.

Nest-Site Selection

Nest-site characteristics (predictor variables) were measured at nest burrows (used habitat) and an equal number of random burrows (unused but potential nest sites) (Manly et al. 1993). Data were collected after the young dispersed from the nest burrow. Nest-site characteristics were selected based on both previous research and variables potentially important to owls in the Mojave Desert (Haug et al. 1993, Crowe and Longshore 2007). Burrows with signs of present or past owl occupation (i.e., regurgitated castings, excrement, owl feathers, nest decoration, and remains of disintegrated castings) were not used as random burrows. Random burrows were located within an owl territory at >100m and <800m from the nest burrow.

For each burrow, the following characteristics were recorded: 1) fossorial species that initially excavated the burrow, either desert tortoise (*Gopherus agassizii*) or kit fox; 2) the size of the excavated soil mound outside the burrow entrance; 3) the presence or absence of a caliche horizon over the burrow entrance; 4) whether a burrow was located on the slope of a wash/topographic ridge or alternatively located on level ground; 5) number of satellite burrows occurring within 5 m of the burrow; 6) number of additional satellite burrows within 50 m; 7) amount of cover of creosote bush within 50 m of the nest burrow; 8) amount of perennial cover of subshrubs (e.g., white bursage, white ratany (*Krameria grayi* Rose and Painter) within 50 m of the nest burrow; and 9) plant species nearest to the burrow entrance (Table 1). Size of the excavated soil at the burrow entrance was the sum of mound height, width, and length (m).

Perennial cover for creosote bush and subshrubs was measured as linear intercept (m) of shrubs along three 50 m transects radiating 120˚apart from the nest or random burrow. We measured several of our characteristics within 50 m from the burrow (e.g. vegetative cover, satellite burrows) because this distance encompasses the area where the majority of nesting activity occurs (Haug and Oliphant 1990). We examined the relationship between nest-site characteristics and nest success (explanatory variable).

We used an information-theoretic approach (Burnham and Anderson 2002) to determine support for effects of nest-site characteristics on nest-site selection and nest success of Burrowing Owls. We constructed a set of *a priori* candidate models, which represented hypotheses concerning factors influencing nest success. We used logistic regression and Akaike's Information Criteria (AIC) for model selection to assess both

Table 1. Nest-site characteristics measured for Western Burrowing Owl (*Athene cunicularia hypugaea*) in Sonora-Mojave creosote-white bursage desert scrub and Mojave mid-elevation mixed desert scrub in Clark County, Nevada, 2008-2009. Codes are used in nest-site selection and nest success analyses.

Burrow characteristic	Code	Description
Burrow type	type	Fossorial species that initially excavated burrow; desert tortoise (1) or kit fox (0)
Size of the soil mound	mound	Size of excavated soil mound outside burrow entrance (cm)
Caliche horizon	caliche	Indicates the presence (1) or absence (0) of a layer of caliche over the burrow entrance
Topography	topo	Indicates a burrow located on the slope of a wash or topographic ridge (1) or level ground (0)
Satellite burrows at 5 m	b5m	Number of burrows within 5 m of the burrow
Satellite burrows at 50 m	b50m	Number of burrows within 50 m of the burrow
Creosote bush cover	larcov	Amount of cover of creosote bush measured along three 50 m transects within 50 m of target burrow (m)
Subshrub cover	shrubcov	Amount of cover of perennial subshrubs measured along three 50 m transects within 50 m of target burrow (m)
Nearest shrub	nearspp	Plant species nearest to the burrow entrance; creosote bush (1) or perennial subshrub (0)

nest-site choice and nest success (Hosmer and Lemeshow 2000, Burnham and Anderson 2002). For both analyses, we employed the bias correction (AIC_c) to adjust for small sample size (Burnham and Anderson 2002). We used log-likelihood estimates from each of the logistic regression models to determine AIC_c values (Burnham and Anderson 2002). From these values, we determined ΔAIC_c scores for each model. The smallest delta score (Δ_i) represents the least information lost, given the data and the set of candidate models. We used ΔAIC_c scores to rank the set of candidate models. Models with Δ_i between 0-2 were considered to have a substantial level of support, 4-7 considerably less support, and >10 essentially no support (Burnham and Anderson 2002). We present models with ΔAIC_c of ≤2 as competing models. We used Akaike weights (w_i) and evidence ratios to assess the relative strength of the best model compared to each of the other models (Burnham and Anderson 2002). We evaluated β values and odds ratios from our logistic regression analysis to assess relative strength of each nest-site characteristic from the best approximating models (Burnham and Anderson 2002). Analyses were conducted using SYSTAT statistical software version 11.0 (SYSTAT Software, Inc. Chicago Illinois 2004). Means are presented ± one standard error.

Habitat Model

We constructed a model of potential habitat at 1 km^2 resolution using binary logistic regression and resource selection function methods (Manly et al.1993, Boyce and McDonald 1999). BUOW territory size ranges from 0.14 to 4.8 km^2 (Haug and Oliphant 1990), suggesting that a spatial modeling unit of 1-km^2 is appropriate. We modeled the relationship between owl presence (response/dependent variable) and our suite of habitat variables (predictor/independent variables; environmental and topographic). We performed all GIS analyses using ArcMap 9.3 (Environmental Systems Research Institute, Redlands, California 2008). Topographic information was derived from 30-meter digital elevation models. Two variables we wanted to include as factors that may influence the occurrence of owls were densities of desert tortoise and kit fox. BUOW nest in burrows excavated by both species and desert tortoise population density was found to be an important variable in a model of potential BUOW habitat constructed for the southern Mojave Desert in California (Crowe and Longshore 2007). However, spatially explicit estimates of desert tortoise and kit fox were not available for Clark County. Instead, we used data layers developed to model potential desert tortoise habitat by Nussear et al. (2009) as a proxy for desert tortoise density (http://pubs.usgs.gov/of/2009/1102/). We assumed that if tortoise density were an important predictor of BUOW occurrence, then the same variables that determine the occurrence of the tortoise may be important predictors for BUOW. Variables used in our analysis included elevation, slope, summer precipitation, winter precipitation, coefficient of variation (CV) of summer precipitation, bulk soil density, depth to bedrock, percentage of rocks measuring greater than 254 mm (B-axis) in soil mass, and perennial plant cover. We were not able to include kit fox population density in the model.

We used grid cells that contained occupied territories found on transects surveyed during 2008-2009 (used habitat) and random locations (available habitat) generated using the Hawth's tools© extension in ArcMap for our habitat model analysis. All analyses were conducted using SPSS statistical software version 9.0 (SPSS Inc., Chicago, Illinois 1999). We used Akaike's Information Criteria (AIC) for model selection (see AIC description above). Our global model was based on the assumption that a variety of environmental variables would explain the variation in owl occurrence. We present the top models with ΔAIC_c of ≤ 2 as possible competing models. The logistic regression formula derived from the most parsimonious of the plausible AIC models was entered into GIS software (ArcMap 9.3). Resource Selection Function (RSF) values were generated for each 1 km grid cell across the study area (Manly et al.1993, Boyce and McDonald 1999). The resulting (RSF) values were used to model the relative probability of habitat use as a function of the environmental and topographical variables from the model.

We tested model performance using an independent data set of owl locations (31 territory locations) obtained from surveys conducted for BUOW during previous studies in 2003-2005 on the Lake Mead National Recreation Area, Clark County, Nevada, and from avian point count transects conducted by D. Crowe for the Great Basin Bird Observatory during 2005-2007.

We used the derived model of relative probability of habitat use to evaluate the amount of habitat located in conserved lands within Clark County. We superimposed a GIS layer with conservation boundaries onto the owl habitat layer and with ArcMap calculated the amount of suitable owl habitat contained in Areas of Conservation Concern/Desert Wildlife Management Areas (ACEC/ DWMA), Nevada portion of Lake Mead National Recreation Area (LAME), Department of Defense (DOD) lands, and Wilderness Areas within Clark County.

Results

Population Surveys

During the two years of the study, we conducted 95 unique transects (608 km^2, Figure 1). Transects were conducted from 4 March to 16 May 2008 and 23 February to 14 May 2009. In 2008, we conducted 15 transects in desert scrub, blackbrush, and pinyon-juniper and 16 transects in mixed desert scrub. During 2009, we conducted 63 transects in the two Mojave Desert scrub habitats, we resurveyed 29 transects from 2008 in desert scrub and mixed desert scrub as well as 34 new transects. We resurveyed five (33%) transects in blackbrush during 2009. We did not detect owls in either blackbrush or pinyon-juniper habitats.

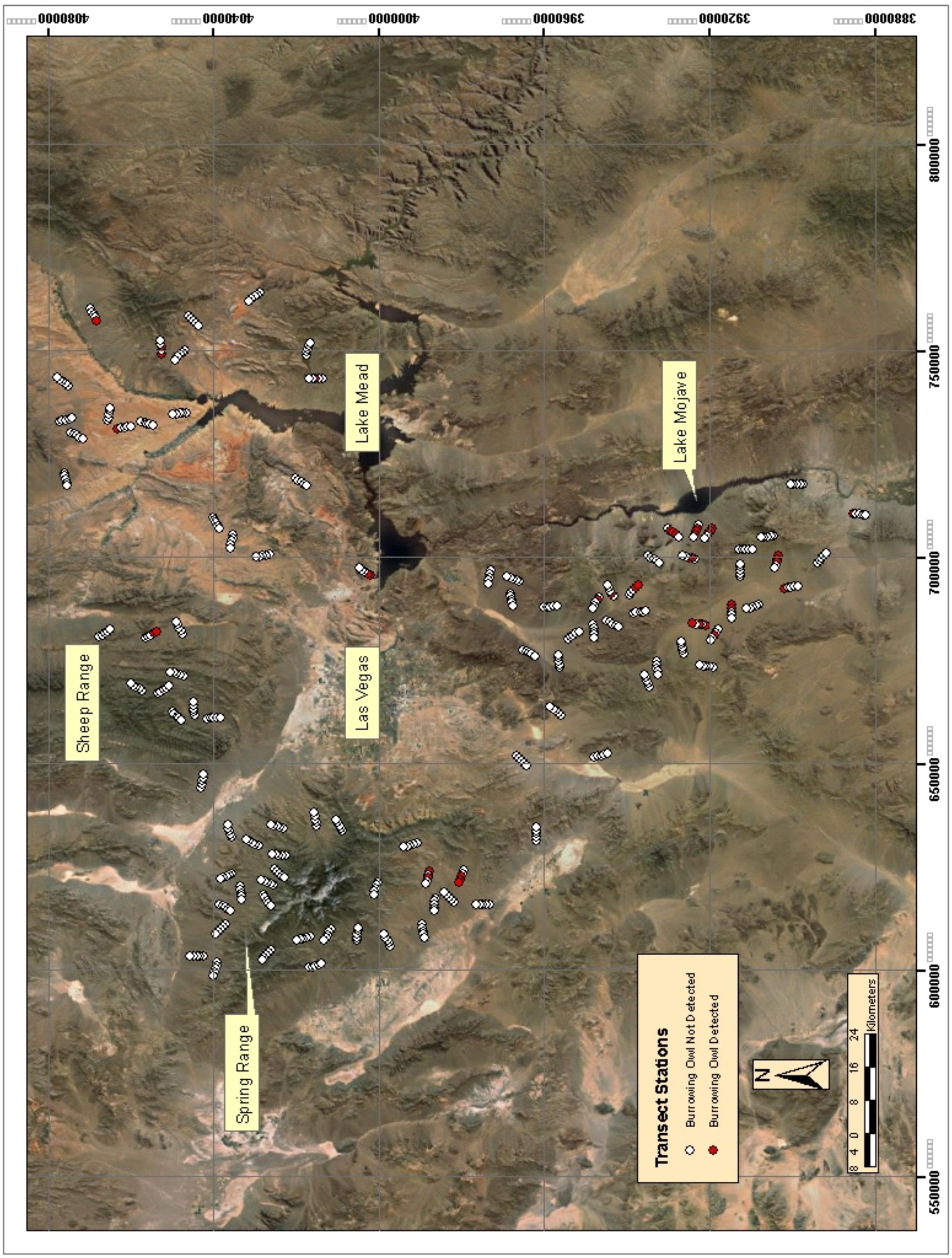
Frequency of occurrence, a measure of relative abundance, was 22.6% ± 7.6% (n = 31) for all Mojave Desert scrub transects in 2008 and 28.6% ± 5.7% (n = 63) for 2009. We estimated frequency of occurrence separately for both years and the two desert scrub types including transects conducted in 2008 and resurveyed during 2009 (Table 2). Frequency of occurrence for the two years and two Mojave Desert scrub habitat types ranged from a low of 17.6% to a high of 40.0%.

Table 2. Mean frequency of occurrence (± SE), a measure of relative abundance and defined as the proportion of transects for Western Burrowing Owl (*Athene cunicularia hypugaea*) where at least one owl is detected. Transects were conducted in Sonora-Mojave creosote-white bursage desert scrub (desert scrub), Mojave mid-elevation mixed desert scrub (mixed desert scrub), blackbrush, and pinyon-juniper in Clark County, Nevada using call-broadcast methods. We did not detect owls in either blackbrush or pinyon-juniper habitat types.

Year and Habitat Type	Frequency of Occurrence (n)
2008	
Desert scrub	26.7 ± 11.8 (15)
Mixed desert scrub	18.8 ± 10.1 (16)
Two desert scrub types combined	22.6 ± 7.6 (31)
2009	
Desert scrub[1]	28.6 ± 12.5 (14)
Mixed desert scrub[1]	40.0 ± 13.1 (15)
Desert scrub[2]	17.6 ± 9.5 (17)
Mixed desert scrub[2]	29.4 ± 11.4 (17)
Desert scrub	22.6 ± 7.6 (31)
Mixed desert scrub	34.4 ± 8.5 (32)
Two desert scrub types combined	28.6 ± 5.7 (63)

[1] 2008 transects repeated during 2009 season
[2] 2009 new transects

Figure 1. Map showing the location of 95 unique transects conducted for Western Burrowing Owl (*Athene cunicularia hypugaea*) using call-broadcasting methods in Clark County, southern Nevada during 2008-2009.


Sheep Range
Spring Range
Las Vegas
Lake Mead
Lake Mojave
Transect Stations
Burrowing Owl Not Detected
Burrowing Owl Detected
N
8 4 0 8 16 24
Kilometers
550000
600000
650000
700000
750000
800000
3880000
3920000
3960000
4000000
4040000
4080000

Total territory count for the two desert scrub habitat types was 12 in 2008 (*n* = 31) and 25 in 2009 (*n* = 63). We separated territory counts by year and desert scrub habitat types (i.e., desert scrub and mixed desert scrub) for comparison (Table 3). We estimated the availability component of detection probability (i.e., the proportion of owls in the transect that vocalize during a survey) for both desert scrub habitats combined at 50.2% ± 34.3 % (*n* = 24) and 54.6% ± 19.2 % (*n* = 38) for 2008 and 2009, respectively. Using the double-observer method, we estimated the perception component of detection probability at $P_p = 1$ (i.e., both observers of a pair detected the same owls). After adjusting for detection probability, we estimated territory count as 23.9 ± 4.1 owl territories per km^2 during 2008 and 45.8 ± 4.8 owl territories per km^2 during 2009.

Table 3. Territory counts of Western Burrowing Owl (*Athene cunicularia hypugaea*) from transects in Clark County, southern Nevada during 2008-2009. Transects were conducted using call-broadcast methods. Territory count is separated by year and Sonora-Mojave creosote-white bursage desert scrub (desert scrub) and Mojave mid-elevation mixed desert scrub (mixed desert scrub). Territory count (± SE) adjusted for detection probability is also presented.

Year and Habitat Type	Territory Count	Adjusted Territory Count
2008		
Desert scrub (15)	7	13.9 ± 2.4
Mixed desert scrub (16)	5	10.0 ± 1.7
Two desert scrub types (31)	12	23.9 ± 4.1
2009		
Desert scrub (14)[1]	6	11.0 ± 1.1
Mixed desert scrub (15)[1]	9	16.5 ± 1.7
Desert scrub (17)[2]	4	7.3 ± 0.8
Mixed desert scrub (17)[2]	6	11.0 ± 1.1
All desert scrub (31)	10	18.3 ± 1.9
All mixed desert scrub (32)	15	27.5 ± 2.9
Two desert scrub types (63)	25	45.8 ± 4.8

[1] 2008 transects repeated during 2009 season
[2] 2009 new transects

Overall, density of BUOW in desert scrub habitat was 0.122 ± 0.022 owl territories per km^2 for 2008 and 0.115 ± 0.013 owl territories per km^2 for 2009 (Table 4). Density ranged from a low of 0.068 owl territories per km^2 in desert scrub in 2009 to a high of 0.173 owl territories per km^2 in mixed desert scrub in 2009 for transects repeated from 2008 (Table 4). We found no significant difference in density among years and habitats ($F_{1,89}$ = all $P > 0.05$)

Reproductive Success

We monitored 60 nest burrows during the two years of the study. BUOW occupied an equal number of desert tortoise (10) and kit fox burrows (10) in 2008 and slightly more desert tortoise burrows (24) than kit fox (16) in 2009. No difference in nest success occurred between the two burrow types with both years combined (Fisher's exact test: P = 0.796, *n* = 60). We estimated apparent nest success at 60.0% ± 11.2% (*n* = 20) during 2008 and 57.8% ± 8.0% (*n* = 40) during 2009. Estimates of apparent nest success for each habitat type and year are in Table 5. Owl pairs produced 5.36 ± 0.43 (*n* = 11, range 2-7) young per successful nest and 3.11 ± 0.67 (*n* = 19, range 0-7) young per nesting attempt during 2008. During 2009, productivity was estimated at 6.73 ± 0.43 (*n* = 20, range 1-10) young per successful nest and 3.32 ± 0.56 (*n* = 37, range 0-10) young per nesting attempt. Of occupied burrows found in 2008, 40% were reoccupied in 2009. We found no difference in apparent nest success between the two years (Fisher's exact test: P = 1.00, *n* = 60) with both desert scrub habitats combined. In 2008, apparent nest success was significantly lower in desert scrub than mixed desert scrub (Fisher's exact test: P = 0.028, *n* = 20). In 2009 apparent nest success was not significantly different between the two desert scrub types (Fisher's exact test: P = 0.069, *n* = 40). Owls nesting in mixed desert scrub produced a significantly higher number of young per nesting attempt ($F_{1,52}$ = 6.692, P = 0.013); no difference was found between years (P = 0.999). The number of young produced per successful nest was not significantly different between the two habitat types ($F_{1,27}$ = 5.780, P = 0.179) or years(P = 0.245).

Table 4. Mean density (± SE) of Western Burrowing Owl (*Athene cunicularia hypugaea*) from transects conducted in Clark County, southern Nevada during 2008-2009. Transects were conducted using call-broadcast methods. Density is reported as the number of owl territories per km^2. Density estimates are separated by year and vegetation types, Sonora-Mojave creosote-white bursage desert scrub (desert scrub) and Mojave mid-elevation mixed desert scrub (mixed desert scrub). An estimate of effective area sampled is also provided.

Year and Habitat Type	Density (Owl territories per km^2)	Area Sampled (km^2)[3]
2008		
Desert scrub	0.147 ± 0.026	95.2
Mixed desert scrub	0.098 ± 0.018	101.5
All desert scrub	0.122 ± 0.022	196.7
2009		
Desert scrub[1]	0.124 ± 0.014	88.9
Mixed desert scrub[1]	0.173 ± 0.019	95.2
Desert scrub[2]	0.068 ± 0.008	107.9
Mixed desert scrub[2]	0.102 ± 0.011	107.9
All desert scrub	0.093 ± 0.010	196.8
All mixed desert scrub	0.135 ± 0.015	203.1
All desert scrub	0.115 ± 0.013	399.9

[1] 2008 transects repeated during 2009 season
[2] 2009 new transects
[3] Area sampled using mean detection threshold distance of 752 m

Table 5. Apparent nest success (± SE) and productivity (± SE) of Western Burrowing Owl (*Athene cunicularia hypugaea*) in Sonora-Mojave creosote-white bursage desert scrub (desert scrub) and Mojave mid-elevation mixed desert scrub (mixed desert scrub) detected during owl transects conducted in 2008-2009, Clark County, Nevada. Productivity estimates include both the number of young (YG) produced per successful nest and the number of young produced per nesting attempt.

	Desert scrub	Mixed desert scrub	Combined
Apparent nest success			
2008	36.4% ± 15.25 (11)	88.9% ± 11.1% (9)	60.0 ± 11.2% (20)
2009	52.4% ± 11.2% (21)	63.2 ± 11.4% (19)	57.5 ± 8.0% (40)
2008-2009	46.9% ± 9.0% (32)	71.4% ± 8.7% (28)	58.3% ± 6.4% (60)
YG nesting attempt			
2008	1.82 ± 0.77 (11)	4.88 ± 0.92 (8)	3.11 ± 0.67 (19)
2009	2.58 ± 0.73 (19)	4.11 ± 0.84 (18)	3.32 ± 0.56 (37)
2008-2009	2.3 ± 0.54 (30)	4.37 ± 0.64 (26)	3.25 ± 0.43 (56)
YG successful nest			
2008	5.0 ± 0.41 (4)	5.57 ± 0.70 (7)	5.36 ± 0.45 (11)
2009	5.44 ± 0.75 (9)	6.73 ± 0.43 (11)	6.73 ± 0.43 (20)
2008-2009	5.31 ± 0.52 (13)	6.28 ± 0.39 (18)	5.87 ± 0.32 (31)

Nest-Site Selection

We measured nest-site characteristics at 55 unique nest sites and 55 random burrows in desert scrub and mixed desert scrub habitat. We combined years for our analysis. For desert scrub habitat we measured variables at 32 nest burrows and 32 random burrows (Table 6). We calculated log-likelihood estimates, number of estimable parameters (k), AIC values, Δ AIC_c, and Akaike weights (w_i) for each of 10 candidate models (Table 7). The global model included type of burrow, topography, caliche layer, soil mound size, plant species nearest to burrow

Table 6. Means with standard errors (SE) for nest-site characteristics measured for logistic regression analysis to determine the probability of Western Burrowing Owl (*Athene cunicularia hypugaea*) choosing a burrow in Sonora-Mojave creosote-white bursage desert scrub during 2008-2009. Refer to Table 1 for descriptions of burrow characteristics.

Burrow Characteristic	Nest burrow (n = 32)	Random burrow (n = 32)
Type of burrow	0.66 ± 0.09	0.59 ± 0.08
Topography	0.59 ± 0.09	0.53 ± 0.09
Caliche Layer	0.13 ± 0.06	0.25 ± 0.08
Soil Mound (m)	3.03 ± 0.21	1.87 ± 0.17
Nearest shrub	0.50 ± 0.09	0.53 ± 0.09
Burrows within 5 m	0.84 ± 0.23	0.50 ± 0.16
Burrows within 50 m	1.66 ± 0.53	0.59 ± 0.17
Creosote bush cover (m)	11.50 ± 0.84	11.14 ± 1.17
Perennial subshrub cover (m)	11.78 ± 1.69	13.51 ± 1.66

Table 7. Comparison and relative ranking of candidate models for Western Burrowing Owl (*Athene cunicularia hypugaea*) nest-site characteristics (burrows) in Clark County, Nevada in Sonora-Mojave creosote-white bursage desert scrub (desert scrub) during 2008-2009. Log-likelihood values, number of estimable parameters (k), AIC_c values, ΔAIC_c values, and Akaike weights (w_i) are listed for each model. Burrow characteristics include burrow type (type), soil mound size (mound), topography (topo), presence of a caliche layer (caliche), nearest species to the burrow entrance (nearspp), the number of available burrows within 5 m (b5m), number of available burrows within 50 m (b50m), creosote bush cover within 50 m (larcov), and perennial subshrub cover within 50 m (shrubcov). Relative ranking of models was determined using Akaike's Information Criteria differences (ΔAIC_c).

	Model terms[1]	-2LogL	k	AIC_c	ΔAIC_c	w_i
1	Mound+topo+b50m+shrubcov	33.317	6	79.888	0	0.357
2	Type+mound+b5m+b50m	33.959	6	81.172	1.28	0.189
3	Mound+b5m+b50m+larcov+shrubcov	33.020	7	81.737	1.85	0.142
4	Mound+nearspp+b50m+larcov+shrubcov	33.085	7	81.867	1.98	0.133
5	Mound+nearspp+larcov+shrubcov	34.883	6	83.020	3.13	0.075
6	Type+mound+topo+caliche+larcov+shrubcov	32.982	8	84.180	4.29	0.042
7	Type+mound+caliche+b5m+larcov	34.391	7	84.479	4.59	0.036
8	Global model	30.063	11	86.384	6.50	0.014
9	Type+mound+topo+nearspp+b50m+larcov+shrubcov	32.860	9	86.533	6.64	0.013
10	B50m+larcov+shrubcov	41.258	5	93.399	13.51	0.0004

entrance, number of burrows within 5 m, number of burrows within 50 m, creosote bush cover within 50 m, and perennial subshrub cover within 50 m. AIC analysis revealed four models with substantial support ($\Delta AIC_c \leq 2$). All remaining models had lower model weights (0.0747 to 0.0004). The best approximating model with the minimum ΔAIC_c included soil mound size, topography, number of burrows within 50 m, and amount of perennial subshrub cover within 50 m. This model had an Akaike weight (w_i) of 0.357 indicating that given the data and set of models, it had a 36% probability of being the best approximating model. This model correctly classified 66% burrows and had a McFadden's *rho*-squared value of 0.281. The next three models had Akaike weights (w_i) of 0.189, 0.142, and 0.133 with a 19%, 14%, and 13% probability of being the best model. Variables in Model 2 included burrow type, size of soil mound, number of burrows within 5 m, and number of available burrows within 50 m. Model 3 consisted of size of soil mound, number of available burrows within 5 m, and number of available burrows within 50 m, cover of creosote bush and cover of perennial subshrubs. The evidence ratios show Model 1 was 1.9×, 2.52×, and 2.69× more likely to be the best model than models 2-4, suggesting that Model 1 had the greatest support for being the best approximating model in the set.

We evaluated the support of each variable in the best approximating model by looking at the odds ratio and 95% confidence interval (CI) for the odds ratio (Table 8). For every one meter increase in soil mound size, the odds of a burrow being selected increased 3.0 times. CI for topography, number of burrows within 50 m, and perennial subshrub cover included 1, indicating that there was insufficient statistical evidence that these variables influenced selection of a burrow as a nest site. Models 2-4 had similar odds ratios (3.02-3.25) for the influence of soil mound. None of the other variables in the models were influential (i.e., all 95% CI included 1).

Our nest-site analysis for desert scrub during 2008-2009 showed that owls selected for nest burrows with a larger soil mound outside the burrow entrance. These mounds were formed

Table 8. Parameter estimates (β), standard errors (SE) of the estimates, odds ratios, and 95% confidence intervals (CI) of the odds ratios, for the best approximating model for Western Burrowing Owl (*Athene cunicularia hypugaea*) nest-site selection in Sonora-Mojave creosote-white bursage desert scrub during 2008-2009, Clark County, southern Nevada. Nest-site characteristics include, soil mound size (mound), topography (topo), number of available burrows within 50 m (b50m), and perennial subshrub cover within 50 m (shrubcov).

Effect	Β	SE	Odds ratio	95% CI
Mound	1.102	0.331	3.01	1.57-5.76
Topo	-0.127	0.613	0.88	0.03-2.93
B50m	0.302	0.236	1.35	0.85-2.15
Shrubcov	-0.046	0.033	1.00	0.90-1.02

by either a desert tortoise or kit fox as they excavated the burrow. Owls selected for none of the other characteristics we measured.

During 2008-2009, we measured nest-site characteristics in mixed desert scrub at 23 nest burrows and 23 random burrows (Table 9). For the analysis of nest-site selection in mixed desert scrub, we calculated log-likelihood estimates, number of estimable parameters (k), AIC values, and Akaike weights (w_i) for each candidate model for 8 models (Table 10). The global model and 7 competing models were identical to those used in the desert scrub analysis. We removed models containing caliche because in mixed desert scrub it only occurred at one burrow. AIC analysis revealed three models with substantial support (Δ $AIC_c \leq 2$). All remaining models had AIC differences > 2 and decreasingly lower model weights (0.033 to <0.001). The best approximating model with the minimum Δ AIC_c included soil mound size, nearest shrub type to burrow entrance, number of available burrows within 50 m, amount of creosote bush cover, and amount of perennial subshrub cover. This model had an Akaike weight (w_i) of 0.327 indicating that given the data and set of models, it had a 33% probability of being the best approximating model. This model correctly classified 85% of burrows and had a McFadden's *rho*-squared

Table 9. Means with standard errors (SE) for nest-site characteristics measured for logistic regression analysis to determine the probability of Western Burrowing Owl (*Athene cunicularia hypugaea*) choosing a burrow in Mojave mid-elevation mixed desert scrub (mixed desert scrub) during 2008-2009 in Clark County, Nevada. Refer to Table 1 for descriptions of burrow characteristics.

Burrow Characteristic	Nest burrow (*n* = 23)	Random burrow (*n* = 23)
Type of burrow	0.44 ± 0.11	0.52 ± 0.11
Topography	0.30 ± 0.10	0.17 ± 0.08
Soil Mound (m)	3.18 ± 0.15	1.77 ± 0.15
Nearest shrub	0.39 ± 0.10	0.65 ± 0.10
Burrows within 5 m	0.57 ± 0.20	0.09 ± 0.06
Burrows within 50 m	1.13 ± 0.32	0.65 ± 0.18
Creosote bush cover (m)	14.24 ± 1.75	18.53 ± 2.06
Subshrub cover (m)	22.96 ± 1.71	24.07 ± 1.77

Table 10. Comparison and relative ranking of candidate models for Western Burrowing Owl (*Athene cunicularia hypugaea*) nest-site characteristics in Mojave mid-elevation mixed desert scrub (mixed desert scrub) in Clark County, Nevada during 2008-2009. Log-likelihood values, number of estimable parameters (k), AIC_c values, delta AIC_c values, and Akaike weights (w_i) are listed for each model. Burrow characteristics included burrow type (type), soil mound size (mound), topography (topo), nearest shrub to the burrow entrance (nearspp), number of available burrows within 5 m (b5m), number of satellite burrows within 50 m (b50m), amount of creosote bush cover (larcov), and amount of perennial subshrub cover (shrubcov). Relative ranking of models was determined using Akaike's Information Criteria differences for small sample size (ΔAIC_c).

	Model	-2LogL	k	AIC_c	ΔAIC_c	w_i
1	Mound+nearspp+b50m+larcov+shrubcov	10.355	7	36.41	0	0.327
2	Mound+nearspp+larcov+shrubcov	11.578	6	36.41	0.003	0.327
3	Mound+b5m+b50m+larcov+shrubcov	10.549	7	36.79	0.39	0.269
4	Type+mound+topo+nearspp+b50m+larcov+shrubcov	10.105	9	41.02	4.62	0.033
5	Type+mound+b5m+b50m	14.120	6	41.49	5.09	0.026
6	Mound+topo+b50m+shrubcov	15.038	6	43.33	6.92	0.010
7	Global model	10.105	10	43.70	7.30	0.009
8	B50m+larcov+shrubcov	28.313	5	67.51	31.10	<0.001

value of 0.669. Model 2 had the same Akaike weight of 0.327 and contained the same variables but without the number of burrows at 50 m. Model 3 had a weight of 0.269 and contained size of soil mound, number of burrows at 5 m, number of burrows at 50 m, amount of creosote bush cover, and amount of perennial subshrub cover. All of the three top models were roughly equivalent with evidence ratios of 1.00 (comparing Model 1 to Model 2) and 1.21 (Model 1 to Model 3). We evaluated the support of each variable in the three equivalent best approximating models (Models 1-3) for nest-site selection in mixed desert scrub by examining the odds ratio and 95% confidence interval for the odds ratio (Table11). Size of the soil mound and amount of creosote bush cover were influential in all three models. For every unit increase in soil mound size, the odds of selecting a burrow increased by 4.5× over a burrow with a smaller mound. The odds that a burrow would be selected as a nest site decreased 15% for every one meter increase of creosote bush cover. The CI for the other variables in the three models included 1 indicating that those variables were not significantly influential in the selection of a burrow as a nest site:

Table 11. Parameter estimates (β), standard errors (SE) of the estimates, odds ratios, and 95% confidence intervals (CI) for the odds ratios for the most parsimonious of the three competing models of Western Burrowing Owl (*Athene cunicularia hypugaea*) nest-site selection in Mojave mid-elevation mixed desert scrub, Clark County, Nevada during 2008-2009. Burrow characteristics include soil mound size (mound), number of available burrows within 5 m (b5m), number of available burrows within 50 m (b50m), creosote bush cover within 50 m (larcov), and perennial subshrub cover within 50 m (shrubcov).

Effect	β	SE	Odds ratio	95% CI
Mound	1.504	0.563	4.50	1.49-13.57
B5m	0.462	0.599	1.59	0.34-4.56
B50m	0.189	0.757	1.21	0.27-5.03
Larcov	-0.164	0.078	0.85	0.73-0.99
Shrubcov	-0.006	0.085	0.99	0.84-1.17

nearest shrub type at burrow, number of burrows within 5 m, number of burrows within 50 m, and amount of perennial subshrub cover. In mixed desert scrub, owls selected for larger soil mounds at the entrance of the burrow and less creosote bush cover surrounding the nest site.

We examined the relationship between nest-site characteristics and nest success (successful nest = 1, failed nest = 0) using logistic regression and AIC methods. We found no differences in nest-site characteristics between successful and failed nest burrows in either desert scrub (Table 12, Table 13) or mixed desert scrub (Table 14, Table 15). AIC results showed that the null model (i.e., logistic regression model with no variables) had the lowest AIC_c value compared to the other candidate models, suggesting that none of these nest-site characteristics were important to nest success (Table 13, Table 15). None of the models that included nest-site characteristics were significantly different than the null model (all χ^2 P values > 0.05).

Table 12. Means with standard errors (SE) for nest-site characteristics measured at successful and failed Western Burrowing Owl (*Athene cunicularia hypugaea*) nests in Sonora-Mojave creosote-white bursage desert scrub during 2008-2009, Clark County, Nevada. Refer to Table 1 for descriptions of burrow characteristics.

Burrow Characteristic	Successful (*n* = 15)	Failed (*n* = 17)
Type of burrow	0.73 ± 0.12	0.59 ± 0.12
Soil mound size (m)	2.88 ± 0.23	3.16 ± 0.33
Topography	0.53 ± 0.13	0.67 ± 0.12
Caliche layer	0.20 ± 0.12	0.06 ± 0.06
Nearest shrub species (m)	0.33 ± 0.13	0.65 ± 0.12
Burrows within 5 m	0.80 ± 0.28	0.88 ± 0.37
Burrows within 50 m	1.53 ± 0.52	1.77 ± 0.91
Creosote bush cover (m)	10.70 ± 1.25	12.19 ± 1.12
Perennial subshrub cover (m)	15.31 ± 2.71	13.67 ± 1.85

Table 13. Comparison and relative ranking of candidate models for Western Burrowing Owl (*Athene cunicularia hypugaea*) nest-site characteristics and their relationship to nest success in Sonora-Mojave creosote-white bursage desert scrub in Clark County, Nevada during 2008-2009. Log-likelihood values, number of estimable parameters (k), AIC_c values, delta AIC_c values, and Akaike weights (w_i) are listed for each model. Burrow characteristics included burrow type (type), soil mound size (mound), nearest shrub to the burrow entrance (nearspp), number of available burrows within 5 m (b5m), number of satellite burrows within 50 m (b50m), amount of creosote bush cover (larcov), and amount of perennial subshrub cover (shrubcov). Relative ranking of models was determined using Akaike's Information Criteria differences for small sample size ($\Delta\ AIC_c$).

	Model	-2LogL	k	AIC_c	$\Delta\ AIC_c$	w_i
1	Null model	22.19	2	48.41	0	0.319
2	Mound+nearspp+larcov+shrubcov	17.68	6	48.60	0.199	0.288
3	Mound+ b50m+shrubcov	19.61	5	50.10	1.695	0.136
4	B50m+larcov+shrubcov	19.72	5	50.32	1.919	0.122
5	Type+mound+larcov+shrubcov	18.84	6	50.93	2.519	0.090
6	Mound+b5m+b50m+larcov+shrubcov	18.95	7	53.59	5.184	0.024
7	Global model	17.06	9	54.93	6.529	0.012
8	Type+mound+b5m+b50m	21.23	6	55.72	7.313	0.008

Table 14. Means with standard errors (SE) for nest-site characteristics measured at successful and failed Western Burrowing Owl (*Athene cunicularia hypugaea*) nests in Mojave mid-elevation mixed desert scrub during 2008-2009, Clark County, Nevada. Refer to Table 1 for descriptions of burrow characteristics.

Burrow Characteristic	Successful (*n* = 16)	Failed (*n* = 7)
Type of burrow	0.38 ± 0.13	0.57 ± 0.20
Soil mound size (m)	3.21 ± 0.18	3.11 ± 0.29
Topography	0.44 ± 0.13	0.39 ± 0.18
Nearest shrub species (m)	0.31 ± 0.12	0.57 ± 0.20
Burrows within 5 m	0.50 ± 0.20	0.71 ± 0.47
Burrows within 50 m	0.81 ± 0.26	1.86 ± 0.86
Creosote bush cover (m)	14.28 ± 2.09	14.14 ± 3.46
Perennial subshrub cover (m)	22.09 ± 1.71	24.96 ± 4.17

Table 15. Comparison and relative ranking of candidate models for Western Burrowing Owl (*Athene cunicularia hypugaea*) nest-site characteristics in Mojave mid-elevation mixed desert scrub in Clark County, Nevada during 2008-2009. Log-likelihood values, number of estimable parameters (k), AIC_c values, delta AIC_c values, and Akaike weights (w_i) are listed for each model. Burrow characteristics included burrow type (type), soil mound size (mound) size, nearest shrub to the burrow entrance (nearspp), number of available burrows within 5 m (b5m), number of satellite burrows within 50 m (b50m), amount of creosote bush cover (larcov), and amount of perennial subshrub cover (shrubcov). Relative ranking of models was determined using Akaike's Information Criteria differences for small sample size (Δ AIC_c).

	Model	-2LogL	k	AIC_c	Δ AIC_c	w_i
1	Null model	13.20	2	30.57	0	0.446
2	B50m+larcov+shrubcov	10.93	5	32.75	2.175	0.150
3	Type+mound+b5m+b50m	9.76	6	32.76	2.193	0.149
4	Mound+ b50m+shrubcov	11.32	5	33.53	2.957	0.102
5	Mound+nearspp+larcov+shrubcov	10.50	6	34.25	3.66	0.071
6	Type+mound+larcov+shrubcov	10.78	6	34.82	4.25	0.053
7	Mound+b5m+b50m+larcov+shrubcov	10.38	7	36.45	5.89	0.024
8	Global model	9.37	9	39.56	8.99	0.005

Habitat Model

We used 59 grid cells with occupied territory sites and 99 random location grid cells to construct candidate models for describing owl habitat. Models were developed as alternative hypotheses of factors that influence the occurrence of owls. No variable interactions were found during model development. Top seven models are presented (Table 16). We determined log-likelihood estimates, number of estimable parameters (k), AIC_c values, ΔAIC_c, and Akaike weights (w_i) for each model (Table 16). The AIC evaluation revealed one model (Model 1) with substantial support as the best approximating model ($\Delta AIC_c < 2$). This model included elevation, slope, winter precipitation, summer precipitation, CV of summer precipitation, perennial plant cover, and percentage soil mass with rocks > 254 mm (B-axis diameter). The model had an

Table 16. Comparison and relative ranking of candidate models using 1-km grid cells containing Western Burrowing Owl (*Athene cunicularia hypugaea*) territories found during surveys conducted in Clark County, Nevada with log-likelihood values, number of estimable parameters(k), AIC_c values, delta AIC_c values, and Akaike weights (w_i) for each model. Global model included elevation (elev), slope, winter precipitation (wppt), summer precipitation (sppt), summer precipitation coefficient of variation (spptcv), perennial plant cover (vegcov), percentage of rocks > 254 mm (%rock), depth to bedrock (dpthb), and soil bulk density (blkden). Relative ranking of models was determined using Akaike's Information Criteria differences (Δ AIC_c).

	Model	-2LogL	k	AIC_c	Δ AIC_c	w_i
1	Elev+slope+wppt+sppt+spptcv+vegcov+%rock	104.42	9	125.23	0	0.835
2	Global model	102.71	11	128.97	3.74	0.129
3	Elev+slope+wppt+sppt+spptcv+vegcov	114.85	8	133.07	7.83	0.017
4	Elev+slope+wppt+sppt+spptcv	118.41	7	134.10	8.87	0.010
5	Elev+slope+sppt+spptcv+vegcov+dpthb	115.92	8	134.14	8.90	0.010
6	Elev+slope+%rock+bdpth+blkden	154.47	5	170.16	44.93	<0.001
7	Elev+wppt+sppt+spptcv	171.93	3	185.18	59.95	<0.001

Akaike weight of 0.835, indicating that given the data and set of models, it had 84% probability of being chosen as the best model. This model correctly classified 79% of grid cells/locations and had a McFadden's *rho*-squared value of 0.50 suggesting a high level of variance in variables was explained. All remaining models had AIC_c differences >2 and lower model weights (0.129 to <0.001).

Grid cells containing occupied owl territories were found at elevations ranging from 237.2 m to 1260.9 m (746.5 ± 41.3 m, *n* =59) and slopes ranging from 0.0% to 4.7% (2.0% ± 0.2 %, *n* = 59). Average winter precipitation ranged from 26.8 mm to 149.8 mm (94.9 mm ± 4.7 mm, *n* = 59), summer precipitation from 47.0 mm to 87.0 mm (70.5 mm ± 1.9 mm, *n* = 59), and soil mass with rocks > 254 mm ranged from 0.00% to 0.66% (0.18% ± 0.03%, *n* = 59).

Table 17. Parameter estimates (β), standard errors (SE) of the estimates, odds ratios, and 95% confidence intervals (CI) for the odds ratios of the variables in the best approximating model for the occurrence of a Western Burrowing Owl (*Athene cunicularia hypugaea*) territory in Clark County, Nevada. Variables include elevation (elev), slope, winter precipitation (wppt), summer precipitation (sppt), summer precipitation coefficient of variation (spptcv), perennial plant cover (vegcov), percentage of rocks > 254 mm (%rock).

Effect	β	SE	Odds ratio	95% CI
Wppt	0.064	0.029	1.066	1.007-1.129
Sppt	0.198	0.048	1.219	1.111-1.338
Spptcv	1.704	0.667	5.493	1.486-20.307
Slope	-0.732	0.190	0.481	0.698-0.332
Vegcov	-0.101	0.045	0.904	0.986-0.828
%rock	-0.502	0.571	0.605	0.198-1.853
Elev	-0.014	0.004	0.986	0.933-0.979

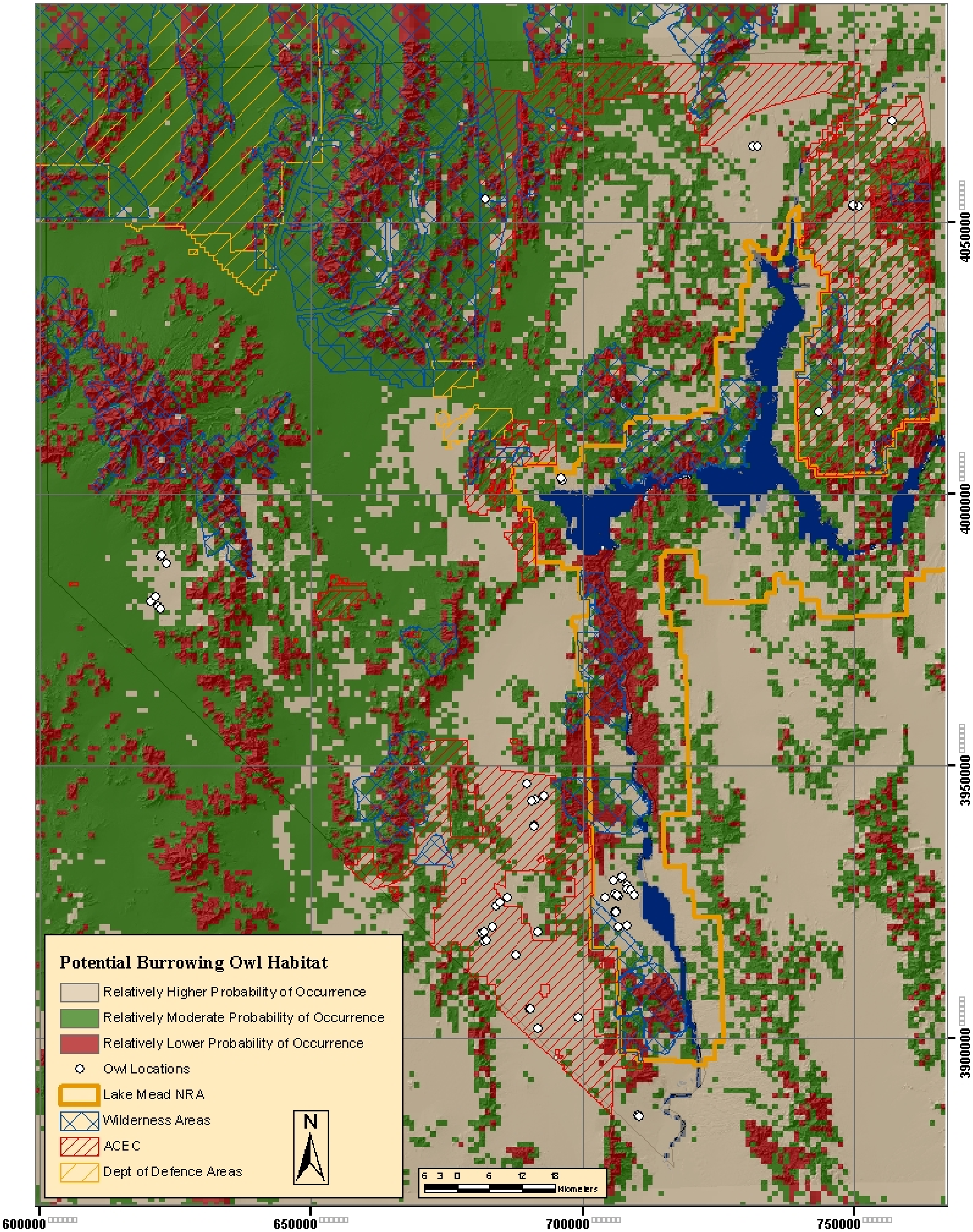
Logistic regression analysis of the best model showed that owl occurrence was positively associated with winter precipitation (mm), summer precipitation (mm), and summer precipitation CV and was negatively associated with elevation (m), slope (%), perennial vegetation cover (%), and soil mass with rocks greater than 254 mm (%).We evaluated the support of each variable in the best approximating model (Model 1) by examining the odds ratio and 95% confidence interval for the odds ratio (Table 17). For every unit increase in winter precipitation and summer precipitation, the odds of a grid cell containing an owl territory increased by 7% and 22% respectively. Odds of owl occurrence were increased 5.5 times with higher summer precipitation CV. Conversely, odds that a 1 km grid cell contained an owl territory decreased with every unit increase in elevation (1%), slope (52%), and perennial vegetation cover (10 %). The CI for percentage of rocks > 254 mm included 1 indicating that this variable was not significantly influential in the model. We used the best approximating model to construct a map of potential owl habitat:

Habitat = 4.638 + (0.064)Winter Precipitation + (0.198)Summer Precipitation + (1.704)Summer Precipitation CV – (0.732)Slope – (0.101)Vegetation Cover – (0.502)%Rock – (0.014)Elevation

RSF values were placed in three bins into three categories. The upper 33% of RSF values was considered potential higher quality Mojave Desert with the greatest probability of owl occurrence (Figure 2). Area within the middle third was considered potential moderate owl habitat and the remaining third was considered low quality habitat with the lowest probability of owl occurrence. In general, most valley basins and alluvial fans in Clark County contained areas consistent with suitable owl habitat. Those areas that contained little suitable owl habitat were comprised of areas with greater slope and elevation (e.g., mountainous terrain). Evaluation of the model performance using an independent data set of owl locations showed that 90% of the new territories were located within the upper 33% of predicted potential habitat, 6.5% were located within the middle 33%, and 5% were in the lower 33% of predicted potential habitat. These results show a strong correspondence between model predictions and our independent data set and support the validity of the model.

We assessed the amount of suitable owl habitat in Clark County. According to our model, Clark County contains 27.2% (5,476 km^2) habitat with relatively higher probability of owl occurrence, 53.4% (10,731 km^2) habitat with a relatively moderate probability of occurrence, and 19.4% (3,898 km^2) of habitat with a relatively low probability of occurrence. We assessed the amount of suitable habitat in LAME, ACEC, DOD lands, and Wilderness Areas within Clark County. LAME contained 611 km^2 of habitat with a relatively higher probability of owl occurrence and 641 km^2 of habitat with a relatively moderate probability of occurrence. ACECs contained the greatest amount of habitat with a relatively higher probability of occurrence (1,631 km^2) and 1,242 km^2 of habitat with a relatively moderate probability of occurrence. Wilderness Areas contained 390 km^2 of habitat with a relatively higher probability of owl occurrence and the greatest amount of habitat with a relatively moderate probability of occurrence, 2,692 km^2. DOD lands had 11 km^2 with a relatively higher probability of owl occurrence and 1,009 km^2 of habitat and with a relatively moderate probability of occurrence, respectively.

Figure 2. Map showing overlap of potential Western Burrowing Owl (*Athene cunicularia hypugaea*) habitat and designated conservation areas in Clark County, southern Nevada. Potential habitat has been divided into three bins based on relative RSF values. Relative higher probability of owl occurrence corresponds to the top 33% of RSF values, moderate probability of owl occurrence, corresponds to the middle 33%, and lowest probability of occurrence corresponds to the lower 33% of RSF values.


Potential Burrowing Owl Habitat
Relatively Higher Probability of Occurrence
Relatively Moderate Probability of Occurrence
Relatively Lower Probability of Occurrence
Owl Locations
Lake Mead NRA
Wilderness Areas
ACEC
Dept of Defence Areas
N
6 3 0 6 12 18
Kilometers
600000
650000
700000
750000
4050000
4000000
3950000
3900000

Discussion

Population surveys

Our survey results provide valuable insight into owl occurrence in Clark County. Based on our population surveys, we found BUOW in Clark County to be sparsely but widely distributed across Mojave Desert scrub but did not find owls in blackbrush or pinyon-juniper communities. Although BUOW have been documented to occur in blackbrush in the transition zone between Mojave and Great Basin Deserts, they were mostly observed nesting in man-made culverts and pipes (Hall et al. 2003). BUOW have also been observed nesting in pinyon-juniper habitat, but only in areas of widely spaced trees with open understory (Carothers et al. 1973). In Clark County, pinyon-juniper generally occurs on steeper slopes with thick understory vegetation (SWReGAP 2007). Blackbrush and pinyon-juniper habitats in southern Nevada may not provide the necessary attributes for nesting BUOW. Our study suggests that if BUOW in the Mojave Desert do occur in the blackbrush or pinyon-juniper communities, they do so at extremely low numbers or under environmental conditions that did not occur during the years of our surveys.

Although BUOW were widely distributed throughout Clark County, their relative abundance and density was not uniform. Gently sloping alluvial fans supported the greatest number of territories, results consistent with the established literature on BUOW habitat use, i.e., flat to rolling hills (Haug et al. 1993). BUOW density estimates throughout western North America vary from 26.3 to 0.02 pairs per km^2 (Table 18). Our estimates of owl densities in Clark County are at the low end of this range and are similar to those found at LAME in 2003-2004 and MCAGCC near Twentynine Palms, California during 2004-2005 (Crowe and Longshore 2007). BUOW also occur in low densities in sagebrush-steppe and grassland ecosystems. Highest densities are reported where owls and their burrows are concentrated into smaller habitat patches such as prairie dog towns within perennial grasslands (Table 18). Our density estimates did not vary between years or habitats. These results are consistent with observations by Crowe and Longshore (2007), who also found no difference in density during the two years of their study in desert scrub habitat at LAME during 2003-2004 and MCAGCC in 2004-2005.

Table 18. Density estimates from studies conducted in a variety of habitats in which the Western Burrowing Owl (*Athene cunicularia hypugaea*) breeds. Table adapted from Crowe and Longshore (2010).

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[e]	Mojave Desert	0.07-0.17 territories/km^2
Southern California[f]	Mojave Desert	0.08-0.09 territories/km^2
Eastern Wyoming[g]	Grassland and agricultural	0.074 nest sites/km^2
Southeastern Idaho[h]	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, Rosenberg and Haley 2004 (Imperial Valley), [d]Rosenberg and Haley 2004 (Carrizo Plain), [e]this study, [f]Crowe and Longshore 2010, [g]Conway and Simon 2003, [h]Gleason and Johnson 1985

Reproductive Success

Nest success reported from other studies of BUOW varies from 33% to 100% (Thomsen 1971, Martin 1973, Hjertaas et al. 1995, James et al. 1997). Our estimates of nest success were within these values and are similar to estimates of 55-65% reported for grassland habitat in the Chihuahuan Desert (Martin 1973, Rodriguez-Estrella 1997, Botelho and Arrowood1998). Productivity estimates are also available from various habitats (Table 19). Our productivity estimates are at the high end of this range, especially estimates of the number of young per successful nest during 2009. Results on productivity from our study and the Chihuahuan Desert suggest that overall, desert populations can be quite productive (Rodriguez-Estrella 1997).

Table 19. Nesting productivity (range or mean ± standard error when available) reported from Western Burrowing Owl (*Athene cunicularia hypugaea*) studies conducted in a variety of habitats. N/A indicates when a reproductive estimate was not available. Productivity results from this study, for 2008 and 2009 separately, are provided for comparison.

Location	Habitat	Young per successful nest	Young per nesting attempt or pair
Regina Plain, Canada[a]	grassland, agriculture	2.9-5.3 (multiple studies)	1.6-4.5 (multiple studies)
Eastern Colorado[b]	grassland	N/A	3.62 ± 0.19 (*n* = 167)
California[c]	agriculture	4.5 ± 0.6 (*n* = 21)	N/A
New Mexico[d]	Chihuahuan Desert	N/A	4.9 young per pair
Nevada Test Site[e]	Mojave Desert	N/A	3.0 ± 0.0 (*n* = 3)
Southern Nevada[f]	Mojave Desert	4.8-5.5 (multiple years)	2.8-3.8 (multiple years)
Southern Nevada 2008[g]	Mojave Desert	5.36 ± 0.43 (*n* = 11)	3.11 ± 0.67 (*n* = 19)
Southern Nevada 2009[g]	Mojave Desert	6.15 ± 0.42 (*n* = 20)	3.32 ± 0.56 (*n* = 37)

[a]James et al. 1997, [b]Lutz and Plumpton 1999, [c]Gorman et al. 2003, [d]Martin 1973 [e] Hall et al. 2003 [f]Crowe and Longshore, unpubl.data, [g]this study

Our results show that BUOW had the greatest reproductive potential in mixed desert scrub. BUOW produced similar numbers of young at successful nests in both desert scrub and mixed desert scrub habitats, but nest success and the number of young produced per nesting attempt was highest in mixed desert scrub habitat. Reasons for higher production rates are unknown but could be the result of greater available resources and less severe temperatures during nesting at these relatively higher elevations. Lantz and Conway (2007) found that ambient temperature was negatively correlated to nest survival (i.e., a 1˚C increase in ambient temperature decreased daily nest survival by 4%). Owls increase behavior associated with thermoregulation (i.e., wing drooping, gular flutter) and increase drinking as ambient temperature increases (Coulombe 1971). Owls may have higher reproductive potential at these relatively higher elevations because higher temperatures may have less impact on owl physiology.

Nest-Site Selection

The most influential nest-site characteristic for owls in both desert scrub and mixed desert scrub was the size of the soil mound at the entrance of the burrow. Soil mound size was the only variable selected for by BUOW nesting in desert scrub. BUOW in mixed desert scrub also selected for areas with less creosote bush cover within 50 m of the burrow. Predation plays an important role in nest success and may be an especially important factor for ground-nesting raptors (Ricklefs 1969, Newton 1979, Mikkola 1983, Martin 1995, MacWhirter and Bildstein 1996). Both adults and young may benefit from large mounds when they stand just inside the burrow entrance because they may be less conspicuous to predators. Poulin et al. (2005) also found that BUOW selected for taller soil mounds in grassland habitats. A larger mound may also be associated with nest success if it signals the occurrence of a longer tunnel. Lantz et al. (2006) found that owls selected for longer tunnels and Lantz and Conway (2007) found nest survival was positively associated with longer nest tunnels. A longer burrow tunnel may hinder larger predators (e.g., kit fox, coyote) from following young owls or adults down into a burrow, or from digging out the burrow to gain access to the owls trapped inside.

BUOW consistently select nest sites characterized by sparse vegetation (Schmutz 1997, Poulin et al. 2005, Teaschner 2005, Griebel and Savidge 2007). We found that creosote bush cover was significantly greater in mixed desert scrub which generally occurs at higher elevations (random burrows, two sample t-test: $P = 0.003$, $n = 55$). Selecting for nest burrows with less cover at mixed desert scrub sites may help owls to detect predators approaching nest sites. Several studies suggest that visibility may reduce predation of owls (MacCracken et al. 1985, Ronan 2002).

None of our measured nest-site characteristics was related to nest success in either desert scrub or mixed desert scrub. Although theory suggests birds should select nest sites that maximize their reproductive success, these choices can be influenced by the impact of predation, available resources, and competition (Hildén 1965, Fretwell and Lucas 1970, Cody 1985, Leonard and Picman 1987, Martin 1995). Studies on a variety of avian species have found that nest-site choice influences the probability of nest success in some species but not in others (Leonard and Picman 1987, Martin and Roper 1988, Filliater et al. 1994, Liebezeit and George 2002). Studies on nest characteristics for BUOW have also failed to find characteristics that influence reproduction (Ronan 2002, Lantz and Conway 2007). Nest success of BUOW in Clark County may be affected by factors we did not measure (e.g., predation rates, prey availability). Lack of experience in breeding behavior for first-year breeders, prey choices, and unfamiliarity with nesting territory may also influencing success.

Habitat Model

Our model had high predictive power for BUOW occurrence within Clark County; both abiotic and biotic factors influenced the distribution of owls. Probability of occurrence was highest in areas characterized by low slopes, low elevation, reduced perennial vegetation cover, greater amounts of winter and summer precipitation, and lower yearly variation in summer precipitation. Many of the factors influencing owl occurrence in the Mojave Desert are similar to those found in other habitats (Haug et al. 1993). Crowe and Longshore (2007) found low elevation and low slope were good predictors of owl presence in the southern Mojave Desert. Selection of low slope and elevation in Clark County is also consistent with the gentle rolling terrain that is characteristic of BUOW habitat in other regions (Coulombe 1971, Rich 1986, Haug et al.1993, Lantz et al. 2006). Due to the ground-dwelling nature of this species, reduced vegetation cover and height are significant habitat factors throughout its range (Green and Anthony 1989, Trulio 1994). To our knowledge, differences in seasonal precipitation and annual variability in precipitation have not been evaluated as determinants of owl habitat. Climatic variability can affect avian reproductive success, especially in arid habitats where breeding success is linked to precipitation (Gibbs and Grant 1987, Christman 2002). In the Mojave Desert, areas with greater levels of precipitation may be associated with greater availability of prey which may contribute to higher reproductive productivity. Several studies conducted in the Mojave Desert have found a correlation between abundance of small vertebrate species and spring precipitation (see Hall et al. 2003). In a supplemental food study, Wellicome et al. (1997) found that the number of young per nesting pair increased with an increase in food resources.

Conservation and Further Research

Based on our habitat model, we found that Clark County contains 27.2 % habitat with relatively higher probability of owl occurrence, 53.4% habitat with a relatively moderate probability of occurrence, and 19.4% of potential habitat with a relatively low probability of occurrence. We did not exclude metropolitan areas because BUOW do occur in urban areas, although habitat quality and survivorship may be different compared to natural areas. During our study, we detected owls on several transects within both the El Dorado-Piute Valley ACEC and Gold Butte ACEC. We also detected a large concentration of owls within LAME, mostly located on the alluvial fan slopes west of Lake Mojave. LAME contained relatively equal amounts of habitat with relatively higher and moderate probability of owl occurrence. The ACECs contained the greatest amount of habitat with a relatively higher probability of occurrence. Although Wilderness Areas contained the least amount of habitat with relatively higher probability of owl occurrence, they had the greatest amount of habitat with a relatively moderate probability of occurrence. DOD lands had the least amount of habitat with a relatively high probability of owl occurrence but did contain habitat and with a relatively moderate probability of occurrence. Although large areas of suitable owl habitat occur in these conservation areas, owl presence may not reflect population persistence. Establishing whether these lands can support a viable population of BUOW would require information on survivorship, productivity, immigration and emigration.

We suggest that further research for BUOW in Clark County include:

- Studies investigating survivorship, productivity, immigration and emigration of BUOW occurring on conservation lands.

- The impact of anthropogenic disturbance on BUOW is not known for urban and agricultural areas of Clark County, especially for owls occurring in the Las Vegas Valley. Determining whether these areas are acting as population sources or sinks would address this question.

- In the Mojave Desert, BUOW mostly nest in desert tortoise and kit fox burrows. Predictability of the potential habitat model may be refined with spatially explicit estimates of both desert tortoise and kit fox densities. Estimates of kit fox distribution and density require population surveys.

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