# BURROW SELECTION BY BURROWING OWLS IN AN URBAN ENVIRONMENT

by

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# DEDICATION

To Mom and Dad, for the gift of a childhood spent watching bugs, stalking birds, catching frogs, dropping snakes, tracking deer, and "counting" fish, and especially for never missing an opportunity to assure me that I could keep right on doing all those things when I grew up. With all my love.

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## ABSTRACT

I surveyed parts of Tucson, Arizona to determine numbers of burrowing owl (Speotyto cunicularia) burrows present, identify characteristics associated with burrow sites, and assess reproductive success. I measured habitat characteristics at 48 winter, 58 breeding, and 48 random burrows. Random burrows were closer to perches ($\underline{P} < 0.0001$) and farther from wash banks ($\underline{P} < 0.01$) than were active burrows, and had smaller entrance dimensions ($\underline{P} < 0.0001$). Winter burrows were farther from human activity than were breeding burrows ($\underline{P} < 0.01$). Active sites had less total vegetation, and less visual obscurity than did random sites. Owls may have selected open sites to facilitate detection of predators or prey. Urbanization sometimes created conditions which appeared to attract owls, but also destroyed burrows. An average of 2.31 young fledged from 116 active burrows during 1997 - 1998. While comparable to other studies of burrowing owls occupying urban environments, this was lower than rates typically reported for the species.

# INTRODUCTION

The burrowing owl (Speotyto cunicularia) is a small owl that nests and roosts in burrows (Haug et al. 1993). The species is locally distributed throughout treeless grasslands and deserts of North, Central, and South America; smaller populations exist in Florida, the Caribbean Islands, and on some islands off the west coast of Mexico (Haug et al. 1993). Although the burrowing owl is a year-round resident throughout much of its range, it is considered a neotropical migrant species. At least some portion of the North American population apparently migrates south from breeding areas in Canada and the northern United States, but migratory patterns are poorly documented and information on wintering habitat and behavior of the burrowing owl is scarce (Haug et al. 1993).

Populations of burrowing owls are declining throughout most of their North American range (Johnsgard 1988, Lincer 1997). The species is designated as "threatened" in Mexico (Sheffield 1998), "endangered" in Canada (Sheffield 1998), and receives special designation in California, Florida, Idaho, Iowa, Minnesota, Montana, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming (James and Espie 1997). Although protected by state and federal law, the burrowing owl has no official status in Arizona. Little is known about the current status of Arizona populations, but numbers of burrowing owls are thought to have declined from historic levels (de Vos 1998).

Existing information suggests that critical components of burrowing owl habitat are the presence of a burrow and a surrounding area of open grassland, low vegetation, or bare ground (Rich 1986, Green and Anthony 1989, Haug et al. 1993, Plumpton and Lutz 1993). In North America, western burrowing owls (S. c. hypugaea) rarely dig their own burrows (Thomsen 1971, Martin 1973); their distribution, therefore, is dependent on the presence of burrowing mammals, such as prairie dogs (Cynomys spp.) and ground squirrels (Spermophilus spp.) (Bent 1938). Major threats to burrowing owl populations include urbanization, conversion of rangeland to agricultural use, and control of burrowing mammals (Johnsgard 1988). Pesticide use also may affect burrowing owls, but the effects of pesticides on the species have not been well-studied (Haug et al. 1993).

Not all human-altered landscapes are unsuitable for burrowing owls; agricultural and grazing practices may improve the suitability of some landscapes by decreasing the amount of vegetation present (Haug et al. 1993). Burrowing owls are known to nest in open areas of airports, industrial parks, and golf courses in some parts of their range (Haug et al. 1993), and recent studies in Florida (Wesemann and Rowe 1987, Millsap and Bear 1997, ) indicate that burrowing owls can persist in urbanized environments characterized by regular housing and road construction when key habitat features are present.

Historically, burrowing owls were reported to be locally abundant in open grassland areas throughout Arizona (Brandt 1951, Phillips et al. 1964, Carothers et al. 1973). The desert vegetation communities native to the Colorado River, Santa Cruz River, and Salt River Valleys probably did not support large numbers of burrowing owls, but the vegetative and landscape modification which has occurred as a result of agricultural and grazing practices, and the subsequent lowering of the water table in these areas, has apparently favored colonization by the species (Rosenberg et al. 1991, de Vos 1998).

Burrowing owls currently nest in Tucson, Arizona. They are of particular management interest because they are declining over much of their range and because they are a charismatic and non-disruptive species that affords enjoyment to the public. It is unclear what effect urbanization is having on burrowing owls in Tucson. However, due to their unusual habitat requirements, burrowing owls may be more susceptible to negative effects of development than many other avian species.

My objectives were to: (1) survey a selected area of Tucson, Arizona to determine numbers of active burrows present during the breeding and non-breeding seasons; (2) estimate the total number of active burrows present in the Tucson basin during the breeding and non-breeding seasons; (3) identify important physiographic, vegetative, and anthropogenic characteristics associated with burrow sites; and (4) assess reproductive success of burrows in relation to the degree of human activity and disturbance. Information obtained from this study will help wildlife managers and city planners formulate urban development and habitat management plans that maintain the burrowing owl in Tucson.

# STUDY AREA

I selected a study area partly based on historic locations of burrowing owl nest sites in southwestern Tucson, Arizona (32°, 12' N, 110°, 57' W). Historically, Tucson contained Lower and Upper Sonoran Desert vegetation types and riparian corridors (Brown et al. 1979), but much of the vegetation has been altered or removed due to urban development and subsequent lowering of the water table. The study area consisted of a mosaic pattern of urban development, riparian corridors and flood plains, and open areas of native and exotic vegetation. The study area was approximately 11,000 ha in size and was bounded by 36th St. and Golf Links Rd. to the north, Camino Seco and Kolb Rd. to the east, Irvington Rd. and Valencia Rd. to the south, and Mission Rd. to the west. These boundaries included much of Davis-Monthan Air Force Base (DMAFB), but access to parts of the base was restricted (Figure 1).

# METHODS

## Surveys

Few studies (Thomsen 1971, Haug 1985) have examined territoriality or home range size of the burrowing owl, but Thomsen (1971) estimated a minimum home range size of 0.04 ha. I, therefore, drove all roads within the study area, and identified all undeveloped areas of $\geq$400 m$^2$. I did not consider areas with a length or width of $\leq$10 meters. During the second field season, I further excluded those parts of the study area which lacked burrows of the dimensions I determined to be the minimum suitable for use by burrowing owls. Random preliminary surveys, combined with the published literature (e.g., Haug et al. 1993) describing habitat preferences of burrowing owls, initially led me to exclude areas that were heavily vegetated with creosote bush (Larrea tridentata) or other shrubs. However, during the 1997 breeding season I located an active burrow in a shrub-covered lot, near the edge of a surveyed area. I subsequently modified my survey protocol to include areas with similar vegetative cover which were located adjacent to surveyed, open areas.

I used roadside and foot surveys to search all areas such as those described above for burrowing owls. Perching and active burrowing owls were reliably located from distances of up to 50 meters by using binoculars. Therefore, during roadside surveys, one person would slowly drive roads while a passenger scanned for owls within 50 meters of the road. This technique was used successfully to survey an urban population of burrowing owls in Florida (Wesemann and Rowe 1987). Areas located further than 50 meters from a road, or those where visibility was obscured, were surveyed on foot in such a pattern that the entire area was systematically searched. Burrowing owls are conspicuous during the morning and evening hours (Grant 1965, Thomsen 1971, Martin 1973), so I conducted surveys during the first four hours after sunrise and the last four hours before sunset. Surveys during the breeding season were conducted from April - July 1997 and April - June 1998. Surveys in the non-breeding season were conducted from November - February in 1997 and 1998.

Based on my observations of the gross landscape characteristics preferred by burrowing owls within the study area, I conducted additional surveys of selected parts of Tucson outside the study area which appeared likely to support burrowing owls. Survey protocol was consistent with that described above. Areas surveyed included the banks and adjacent undeveloped areas of the Santa Cruz River from Silverlake Road north to the Rillito River confluence, the banks and adjacent undeveloped areas of the Rillito River from the confluence east to 1st Avenue, and a large undeveloped area located southeast of the Rillito River where Swan Road crosses the channel. I also surveyed all suitable areas at the Tucson International Airport.

Habitat Characteristics

At each breeding and winter burrow active during the 1997 - 98 field season, I measured the height and width of the main entrance tunnel, and recorded the slope of the entrance tunnel and slope of the ground beside the burrow. The orientation of the burrow entrance was categorized as falling into one of four 90° quadrants (Figure 2).

I used a laser range finder to measure the distance from the burrow entrance to each of eight landscape features: paved road, unpaved road, building, light source, potential perch, closest human activity area, primary human activity area, and the nearest wash within 200 meters. I defined a potential perch as any natural or man-made object which could be used by a perching burrowing owl to increase its field of vision (e.g., rock, shrub, fence, earthen mound, etc). Human activity areas were subjectively categorized as "primary" and "closest", rather than by measuring the rate of activity that occurred. The nearest location at which I observed, or predicted, regular or irregular pedestrian and/or vehicular traffic (e.g., unpaved access roads, un-maintained trails, etc) was designated as the "closest" activity area. The nearest location at which I observed, or predicted, regular and frequent levels of pedestrian and/or vehicular traffic (e.g., paved roads, residential yards, bike trails, etc) was designated as the "primary" activity area. Each building, light source, potential perch, primary human activity area, and closest human activity area measured, as well as the position of the burrow relative to the nearest wash, were further described by assigning them to a descriptive category (Figures 3 - 8).

At each breeding and non-breeding burrow active during the 1997-98 field season, I laid out three parallel 50-meter transects that followed a randomly generated orientation. One transect bisected the burrow, and the other two transects were positioned at 15 meters to either side of, and parallel to, the first. To avoid double-sampling, I did not obtain transect measurements from burrows that fell within 50 meters of a previously measured burrow.

I measured percent cover of ground vegetation (e.g., grasses, forbs, shrubs) and canopy vegetation (i.e., trees) along each of the transects with the line intercept method (Canfield 1941). In addition to vegetative cover, I measured percent of bare ground, rock (including gravel), and man-made impervious surface (e.g., pavement, building). I recorded the height of all shrubs and all trees encountered along each transect.

I measured vertical vegetation structure at five meter intervals along each transect. Vertical structure was measured by counting the number of vegetation contacts within each 10 cm interval of a 200 cm tall pole. In addition, I measured horizontal visual obscurity using a cover pole. Visual obscurity was measured at 5 meters, 15 meters, and 25 meters from the burrow, both along the main vegetation transect, and perpendicular to it. I looked through a viewing piece positioned at 25 cm from the ground, to approximate the height of a burrowing owl. I then recorded the number of 10 cm segments which were $\geq$ 25% obscured by vegetation (Griffith and Youtie 1988). I took visual obscurity measurements from the point on the ground near the burrow entrance most commonly used by burrowing owls.

By analyzing a sub-sample ($\underline{n}$ = 18) of active burrows, I determined that burrowing owls were selecting burrows with minimum entrance tunnel dimensions of 7 cm x 9 cm. Therefore, I categorized intact burrows as "small" (i.e., having entrance tunnel dimensions < 7 cm x 9 cm; too small for use by burrowing owls) or "large" (having entrance tunnel dimensions $\geq$ 7 cm x 9 cm; suitable for use by burrowing owls). I recorded the number of "small" and "large" burrows present within a 2 meter wide strip on either side of each transect. I also thoroughly searched a 25m radius area around the burrow and recorded the number of all "large" burrows present, which could function as potential alternate burrows for escape cover and for the first stages of fledgling dispersal.

Western burrowing owls do not normally dig their own burrow, but will modify existing burrows (Coulombe 1971, Johnsgard 1988). Burrow dimensions vary, but at least one sharp turn in the tunnel appears to be necessary, probably to maintain darkness in the nest chamber (Collins and Landry 1977). Due to the difficulty of establishing the exact parameters of acceptable burrow structure, I assumed that any intact burrow with an entrance $\geq$ 7 cm x 9 cm and a tunnel that was intact for $\geq$ 65 cm, and which also contained a readily apparent turn in the tunnel structure, was potentially suitable for use by burrowing owls. I generated 48 randomly located points within the surveyed area. I then systematically searched a 200 meter radius area around each point for the nearest potentially suitable burrow, which was not currently in use by burrowing owls. I recorded the measurements as described above at these random, potential burrow sites (hereafter called "random burrows").

Statistics: At each burrow site, percent cover was calculated as the total percentage of each cover type which occurred over three transects (150 m). Vertical vegetation structure and horizontal visual obscurity were likewise calculated, at all heights measured, by combining the data from each transect. Data on habitat characteristics could not be normalized with log transformation (Shapiro and Wilk

1965). Therefore, I tested for differences in sample means among breeding burrows, winter burrows, and random burrows with Kruskal-Wallis approximations (SAS Institute Inc. 1996). I compared pairs of means using the Tukey-Kramer Honestly Significant Difference test (SAS Institute Inc. 1996). I defined data points as outliers when they fell further than 1.5 interquartile ranges from the quartiles, as shown in outlier box plots (SAS Institute Inc. 1996). I believe the outliers in the data sets to be legitimate measurements, but when outliers were present I reported the results with and without the outliers.

I used contingency tables and the Pearson chi-square to test the descriptive categories of burrow orientation (Figure 2) and six landscape features (Figures 3 - 8) for homogeneity of distribution among breeding, winter, and random burrows (SAS Institute Inc. 1996).

Reproductive Success

I monitored reproductive success at active breeding burrows from April to July in 1997 and 1998. I attempted to visit nest burrows at least twice during the incubation, nestling, and fledgling stages, but was unable to do so for all burrows due to limited access to some areas of Davis-Monthan Air Force Base. During each visit, I observed nest burrows for a minimum of 20 minutes. I visited nests during the first four hours after sunrise, or the last four hours before sunset to maximize the chance of observing owls. I considered nests to be active if a pair of adult owls, a single adult with young, or nesting behaviors such as burrow modification or collection of lining materials were observed.

Adult owls typically fly away from the burrow when approached, whereas nestling owls retreat inside the burrow. Juvenile owls are capable of short flights by four weeks of age, or approximately two weeks from the time they first emerge from the burrow entrance (Haug et al. 1993). Therefore, I defined juvenile burrowing owls as fledglings when they were known to be a minimum of four weeks of age. Nests were defined as successful when they produced at least one fledgling.

Statistics: I used the Wilcoxon rank-sum test (SAS Institute, Inc. 1996) to test for differences between years in the mean number of nestlings per active nest, the mean number of fledglings per active nest, the mean number of nestlings per successful nest, and the mean number of fledglings per successful nest. I reported the chi-square approximation of the Wilcoxon statistic. I used regression analysis (SAS Institute, Inc. 1996) to test for correlations between the number of young fledged from burrows active during 1997, and the distance to the following variables: paved road, unpaved road, building, light source, potential perch, closest human activity area, and primary human activity area, as well as the number of potential alternate burrows present within 25 m of the breeding burrow. I also tested for correlations between the number of young fledged from burrows active during 1997, and both horizontal visual obscurity and vertical vegetation structure.

# RESULTS

## Surveys

I located 67 active winter burrows (26 of which were located on DMAFB) and 72 active breeding burrows (28 of which were located on DMAFB) during the 1997 surveys. During the 1998 surveys, 54 active winter burrows (17 of which were located on DMAFB) and 59 active breeding burrows (29 of which were located on DMAFB) were located.

I located only five active burrows outside the primary study area. Three of the burrows were located in areas adjacent to the runways at Tucson International Airport. Two burrows were located along the Santa Cruz River in the open areas adjacent to its banks: one was located in a lot near the base of A Mountain and the other was in a natural bank southeast of Silverbell Golf Course and Silverbell Road. Based on the distribution of potentially suitable burrowing owl habitat throughout Tucson, I estimate that an additional 10 - 20 burrows may be located in areas I did not survey.

My access to the runway and aircraft storage areas of DMAFB was limited. In addition to the burrows located during this study, there appeared to be 5-10 active burrows in the open grassland bordering the runway at all times of the year. Cursory surveys indicated that few burrowing owls used the aircraft storage areas, possibly because the aircraft functioned as potential perches for avian predators. Davis-Monthan Air Force Base probably supports 25 - 40 active burrows.

Based on our surveys of the study area, as well as of the additional target areas, I estimate that there are between 75 and 110 active burrows in the urbanized area of the Tucson basin.

Habitat Analysis

I obtained measurements at 48 winter burrow sites, 58 breeding burrow sites, and 48 random burrow sites. Burrow entrance dimensions of width ($X^2$ = 40.19, df = 2, P < 0.0001) and height ($X^2$ = 38.85, df = 2, P < 0.0001) were smaller at random burrows than at either breeding or winter burrows (Table 1). Burrows did not significantly differ in the slope of the burrow entrance tunnel ($X^2$ = 1.08, df = 2, P = 0.58), or the slope of the ground around the burrow entrance ($X^2$ = 4.02, df = 2, P = 0.13) (Table 1). When outliers were dropped, the slope of the ground around the entrance tunnel was greater at active burrows than at random burrows ($X^2$ = 14.04, df = 2, P < 0.01) (Table 1).

I found the mean distance to the nearest potential perch to be greater at both breeding and winter burrows than at random burrows ($X^2$ = 22.51, df = 2, P < 0.0001). The mean distance to the nearest wash bank was greater at random burrows than at either breeding or winter burrows ($X^2$ = 13.91, df = 2, P < 0.01), and when outliers were removed, breeding burrows were also closer to wash banks than were winter burrows ($X^2$ = 19.27, df = 2, P < 0.0001) (Table 2). The mean distance to the closest human activity area was less at breeding burrows than at winter burrows ($X^2$ = 10.54, df = 2, P < 0.01). The mean distance to the primary human activity area was also significantly different among burrow categories ($X^2$ = 9.81, df = 2, P < 0.01). Although a Tukey-Kramer HSD test failed to identify which categories differed, the means seemed to indicate that both breeding burrows and randomly located potential burrows were closer to primary human activity areas than were winter burrows (Table 2).

The categorical distribution of burrow entrance orientation ($\underline{X}^2 = 0.39$, $\underline{df} = 6$, $\underline{P} = 1.00$) (Figure 2), as well as the distributions of the nearest building ($\underline{X}^2 = 4.10$, $\underline{df} = 6$, $\underline{P} = 0.66$) (Figure 3), nearest light source ($\underline{X}^2 = 1.52$, $\underline{df} = 2$, $\underline{P} = 0.47$) (Figure 4), primary activity area ($\underline{X}^2 = 14.16$, $\underline{df} = 8$, $\underline{P} = 0.08$) (Figure 6), and closest activity area ($\underline{X}^2 = 11.50$, $\underline{df} = 6$, $\underline{P} = 0.07$) (Figure 7), did not differ among breeding, winter, and random burrows. However, the primary activity area at breeding burrows was characterized by irregular pedestrian and vehicular activity more frequently than at winter or random burrows (Figure 6). Breeding burrows were also somewhat less associated with primary activity areas characterized by pedestrian and vehicular activity of moderate intensity than were winter or random burrows. Winter burrows were less associated with primary activity areas characterized by regular, sustained pedestrian and vehicular activity of moderate to high intensity than were breeding or random burrows (Figure 6). The closest activity area at breeding burrows was more frequently characterized by regular, low intensity pedestrian or vehicular activity than at winter or random burrows (Figure 7).

Categorical distribution of perches ($\underline{X}^2 = 27.25$, $\underline{df} = 6$, $\underline{P} < 0.01$) did differ significantly among burrows (Figure 5). Perches formed by vegetation were more common at random burrows, whereas breeding burrows and winter burrows were more often associated with perches formed by wash banks, dirt mounds, or man-made structures. Significant differences were also identified among burrows in terms of their location relative to the nearest wash bank ($\underline{X}^2 = 22.44$, $\underline{df} = 4$, $\underline{P} < 0.01$). Breeding and winter burrows were more frequently located on wash banks than were random burrows, while random burrows were more often located more than 200 meters from the nearest wash (Figure 8).

Bare ground was the predominant cover type present at active burrow sites (95.9 %; $\underline{n} = 93$), followed by impervious surface (3.0 %; $\underline{n} = 3$), and rock (1.0 %; $\underline{n} = 1$). The predominant vegetative cover type at active burrow sites was grass (42.7 %; $\underline{n} = 41$), followed by forbs (40.2 %; $\underline{n} = 39$), and shrubs (11.5 %; $\underline{n} = 11$).

Owls used breeding and winter burrow sites with less shrub cover ($\underline{X}^2 = 28.96$, $\underline{df} = 2$, $\underline{P} < 0.0001$), and less tree cover ($\underline{X}^2 = 12.83$, $\underline{df} = 2$, $\underline{P} < 0.01$) than was present at random burrow sites (Table 3). There was less rock cover ($\underline{X}^2 = 13.03$, $\underline{df} = 2$, $\underline{P} < 0.01$) present at winter burrow sites than at random sites (Table 3). The percentage of rock cover at breeding burrow sites also appeared to be less than at random potential sites, but the Tukey-Kramer HSD did not identify these categories as significantly different (Table 3). Breeding and winter burrow sites both had a greater mean percentage of bare ground than did random burrow sites ($\underline{X}^2 = 16.43$, $\underline{df} = 2$, $\underline{P} < 0.01$) (Table 3).

Mean shrub height was greater at random burrow sites than at breeding burrow sites, ($\underline{X}^2 = 5.86$, $\underline{df} = 2$, $\underline{P} = 0.05$), but the level of statistical significance was marginal (Table 4).

I recorded consistently greater levels of horizontal visual obscurity at random burrow sites than at breeding burrow sites at all heights measured (Table 5). At heights of 50 - 200 cm, the visual obscurity at random sites was also greater than that at winter sites (Table 5). Visual obscurity was also greater from 0 - 50 cm above the ground at winter burrow sites than at breeding sites, when the measurement was taken at a distance of 15 meters from the burrow (Table 5). Vertical vegetation structure followed a similar pattern. Vertical structure did not differ among burrow site categories at heights of 0 to 20 cm above the ground, but more vertical structure was present at random burrow sites than at breeding or winter sites at heights of 20 to 180 cm above the ground (Table 6).

I found no significant differences among breeding, winter, and random burrow sites in the number of "small", "large", or "potential alternate" burrows present (Table 7). However, when outliers were removed, the number of "potential alternate" burrows present was significantly greater at breeding burrow sites that at random burrow sites ($\underline{X}^2 = 8.26$, $\underline{df} = 2$, $\underline{P} = 0.02$) (Table 7).

Reproduction

I monitored reproductive success at 67 active breeding burrows from April - July 1997, and at 49 active breeding burrows from April - July 1998 (Table 8). Twenty seven of the burrows in 1997, and 18 of the burrows in 1998, were located on Davis-Monthan Air Force Base. Most of the remaining burrows were located along the western branch of the Santa Cruz River between Ajo Road and Valencia Road.

Of the nests monitored during 1997, 85.1 % hatched young, and 65.6 % produced at least one fledgling (Table 8). During 1998, 57.1 % of the monitored nests hatched young, and 51.0 % produced at least one fledgling (Table 8). In 1997, an average of 2.23

fledglings were produced per nesting attempt, and in 1998, an average of 2.47 fledglings were produced per nesting attempt (Table 9).

I found no significant difference between years in the mean number of nestlings per total number of active burrows ($\underline{X}^2 = 0.14$, $\underline{df} = 1$, $\underline{P} = 0.71$), the mean number of fledglings per total number of active burrows ($\underline{X}^2 = 0.72$, $\underline{df} = 1$, $\underline{P} = 0.40$), the mean number of nestlings per total number of successful burrows ($\underline{X}^2 = 0.03$, $\underline{df} = 2$, $\underline{P} = 0.86$), or the mean number of fledglings per total number of successful burrows ($\underline{X}^2 = 0.27$, $\underline{df} = 2$, $\underline{P} = 0.60$).

Regression analyses failed to detect significant relationships between the number of young fledged from breeding burrows active during 1997, and distance to any of the eight landscape features measured, the number of potential alternate burrows present, the level of horizontal visual obscurity, or the amount of vertical vegetation at the burrow site. However, the positive relationship between the number of young fledged from breeding burrows active during 1997, and increasing amounts of vertical vegetation at heights of 40 - 60 cm ($\underline{R}^2 = 0.0817$, $\underline{F} = 3.470$, $\underline{P} = 0.07$) and 80 -100 cm above the ground ($\underline{R}^2 = 0.0801$, $\underline{F} = 3.397$, $\underline{P} = 0.07$) did approach statistical significance.

# DISCUSSION

I am confident that the survey methods used in this study resulted in the location of most of the active burrows in the study area during the breeding season. Fluctuations in local numbers may have partly resulted from regular seasonal movements by migratory individuals and dispersing young. It is possible that undetected movements by burrowing owls may have occasionally resulted in double-counting of some individuals, and subsequent overestimation of the number of active burrows present. Overall, however, I believe it likely that the numbers reported in this study are conservative, particularly in the case of burrows active during the non-breeding season. Dispersing young or migrating owls may be more transient in their use of burrow sites and roost structures. Burrowing owls may also spend less time perched near their burrows during the non-breeding season (Haug et al. 1993), potentially making them more difficult to count

My original survey protocol did not include undeveloped areas with moderate to dense shrub cover because the literature indicated that this was an unsuitable landscape type for burrowing owls. I did, however, locate one burrow in an area of moderate to heavy shrub cover which was within 50 meters of a site deemed suitable for survey under my original protocol. I, therefore, modified my survey protocol to include shrub-covered sites adjacent to surveyed areas, and subsequently located two more such burrows. I believe, however, that burrows in these situations are uncommon.

Some of the differences I found between active burrows and random burrows may be the result of the original placement of the burrows by burrowing mammals rather than evidence of selection by owls. For example, rock may appear to be a cover type that is avoided by owls only because burrowing mammals may have more difficulty excavating burrows in rocky soil. I did not identify which species of mammal(s) excavated the burrows used by burrowing owls, but rock squirrels (Spermophilus lateralus), badgers (Taxidea taxus), and canids were suspected. Characteristics of internal burrow structure probably also influenced burrow selection by burrowing owls, and might, therefore, have had an undetected influence on habitat analyses. However, burrowing owls appeared to select sites that had less vertical vegetation structure, less visual obscurity, less shrub and tree cover, and more bare ground, than was randomly available. Burrowing owls may have selected open areas because they provided greater visibility. It is likely that the association of random burrows with perches formed by vegetation, and the shorter distance from random burrows to potential perches than was measured at active burrows, was a secondary effect resulting from the owls' selection of open burrow sites, rather than an avoidance of such perch characteristics. Selection of open burrow sites by burrowing owls would also explain the association of active burrows with perches formed by wash banks and dirt mounds, and the greater distance from active burrows to potential perches.

Active burrows were more likely to be located on or closer to wash banks than were random burrows. Many wash banks in the study area were relatively devoid of vegetation due to periodic natural and man-made disturbances. Again, burrow placement may reflect habitat selection by the original excavating species, or selection by burrowing owls for burrow sites with good visibility. Alternatively, it may be indicative of a richer prey base associated with riparian areas.

While there was no apparent selection by burrowing owls for sites containing larger burrows, or greater numbers of potential alternate burrows, my observations during surveys indicated that certain parts of the study area were richer in burrows of all sizes than were others. In general, it appeared that owls were unlikely to be found in areas which supported few, or very small, burrows, even when gross landscape characteristics appeared in other ways suitable. This pattern proved so consistent during the 1997 survey that I felt confident in restricting the area surveyed during 1998. I believe it is reasonable to assume that the distribution of burrowing owls in Tucson is at least partly limited by burrow availability.

Burrowing owls use alternate burrows for escape and as additional cover for fledglings (Haug et. al. 1993). I analyzed the number of potential alternate burrows within 25 m of the main burrow, and significantly more potential alternate burrows were present at breeding burrow sites than at random sites when outliers were removed. In many cases, however, owls were observed using alternate burrows more than 25 m from the main burrow. In 1997, three owl families appeared to relocate from the natal burrow to an alternate burrow more than 100 m away. I am unsure what triggered these moves, but I suspect that availability of alternate burrows may be a more important selection factor than the analysis indicates.

There were two primary locations within the study area which met the habitat requirements of the burrowing owls, and supported the majority of individuals detected. One of these, a riparian area along the west branch of the Santa Cruz River, typically remains dry for most of the year and is heavily impacted by human activity. During this study, Pima County Flood Control periodically used bulldozers to modify the river channel for the purpose of removing vegetation, controlling erosion, and maintaining a smooth channel surface. The river banks also were frequently used by pedestrians as a recreational walkway, and along some portions residential construction encroached within 20 meters of the banks. Burrowing owls in this area tolerated human presence near their burrows and were not obviously affected by human activity.

The other concentration of burrowing owls was on Davis-Monthan Air Force Base. The majority of the base is maintained as an open, mowed grassland with regular, low-intensity, vehicular and pedestrian traffic.

Human activities may play an important role in the distribution of active burrow sites in urban Tucson. In some locations, owls have colonized areas that have been and continue to be modified by humans. On Davis-Monthan Air Force Base, this may have been the result of a regular mowing schedule, which prevented the vegetation from reaching a height of more than approximately 30 cm. The mowing of grass and other herbaceous vegetation reduced visual obscurity around burrows, making detection of both potential predators and potential prey easier for the owls. It should be noted, however, that there were many unoccupied, yet apparently suitable burrows available on the base. Such burrows may have had characteristics which were not readily apparent, but which made them unsuitable for use by owls. Factors such as diversity and abundance of prey, and the competition for use of burrows by burrowing mammals, may also have influenced the density of burrowing owls on the base.

Human modification of the landscape had a negative impact on burrowing owl sites in some locations. During this study, the Santa Cruz River drainage was rapidly being developed by both residential and commercial interests. Although building codes prevented development of the actual river banks, some areas which supported active burrows were open to development. In some cases, preliminary stages of development created conditions (e.g., removal of vegetation) that appeared to attract owls. I observed two cases where this occurred. The burrows were subsequently destroyed when building construction commenced. During this study, at least five other burrows that were originally located in undisturbed areas were later destroyed during development.

Similarly, the periodic modification of the west branch of the Santa Cruz River prevented persistent or sustained vegetation growth, and may have increased the suitability of the area for burrowing owls. However, this modification often destroyed burrows along the banks. Owls appeared to readily shift to nearby undisturbed burrows when their main burrow was destroyed or damaged, which may indicate the possible importance of alternate burrows in the selection of a suitable burrow site. While I found no evidence that owls were killed or injured as a result of stream channel modification, at least four burrows were destroyed early in the nesting cycle. It is probable that such disturbance resulted in the loss of some clutches and/or nestlings. The impact of this and other mortality factors needs to be investigated further.

Burrowing owls appeared to select breeding season burrows which were closer to human activity than were winter burrows. The biological significance of this relationship, if any, is not clear. An investigation of burrowing owl activities and time-budgets would help to clarify the issue.

The reproductive rates reported in this study are comparable to those of two other studies of burrowing owl populations occupying urbanized environments. Mealey (1997) reported nesting success rates for burrowing owls occupying a landscape of residential development, airfields, and pastureland in Dade and Broward Counties, Florida, ranging from 41 % - 54 % over three years. During 1997, 65.6 % of the nesting attempts in the Tucson study area were successful, and 51.0 % were successful during 1998 (Table 8). Millsap (1988) and Mealey (1997) reported 1.59 - 2.75 young fledged per active nest for burrowing owls in Dade and Broward Counties, Florida, and Trulio (1997) reported 2.4 - 4.7 young fledged per active nest during a three year study of burrowing owls in two urbanized areas of Santa Clara County, California. Burrowing owls in the Tucson study area fledged 2.23 young per active nest during 1997, and 2.47 young per nest during 1998 (Table 8).

The tenuous evidence for a positive correlation between the number of young successfully fledged per active burrow and the amount of vertical vegetation present seems counterintuitive, especially in light of the fact that the burrowing owls in the study area appeared to be selecting for burrows in areas with less shrub and tree cover than was randomly available. I expected nesting owls to be more successful at fledging young from burrows where a high level of visibility allowed them to observe approaching predators. It is possible, however, that vertical vegetation structure at heights of 40 - 100 cm increased shade around the burrow entrance and thus provided a more suitable microclimate, as well as concealment and escape cover, for nestling and fledgling burrowing owls when they first emerged from the breeding burrow.

# MANAGEMENT RECOMMENDATIONS

## Surveys

Information on the current number and distribution of burrowing owls in Arizona is limited. Historical records indicate that urbanization of the Santa Cruz River Valley may be creating habitat for burrowing owls where little was historically available. Despite the fact that Tucson probably did not originally support substantial numbers of burrowing owls, I believe that active monitoring and management of this and similar populations would be a prudent considering the confirmed decline in burrowing owl numbers elsewhere in North America, the continuing urbanization of the Santa Cruz River Valley, and the uncertain status of the species in Arizona. While I acknowledge the potential financial and logistical barriers involved, I also recommend that a statewide survey for burrowing owls be undertaken to better determine the status of this species in the state.

Most of the burrows located during this study were concentrated in two areas; the grassland areas on Davis-Monthan Air Force Base, and the sparsely vegetated areas between the west channel and the main channel of the Santa Cruz River, from their convergence point south to Valencia Road. I recommend that these areas be surveyed annually during the breeding season. Annual surveys would allow managers to identify trends in breeding burrow occupancy, and to remain apprized of disruption to burrow sites due to the urbanization and development which is ongoing along the Santa Cruz River corridor. Burrowing owls are relatively easy to identify, and such surveys could provide opportunities for public involvement in burrowing owl management and conservation.

Due to the amount of time/man-power required, intensive surveys would be most efficient in areas where colonies of owls are known or suspected to occur, and where owls are relatively visible. Although I located several burrows in more urbanized and vegetated areas, I doubt that intensive foot surveys or random survey transects would be efficient in locating such burrows, particularly in cases where they are widely distributed. Therefore, I recommend that future survey and monitoring efforts be focused around sites where density of active burrows is known to be high. This will allow managers to monitor the majority of the burrows in southern Tucson; additional burrows might then be located during other urban wildlife work, or by responding to tips from local wildlife rehabilitators and/or the public.

My surveys of target sites outside the main study area yielded few active burrows. The vegetation structure of these areas appeared similar to areas used by owls within the study area, but a lack of suitable burrows may prevent the owls from colonizing them. However, there may be burrows present along and between the west and main channels of the Santa Cruz River south of Valencia Road. Other areas in Tucson which could potentially support burrowing owls include any large, sparsely vegetated lots with low to moderate human disturbance. Particular attention should be given to locations where several months has elapsed since the initial clearing for development, but where construction has not yet taken place.

Habitat

It appears that burrowing owls in Tucson do not use the native desert landscape, but instead almost exclusively use areas that have been altered by some form of human activity. The removal of native vegetation which takes place prior to residential and commercial development apparently creates one of the crucial habitat features required by this species; specifically, a high level of visibility around the burrow. When burrows of suitable size and structure are present in these areas, burrowing owls may colonize them in relatively dense numbers. Human recreation and commercial use of these areas does not appear to affect the owls' selection of burrows or their reproductive success, unless the burrow itself is destroyed or the resident owls are killed. On Davis-Monthan Air Force Base, the primary human manipulation of the landscape is mowing of the vegetation. Mowing probably improves habitat for the owls, so little additional management is required to maintain burrowing owls there.

Habitat management recommendations elsewhere in the study area are more difficult to identify. The greatest numbers of burrowing owls found outside of DMAFB were located along the west branch of the Santa Cruz River from Valencia Road north to the convergence with the main branch. Regular bank and channel maintenance on this section of the river by Pima County Flood Control clears the vegetation from potential and occupied burrow sites, and thus improves the habitat for the owls. However, this activity also results in outright destruction of some burrow sites, as soil is dumped into erosion cuts and large burrow entrances and smaller burrows along the banks collapse from the disturbance caused by the earth-moving equipment. Burrowing owls in our study appeared to be very site tenacious. They frequently moved to nearby burrows if their burrow was destroyed. The timing of the channel maintenance may be crucial to improving the reproductive success of the owls in these areas. I recommend that Pima County Flood Control be encouraged to restrict channel modification to the months of September through March to prevent disruption of the breeding cycle of the burrowing owls, and the possible injury of eggs or nestlings.

I also recommend that soil cement not be used to stabilize riparian corridors in areas where colonies of burrowing owls are known to occur. My surveys indicated that riparian channels that have been modified in this way do not provide suitable habitat for the owls.

Future Research

To achieve a better understanding of the dynamics of burrowing owl populations in Tucson, information is needed on several topics. First, I recommend that long-term monitoring of at least some component of the Tucson population (e.g., the Santa Cruz River) be attempted to establish trends in burrow occupancy and population fluctuations. Even limited banding of nestlings would help managers develop an idea of recruitment and dispersal patterns, and to identify potential source and sink areas within the Tucson basin. This information would be useful in determining which locations or landscape types within the city might benefit from active management for burrowing owls.

Although this study did not examine foraging habits, my observations indicate that the owls may be using both man-made structures (e.g., streetlights, porch lights, athletic fields) and natural areas (e.g., washes) as foraging sites. More information is needed on the burrowing owls' use of urban habitat for foraging and on the type and abundance of their prey species.

My observations during this study indicate that the availability of suitable burrow sites may be limiting owl numbers in some locations, particularly those sites which already support colonies. A number of models exist for the construction of artificial burrows, but there is little information available on the effectiveness of artificial burrows as a management tool (Haug et al. 1993). In one study, burrowing owls consistently adopted artificial burrows that were put in place within seven days of the destruction or removal of the birds' natural breeding burrow (Olenick 1990). In Tucson, artificial burrows have been used with some success to foster owls from sites where they were displaced. It is possible that there are locations in Tucson where artificial burrows might facilitate increased density of owls in areas of projected habitat stability, such as Davis-Monthan Air Force Base. They might also be used to augment naturally occurring burrows in areas that are frequently disturbed, such as the west branch of the Santa Cruz River. At burrow sites that are slated for destruction or disturbance, artificial burrows might be built nearby to provide potential alternate sites for the resident owls. The construction of artificial burrows also allows the public an opportunity to become more aware of, and involved in, the maintenance of this unique urban species.

Finally, artificial burrows should be considered as an option to mitigate disturbance if a suitable area is found near the original burrow site. I also encourage experimentation with their use in the open grassland areas of Tucson International Airport. The vegetative and landscape structure of this area suggest that it could support a fairly sizeable colony of owls, but it appears to have very few suitable burrows. Similarly, the number of potential burrows appears to decrease near the southern end of the Davis-Monthan Air Force Base runways. It is possible that the area around the southern landing lights would support several pairs of owls if artificial burrows were constructed there. In both of these cases, however, consideration should be given to burrow placement with regards to aircraft safety and flight patterns.

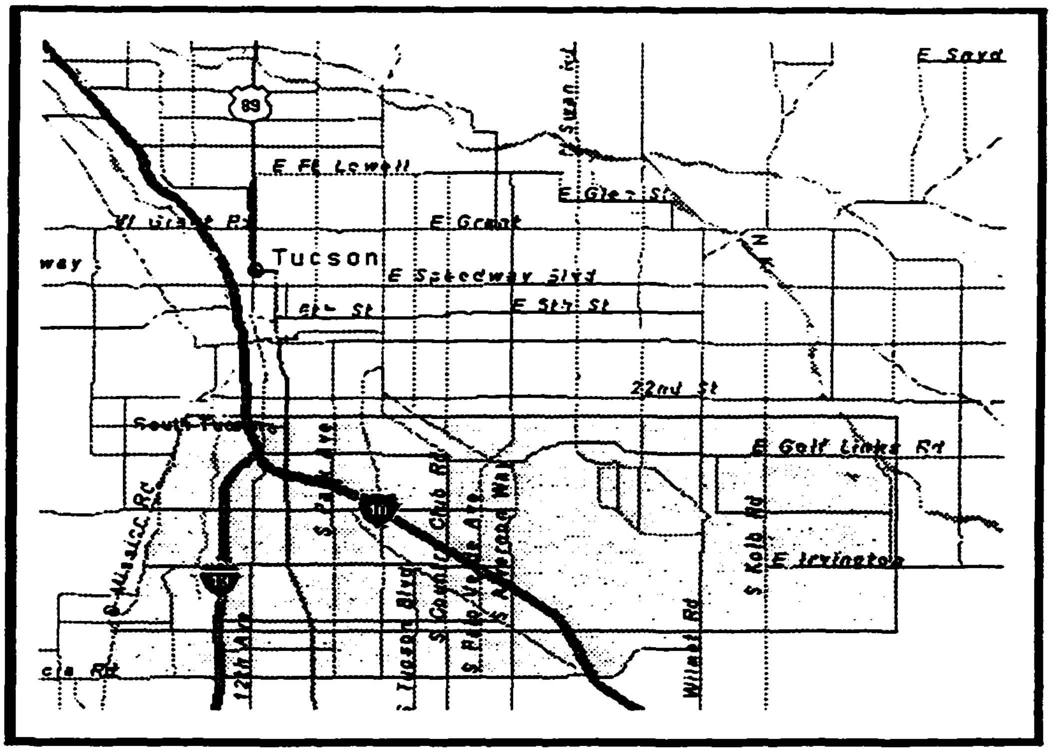


Figure 1. Burrowing owl study area (shaded) in Tucson, Arizona.

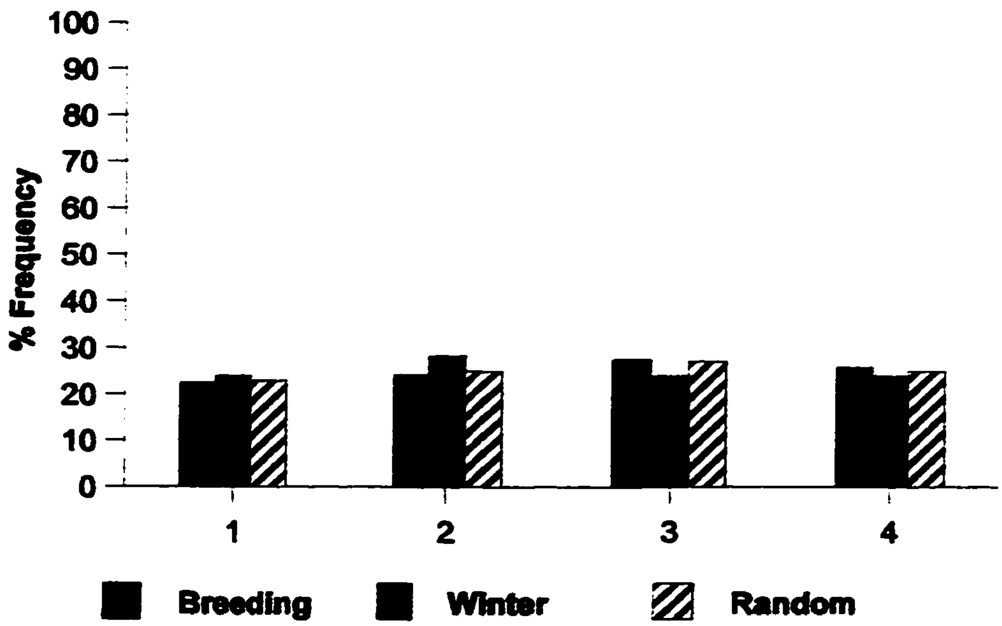


Figure 2. Categorical distribution of burrow entrance orientation among breeding ($\underline{n}$ = 58), winter ($\underline{n}$ = 46), and randomly located potential burrows ($\underline{n}$ = 48), in Tucson, Arizona, 1997 - 1998.

| Code | Description |
|---|---|
| 1 | Orientation between 0° and 89° |
| 2 | Orientation between 90° and 179° |
| 3 | Orientation between 180° and 269° |
| 4 | Orientation between 270° and 359° |

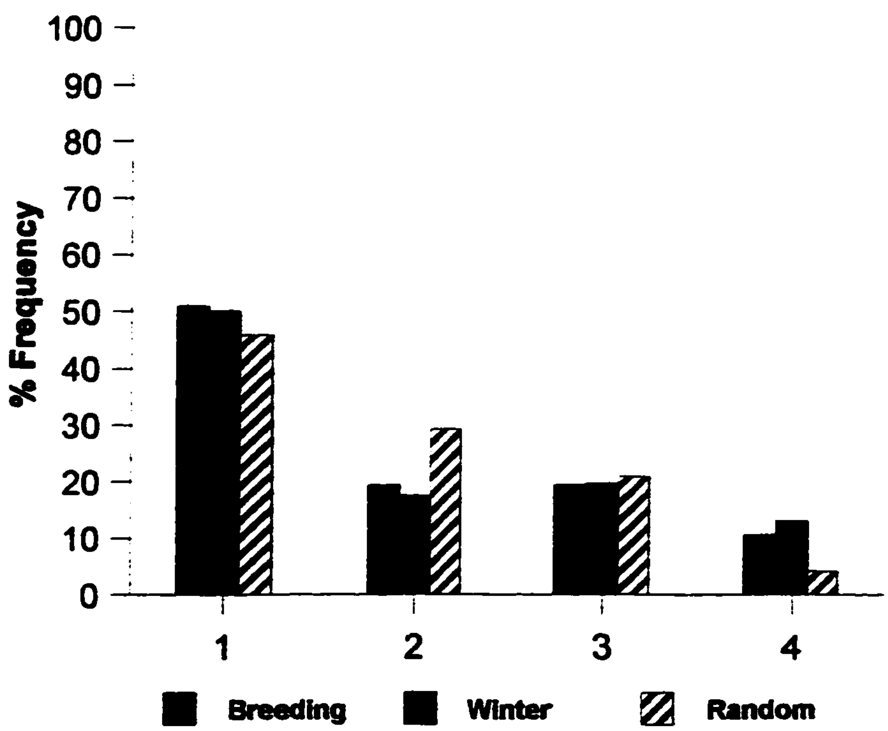


Figure 3. Categorical distribution of nearest building among breeding (n = 57), winter (n = 46), and randomly located potential burrows (n = 48), in Tucson, Arizona, 1997 - 1998.

| Code | Description |
|---|---|
| 1 | Residential (e.g., house, apartment, mobile home) structures characterized by regular pedestrian and/or vehicular activity of relatively low intensity |
| 2 | Commercial (e.g., office, factory, church) structures characterized by regular pedestrian and/or vehicular activity of high frequency and intensity |
| 3 | Storage, maintenance, or public restroom structures characterized by irregular pedestrian and/or vehicular activity of low varying intensity |
| 4 | Schools and recreation buildings (e.g., swimming pool facility) characterized by regular pedestrian and/or vehicular activity of high intensity |

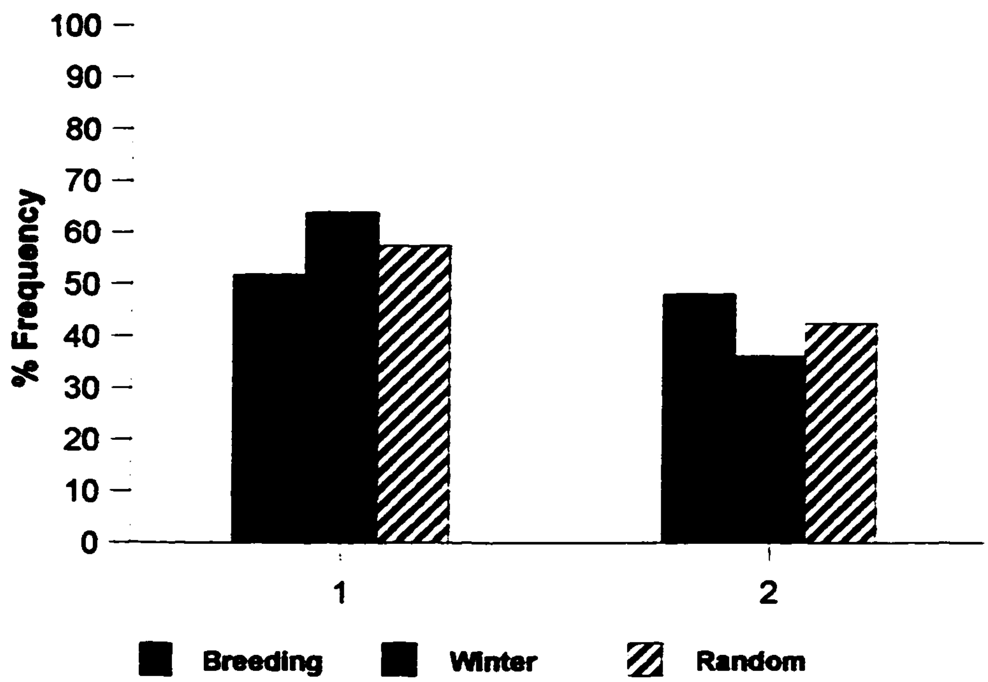


Figure 4. Categorical distribution of nearest light source among breeding (n = 56), winter (n = 47), and randomly located potential burrows (n = 47), in Tucson, Arizona, 1997 - 1998.

| Code | Description |
|---|---|
| 1 | Lights that operate on a regular schedule (e.g., streetlights, airfield light) |
| 2 | Lights that operate on an irregular or unknown schedule (e.g., porch lights, sports field lights) |

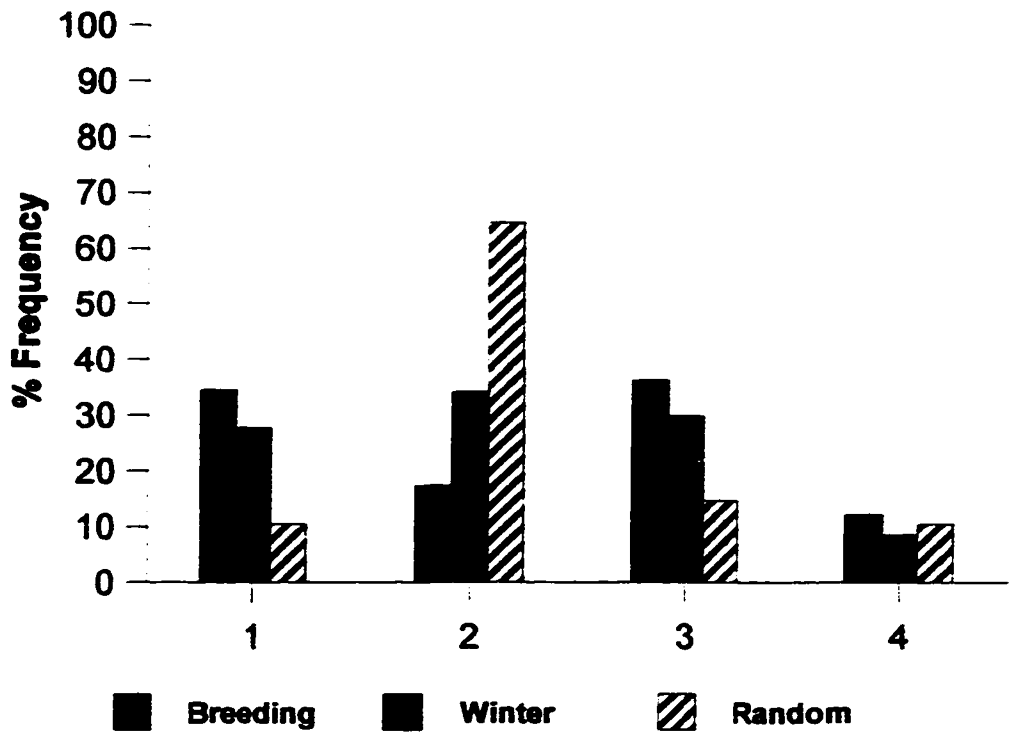


Figure 5. Categorical distribution of nearest perch among breeding ($\underline{n}$ = 58), winter ($\underline{n}$ = 47), and randomly located potential burrows ($\underline{n}$ = 48), in Tucson, Arizona, 1997 - 1998.

| Code | Description |
|---|---|
| 1 | Structures of earth (e.g., top of wash bank, earthen mound at burrow entrance) |
| 2 | Perches formed from natural vegetation (e.g., trees, shrubs, brush, stumps) |
| 3 | Man-made structure (e.g., wall, fence, sign, telephone wire) |
| 4 | Rock or rocklike structure (e.g., asphalt or concrete debris) |

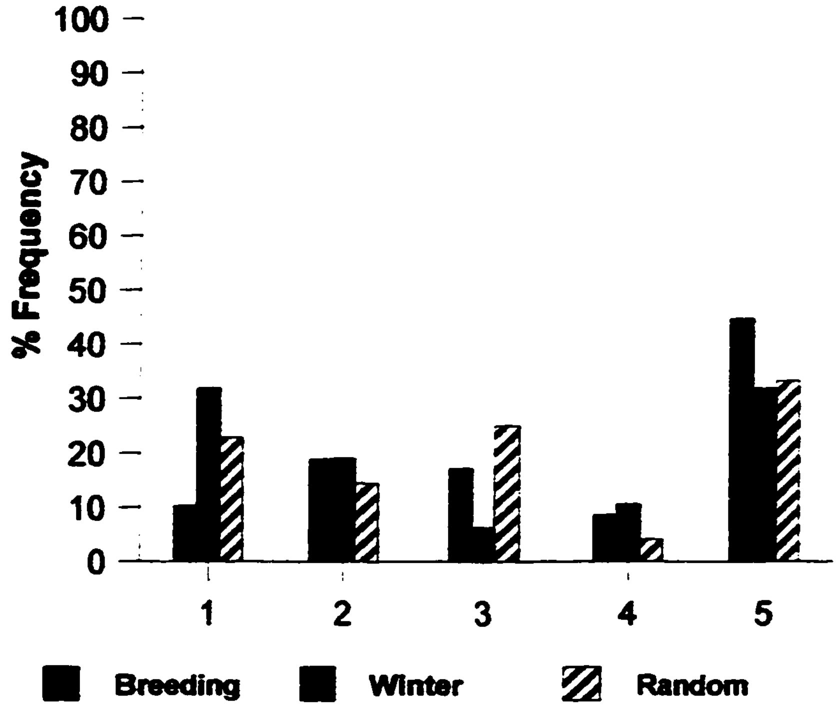


Figure 6. Categorical distribution of primary human activity area among breeding ($\underline{n}$ = 58), winter ($\underline{n}$ = 47), and randomly located potential burrows ($\underline{n}$ = 48), in Tucson, Arizona, 1997 - 1998.

| Code | Description |
|---|---|
| 1 | Areas characterized by regular pedestrian and motorized vehicular activity of moderate intensity (e.g., parking lot, office, commercial building, church) |
| 2 | Areas characterized by regular pedestrian and vehicular activity of low intensity (e.g., bike path, sidewalk, pedestrian pathway, bus stop, unpaved road) |
| 3 | Areas characterized by regular or sustained motorized vehicular activity of moderate to high intensity (e.g., paved road, railroad track, airplane runway) |
| 4 | Areas characterized by regular, seasonal pedestrian activity of high intensity (e.g., school, recreational building) |
| 5 | Areas characterized by irregular pedestrian and vehicular activity of varying intensity (e.g., house, backyard, trailer park, storage building, mobile home, apartment, transient camp, storage building, maintenance building, construction site) |

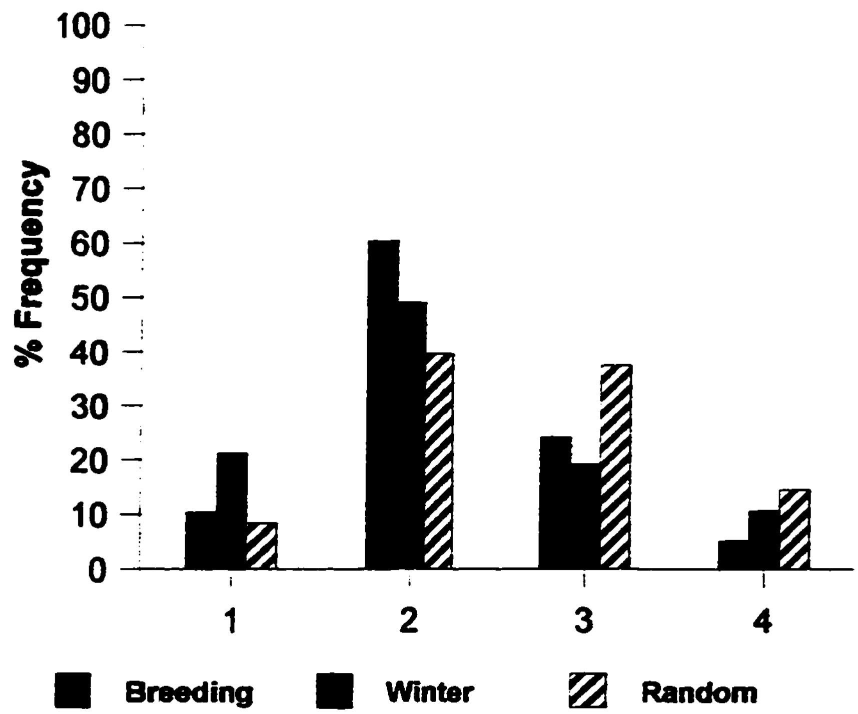


Figure 7. Categorical distribution of closest human activity area among breeding (n = 58), winter (n = 47), and randomly located potential burrows (n = 48), in Tucson, Arizona, 1997 - 1998.

| Code | Description |
|---|---|
| 1 | Areas characterized by regular pedestrian and motorized vehicular activity of moderate intensity (e.g., parking lot, office, commercial building, church) and by regular, seasonal pedestrian activity of high intensity (e.g., school, recreational building) |
| 2 | Areas characterized by regular pedestrian and vehicular activity of low intensity (e.g., bike path, sidewalk, pedestrian pathway, bus stop, unpaved road) |
| 3 | Areas characterized by regular or sustained motorized vehicular activity of moderate to high intensity (e.g., paved road, railroad track, airplane runway) |
| 4 | Areas characterized by irregular pedestrian and vehicular activity of varying intensity (e.g., house, backyard, trailer park, storage building, mobile home, apartment, transient camp, storage building, maintenance building, construction site) |

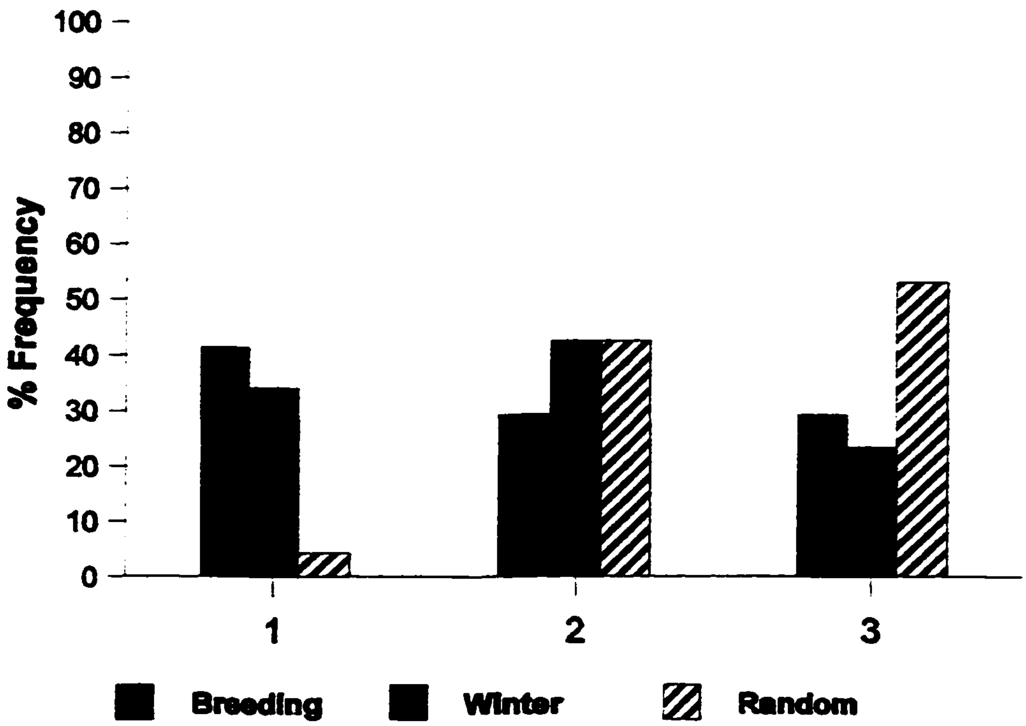


Figure 8. Categorical distribution of the location of breeding (n = 58), winter (n = 47), and randomly located potential burrows (n = 47), in Tucson, Arizona, 1997 - 1998, relative to the nearest wash bank.

| Code | Description |
|---|---|
| 1 | Burrow is located on the bank of a wash |
| 2 | Nearest wash is located within 200 meters of the burrow |
| 3 | Nearest wash is located further than 200 meters from the burrow |

Table 1. Slope of ground around the burrow entrance (degrees), and the slope (degrees), width (cm), and height (cm) of tunnel entrances at burrows used by burrowing owls, and at randomly selected potential burrows, in Tucson, Arizona, 1997 - 98.

| | BREEDING | | | WINTER | | | RANDOM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **P** |
| Slope Ground | 58 | 10.38 | 1.52 | 46 | 10.24 | 2.53 | 48 | 7.15 | 2.41 | .1338 |
| Slope Ground* | 58 | 10.38 | 1.52 | 45 | 8.47 | 1.85 | 40 | 1.23 | 0.37 | .0009 |
| Slope Tunnel | 56 | 22.86 | 2.68 | 45 | 28.04 | 3.69 | 46 | 25.15 | 2.98 | .5823 |
| Slope Tunnel* | 52 | 23.31 | 1.63 | 42 | 23.62 | 2.91 | 43 | 23.42 | 1.94 | .8695 |
| Width | 52 | 21.63 | 2.16 | 44 | 25.86 | 3.56 | 48 | 13.00 | 0.67 | <.0001 |
| Width* | 48 | 18.04 | 0.77 | 40 | 19.33 | 0.87 | 46 | 12.37 | 0.52 | <.0001 |
| Height | 52 | 17.25 | 1.28 | 44 | 23.30 | 3.00 | 48 | 11.53 | 0.58 | <.0001 |
| Height* | 48 | 14.90 | 0.58 | 40 | 18.13 | 1.11 | 44 | 10.58 | 0.35 | <.0001 |

* outliers removed

Table 2. Distance (in meters) to key landscape features at burrow sites used by burrowing owls, and at randomly selected potential sites, in Tucson, Arizona, 1997-98.

| | BREEDING | | | WINTER | | | RANDOM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Feature** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **P** |
| Building | 52 | 133.67 | 13.14 | 48 | 123.95 | 11.18 | 48 | 117.67 | 13.92 | .4018 |
| Building* | 52 | 133.67 | 13.14 | 45 | 109.10 | 7.84 | 46 | 105.89 | 11.69 | .2722 |
| Light | 51 | 95.55 | 11.55 | 48 | 93.92 | 9.47 | 47 | 69.34 | 6.41 | .1892 |
| Light* | 49 | 86.12 | 9.85 | 46 | 85.91 | 7.82 | 41 | 55.85 | 3.86 | .0412 |
| Perch | 53 | 16.75 | 4.03 | 48 | 10.33 | 2.01 | 48 | 4.86 | 1.74 | <.0001 |
| Perch* | 45 | 5.73 | 1.09 | 44 | 6.77 | 1.08 | 41 | 0.72 | 0.15 | <.0001 |
| W. Bank[1] | 41 | 14.77 | 5.06 | 36 | 22.54 | 6.59 | 22 | 34.50 | 7.05 | .0010 |
| W. Bank*[1] | 33 | 1.56 | 0.73 | 35 | 17.99 | 4.90 | 21 | 29.62 | 5.34 | <.0001 |
| UP Road[1] | 43 | 35.57 | 6.76 | 29 | 37.17 | 8.59 | 36 | 29.56 | 3.69 | .4504 |
| UP Road*[1] | 39 | 24.53 | 4.59 | 26 | 24.23 | 4.99 | 35 | 27.49 | 3.15 | .1162 |
| P Road[1] | 52 | 82.40 | 9.84 | 46 | 86.04 | 11.65 | 48 | 64.90 | 10.91 | .1180 |
| P Road*[1] | 51 | 76.94 | 8.35 | 44 | 75.40 | 9.26 | 46 | 53.07 | 6.45 | .0705 |
| CAA[1] | 53 | 29.29 | 5.85 | 48 | 42.67 | 5.37 | 48 | 23.23 | 2.63 | .0051 |
| CAA*[1] | 49 | 18.99 | 2.84 | 47 | 39.68 | 4.56 | 47 | 22.13 | 2.44 | .0006 |
| PAA[1] | 53 | 60.94 | 7.63 | 48 | 94.48 | 11.29 | 48 | 60.68 | 8.18 | .0074 |
| PAA*[1] | 51 | 55.16 | 6.72 | 44 | 76.86 | 7.70 | 42 | 42.63 | 3.79 | .0027 |

* outliers removed

1 W. Bank = wash bank, UP Road = unpaved road, P Road = paved road, CAA = closest human activity area, PAA = primary human activity area

Table 3. Type and percentage of ground and canopy (tree) cover at burrow sites used by burrowing owls, and at randomly selected potential sites, in Tucson, Arizona, 1997 - 98.

| | BREEDING | | | WINTER | | | RANDOM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cover Type | n | $\bar{x}$ | se | n | $\bar{x}$ | se | n | $\bar{x}$ | se | P |
| Bare Ground | 51 | 79.68 | 2.68 | 46 | 76.94 | 2.31 | 47 | 65.23 | 3.16 | .0003 |
| Bare Ground* | 46 | 84.81 | 1.40 | 44 | 78.92 | 1.93 | 46 | 66.64 | 2.89 | <.0001 |
| Impervious | 51 | 6.11 | 1.88 | 46 | 7.51 | 1.96 | 47 | 7.07 | 2.08 | .7424 |
| Impervious* | 44 | 1.61 | 0.45 | 41 | 3.52 | 0.89 | 41 | 2.33 | 0.68 | .4782 |
| Rock | 51 | 3.75 | 0.97 | 46 | 2.00 | 0.62 | 47 | 11.70 | 2.58 | .0015 |
| Rock* | 46 | 2.00 | 0.50 | 42 | 1.03 | 0.30 | 44 | 8.22 | 1.61 | .0006 |
| Litter | 51 | 5.10 | 0.59 | 46 | 3.47 | 0.47 | 47 | 4.40 | 0.78 | .1023 |
| Litter* | 49 | 4.65 | 0.52 | 45 | 3.21 | 0.40 | 41 | 2.61 | 0.28 | .0276 |
| Grass | 51 | 3.08 | 0.55 | 46 | 4.74 | 1.20 | 47 | 3.99 | 0.67 | .6986 |
| Grass* | 48 | 2.30 | 0.33 | 41 | 2.37 | 0.48 | 45 | 3.39 | 0.55 | .3821 |
| Forb | 51 | 1.71 | 0.25 | 46 | 3.80 | 0.62 | 47 | 3.73 | 1.03 | .2186 |
| Forb* | 49 | 1.47 | 0.20 | 45 | 3.56 | 0.59 | 41 | 1.65 | 0.33 | .0763 |
| Shrub | 51 | 0.57 | 0.19 | 46 | 1.54 | 0.56 | 47 | 3.89 | 0.63 | <.0001 |
| Shrub* | 45 | 0.15 | 0.04 | 40 | 0.33 | 0.10 | 46 | 3.54 | 0.54 | <.0001 |
| Tree | 51 | 0.50 | 0.24 | 42 | 0.80 | 0.38 | 47 | 1.71 | 0.47 | .0016 |
| Tree* | 42 | 0.00 | 0.00 | 34 | 0.00 | 0.00 | 43 | 0.88 | 0.22 | <.0001 |

* outliers removed

Table 4. Height (cm) of shrubs and trees at burrow sites used by burrowing owls, and at randomly located potential burrow sites, in Tucson, Arizona, 1997 - 98.

| | BREEDING | | | WINTER | | | RANDOM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **P** |
| Shrub | 19 | 91.51 | 14.19 | 20 | 129.01 | 14.96 | 38 | 146.24 | 13.66 | .0535 |
| Tree | 9 | 245.44 | 60.03 | 7 | 315.99 | 57.25 | 22 | 424.27 | 54.62 | .3206 |

Table 5. Horizontal visual obscurity (number of 10 cm segments of the cover pole that were ≥ 25 % obscured from view) at burrow sites used by burrowing owls, and at randomly selected potential sites, in Tucson, Arizona, 1997-98. Measurements (Distance from burrow (m): at Height from the ground (cm) ) taken from four transects were combined.

| | BREEDING | | | WINTER | | | RANDOM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Distance: Height** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **P** |
| 5:0-50 | 58 | 2.95 | 0.49 | 46 | 3.96 | 0.53 | 48 | 7.48 | 0.86 | <.0001 |
| 5:0-50* | 56 | 2.57 | 0.43 | 45 | 3.73 | 0.50 | 48 | 7.48 | 0.86 | <.0001 |
| 5:50-100 | 58 | 1.45 | 0.41 | 46 | 1.37 | 0.37 | 48 | 6.02 | 0.86 | <.0001 |
| 5:50-100* | 47 | 0.11 | 0.05 | 43 | 0.86 | 0.24 | 48 | 6.02 | 0.86 | <.0001 |
| 5:100-200 | 58 | 1.62 | 0.62 | 46 | 1.28 | 0.46 | 48 | 9.09 | 1.38 | <.0001 |
| 5:100-200* | 48 | 0.00 | 0.00 | 36 | 0.00 | 0.00 | 48 | 9.09 | 1.38 | <.0001 |
| 15:0-50 | 58 | 4.79 | 0.61 | 46 | 7.15 | 0.67 | 48 | 11.85 | 0.88 | <.0001 |
| 15:50-100 | 58 | 2.17 | 0.45 | 46 | 3.48 | 0.56 | 48 | 8.33 | 0.99 | <.0001 |
| 15:50-100* | 57 | 1.89 | 0.36 | 45 | 3.24 | 0.52 | 48 | 8.33 | 0.99 | <.0001 |
| 15:100-200 | 58 | 3.07 | 0.79 | 46 | 4.31 | 0.79 | 48 | 14.61 | 1.88 | <.0001 |
| 15:100-200* | 55 | 1.98 | 0.46 | 46 | 4.31 | 0.79 | 48 | 14.61 | 1.88 | <.0001 |
| 25:0-50 | 58 | 5.95 | 0.64 | 45 | 8.31 | 0.78 | 48 | 14.29 | 0.83 | <.0001 |
| 25:50-100 | 58 | 3.74 | 0.56 | 45 | 4.38 | 0.64 | 48 | 11.50 | 1.01 | <.0001 |
| 25:50-100* | 57 | 3.46 | 0.49 | 45 | 4.38 | 0.64 | 48 | 11.50 | 1.01 | <.0001 |
| 25:100-200 | 58 | 4.88 | 0.91 | 45 | 5.71 | 0.90 | 48 | 19.81 | 1.95 | <.0001 |
| 25:100-200* | 57 | 4.39 | 0.78 | 45 | 5.71 | 0.90 | 48 | 19.81 | 1.95 | <.0001 |

* outliers removed

Table 6. Vertical vegetative structure at burrow sites used by burrowing owls, and at randomly selected potential sites, in Tucson, Arizona, in 1997 - 98. Vertical structure was determined by the number of times vegetation intersected each 20 cm vertical segment. Measurements were taken at 5 m intervals along three 50 m transects.

| Vertical Segment | BREEDING n | BREEDING $\bar{x}$ | BREEDING se | WINTER n | WINTER $\bar{x}$ | WINTER se | RANDOM n | RANDOM $\bar{x}$ | RANDOM se | P |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-20: | 51 | 18.43 | 2.54 | 46 | 29.46 | 4.77 | 48 | 35.98 | 5.37 | .1201 |
| 0-20* | 49 | 15.88 | 1.87 | 44 | 24.86 | 3.65 | 47 | 33.64 | 4.94 | .0851 |
| 20-40 | 51 | 3.08 | 0.84 | 46 | 4.11 | 1.04 | 48 | 9.83 | 2.18 | .0061 |
| 20-40* | 47 | 1.55 | 0.34 | 42 | 2.38 | 0.58 | 44 | 6.23 | 1.33 | .0027 |
| 40-60 | 51 | 1.69 | 0.69 | 46 | 3.35 | 1.02 | 48 | 4.98 | 0.87 | <.0001 |
| 40-60* | 48 | 0.65 | 0.18 | 42 | 1.57 | 0.44 | 45 | 3.91 | 0.66 | <.0001 |
| 60-80 | 51 | 0.88 | 0.46 | 46 | 2.22 | 0.86 | 48 | 4.42 | 0.86 | <.0001 |
| 60-80* | 45 | 0.00 | 0.00 | 38 | 0.16 | 0.08 | 46 | 3.54 | 0.63 | <.0001 |
| 80-100 | 51 | 0.61 | 0.26 | 46 | 1.61 | 0.88 | 48 | 3.10 | 0.72 | .0001 |
| 80-100* | 43 | 0.00 | 0.00 | 37 | 0.00 | 0.00 | 44 | 1.91 | 0.45 | <.0001 |
| 100-120 | 51 | 0.35 | 0.21 | 46 | 1.43 | 0.75 | 48 | 2.50 | 0.66 | <.0001 |
| 100-120* | 46 | 0.00 | 0.00 | 35 | 0.00 | 0.00 | 44 | 1.34 | 0.29 | <.0001 |
| 120-140 | 51 | 0.12 | 0.09 | 46 | 1.67 | 0.81 | 48 | 3.10 | 0.99 | .0001 |
| 120-140* | 49 | 0.00 | 0.00 | 39 | 0.00 | 0.00 | 39 | 0.36 | 0.12 | <.0001 |
| 140-160 | 51 | 0.12 | 0.08 | 46 | 1.09 | 0.57 | 48 | 2.38 | 0.86 | .0004 |
| 140-160* | 49 | 0.00 | 0.00 | 40 | 0.00 | 0.00 | 42 | 0.62 | 0.20 | <.0001 |

Table 6. *Continued*

| Vertical Segment | BREEDING | | | WINTER | | | RANDOM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | n | $\bar{x}$ | se | n | $\bar{x}$ | se | n | $\bar{x}$ | se | P |
| 160-180 | 51 | 0.18 | 0.14 | 46 | 1.28 | 0.72 | 48 | 1.81 | 0.76 | .0125 |
| 160-180* | 49 | 0.00 | 0.00 | 38 | 0.00 | 0.00 | 38 | 0.05 | 0.04 | .0995 |
| 180-200 | 51 | 0.08 | 0.05 | 46 | 1.09 | 0.69 | 48 | 1.75 | 0.79 | .0445 |
| 180-200* | 48 | 0.00 | 0.00 | 42 | 0.00 | 0.00 | 38 | 0.00 | 0.00 | 1.000 |

* outliers removed

Table 7. Number of "large" (entrance tunnel dimensions ≥ 9 cm x 7 cm) and "small" (entrance tunnel dimensions < 9 cm x 7 cm) burrows located along three transects, and number of alternate burrows located within a 25 meter radius of burrow sites used by burrowing owls, and at randomly selected potential sites, in Tucson, Arizona, 1997-98.

| | BREEDING | | | WINTER | | | RANDOM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Vertical Segment** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **P** |
| # Small Brws | 51 | 12.39 | 2.24 | 48 | 15.13 | 2.24 | 48 | 10.50 | 1.82 | .1005 |
| # Small Brws* | 48 | 9.27 | 1.25 | 44 | 11.70 | 1.27 | 45 | 8.02 | 1.20 | .0938 |
| # Large Brws | 51 | 0.61 | 0.16 | 48 | 0.56 | 0.11 | 48 | 0.29 | 0.08 | .1896 |
| # Large Brws* | 48 | 0.38 | 0.08 | 47 | 0.55 | 0.11 | 46 | 0.22 | 0.06 | .1038 |
| # Alt Brws | 58 | 0.98 | 0.14 | 48 | 0.81 | 0.14 | 48 | 0.75 | 0.16 | .3287 |
| #Alt Brws* | 58 | 0.98 | 0.14 | 46 | 0.70 | 0.12 | 42 | 0.40 | 0.10 | .0161 |

* outliers removed

Table 8. Nesting success of burrowing owl nests located in Tucson, Arizona. Nests were defined as "active" if a pair of adult owls, a single adult with young, or diagnostic nesting behaviors were observed. A "successful" nest was one which produced $\geq$ 1 fledgling.

| | 1997 | | 1998 | | Total | |
|---|---|---|---|---|---|---|
| **Variable** | **n** | **%** | **n** | **%** | **n** | **%** |
| # Active Nests | 67 | 100.0 | 49 | 100.0 | 116 | 100.0 |
| # Nests Hatching Young | 57 | 85.1 | 28 | 57.1 | 85 | 73.3 |
| # Successful Nests | 44 | 65.6 | 25 | 51.0 | 69 | 59.5 |
| # Nests Which Failed | 13 | 19.4 | 5 | 10.2 | 18 | 15.5 |
| # Nests W/Unknown Outcome | 10 | 14.9 | 19 | 38.8 | 29 | 25.0 |

Table 9. Reproductive success of burrowing owl nests located in Tucson, Arizona. Nests were defined as "active" if a pair of adult owls, a single adult with young, or diagnostic nesting behaviors were observed. A "successful" nest was one which produced ≥ 1 fledgling.

| | 1997 | | | 1998 | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** | **n** | $\bar{x}$ | **se** |
| # Nestlings/Active Nests[1] | 67 | 2.66 | 0.24 | 32 | 2.66 | 0.29 | 99 | 2.66 | 0.20 |
| # Fledglings/Active Nests[2] | 57 | 2.23 | 0.26 | 30 | 2.47 | 0.33 | 87 | 2.31 | 0.20 |
| # Nestlings/Successful Nests | 44 | 3.41 | 0.28 | 25 | 3.16 | 0.28 | 69 | 3.32 | 0.20 |
| # Fledglings/Successful Nests | 44 | 2.89 | 0.26 | 25 | 2.96 | 0.31 | 69 | 2.91 | 0.20 |

1 Active nests = includes only those nests for which outcome of nestling stage was known

2 Active nests = includes only those nests for which outcome of fledgling stage was known

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