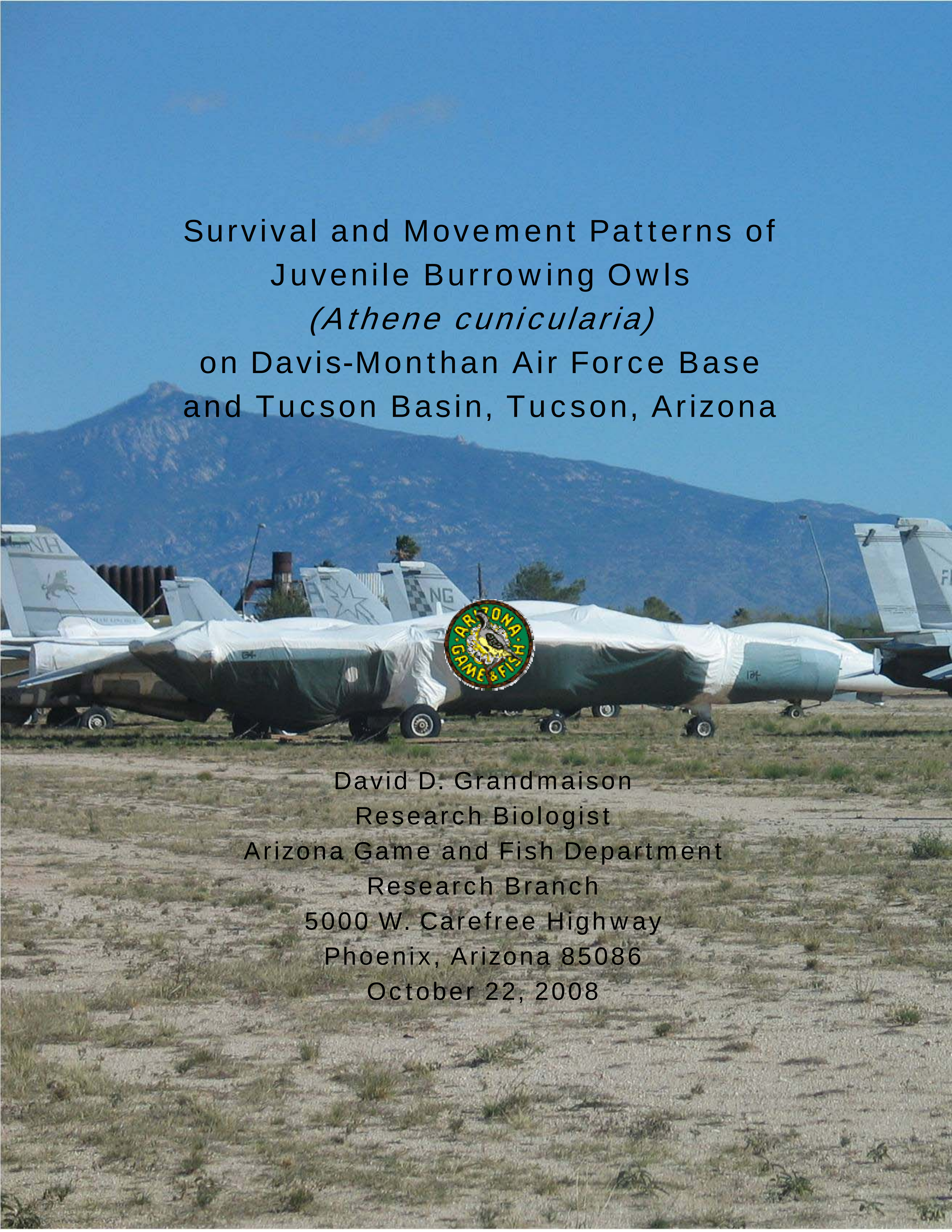


Survival and Movement Patterns of Juvenile Burrowing Owls *(Athene cunicularia)* on Davis-Monthan Air Force Base and Tucson Basin, Tucson, Arizona

David D. Grandmaison
Research Biologist
Arizona Game and Fish Department
Research Branch
5000 W. Carefree Highway
Phoenix, Arizona 85086

October 22, 2008

RECOMMENDED CITATION

Grandmaison, D. D. 2008. Survival and movement patterns of juvenile burrowing owls (*Athene cunicularia*) on Davis-Monthan Air Force Base and Tucson Basin, Tucson, Arizona. Arizona Game and Fish Department, Research Branch, Phoenix, AZ.

ACKNOWLEDGMENTS

Michael Ingraldi supported this project through contract administration. Scott Blackman, Dennis Abbate, and Michael Ingraldi provided assistance with manuscript revision. Many thanks to our field crew: Lirain Urreiztieta, Scott Blackman, Eduardo Moreno, Valerie Horncastle, Zach Hurst, Angie Stingelin, Dennis Abbate, Shawn Lowery, Mark Hatfield, Elizabeth Reif, and Sara Schuster. Thanks also to our colleagues at the University of Arizona working with burrowing owls in Tucson, Mark Ogonowski and Dr. Courtney Conway. This project could not have been a success without the unending support of Gwen Lisa, 355th Civil Engineer Squadron Natural and Cultural Resources Manager.

AMERICANS WITH DISABILITIES ACT COMPLIANCE

The Arizona Game and Fish Department complies with all provisions of the Americans with Disabilities Act. If you need this material in an alternative format of believe you have been discriminated against, contact the Deputy Director, Arizona Game and Fish Department, 2221 West Greenway Road, Phoenix, Arizona 85023-4399; Telephone (602) 942-3000.

PROJECT FUNDING

Funding for this project was provided under Cooperative Agreement #2003-02 between The Arizona Game and Fish Department and the 355th Civil Engineer Squadron, Environmental Quality Flight, Natural Resources Office, Davis-Monthan AFB, Arizona.

Table of Contents

INTRODUCTION

Although once considered a common breeding bird in the western United States, burrowing owls (*Athene cunicularia*) have experienced recent population declines throughout their range as a result of habitat loss, predation, disease, and rodent control programs (Haug et al. 1993, James and Espie 1997, Desmond et al. 2000, Brown 2001). The burrowing owl is now listed as federally Endangered in Canada (Wellicome and Haug 1995), considered a species of national conservation concern in the United States (U.S. Fish and Wildlife Service 2002), and one of the priority species in the Sonoran Desert Conservation Plan (Sonoran Desert Conservation Plan 2002). In Mexico, burrowing owls are listed as federally threatened. The burrowing owl is protected in Arizona under Arizona Revised Statute Article 17 and under the Migratory Bird Treaty Act in the United States and Mexico. This designation protects the owl from actions resulting in death and the destruction of active nest burrows.

Typical burrowing owl breeding habitat consists of dry, open areas, characterized by short vegetation, the absence of trees, and the presence of suitable burrows (Haug et al. 1993, Klute et al. 2003). Breeding habitats include prairie dog (*Cynomys ludovicianus*) colonies, fallow agricultural fields, road rights-of-way, and urban areas such as airports and golf courses (Klute et al. 2003). Surveys of historic nesting sites in Arizona during the 2001 breeding season indicated that 82.3% of these sites no longer supported breeding burrowing owls (Brown and Mannan 2002) although the specific mechanisms resulting in this apparent decline were not identified.

Historical records indicate that southeastern Arizona once supported robust populations of prairie dogs and burrowing owls (Bendire 1892, Phillips et al. 1964, Brown 2001). With the extirpation of prairie dogs in southeastern Arizona during the 1930's (Arizona Game and Fish Department 2004), and the concomitant loss of burrowing owl habitat that prairie dogs create, the importance of alternative burrow building mammals has been elevated for burrowing owl persistence. Burrowing owls are dependent on fossorial mammals for burrow excavation, nesting in abandoned burrows created by small and medium sized mammals such as black-tailed prairie dogs, round-tailed ground squirrels (*Citellus tereticaudus*), badgers (*Taxidea taxus*), and coyotes (*Canis latrans*). With the reduction and elimination of fossorial mammals, burrow availability can be a potentially limiting factor for population persistence (Desmond and Savidge 1996, Desmond et al. 2000).

In response to regional western burrowing owl declines, the Arizona Partners in Flight Bird Conservation Plan has identified the study of dispersal movements as a primary research need (Latta et al. 1999). Development in the Greater Tucson Area has led to concern regarding the status of the local burrowing owl populations. Western burrowing owls living and breeding within the Tucson Basin face the challenge of dispersing through an urban matrix where natural burrows are becoming increasingly scarce as suitable habitat is converted to human dominated land use patterns. In the Tucson Basin, burrowing owls can currently be found in high density on Davis-Monthan Air Force Base, along the banks of the Santa Cruz River, and at lower density in the Avra Valley (Estabrook and Mannan 1998, Alanen 2004, Conway and Ogonowski 2005, Grandmaison and Urreiztieta 2006).

The objective of this study was to examine selected aspects of burrowing owl demography on Monthan Air Force Base and describe the movement patterns of juvenile burrowing owls in the Tucson Basin. Specific objectives include:

1. Conduct standardized surveys for burrowing owls on Davis-Monthan Air Force Base,
2. Describe post-fledgling movements of juvenile burrowing owls in the Tucson Basin,
3. Evaluate habitat used during post-fledgling movements, and
4. Estimate juvenile survival during the dispersal period.

STUDY AREA

Burrowing owls were sampled from four sites within the Greater Tucson Area, including Davis-Monthan Air Force Base, the Tucson Electric Park, the Santa Cruz River channel, and the Town of Marana (Figure 1). These sites are located within the Arizona Upland Subdivision of the Sonoran Desert scrub biotic community (Brown and Lowe 1980). Dominant landscape features include a highly urbanized matrix with interspersed patches of xeroriparian and semi-arid grassland habitat within the Arizona Upland/Sonoran Desert Scrub vegetation community.

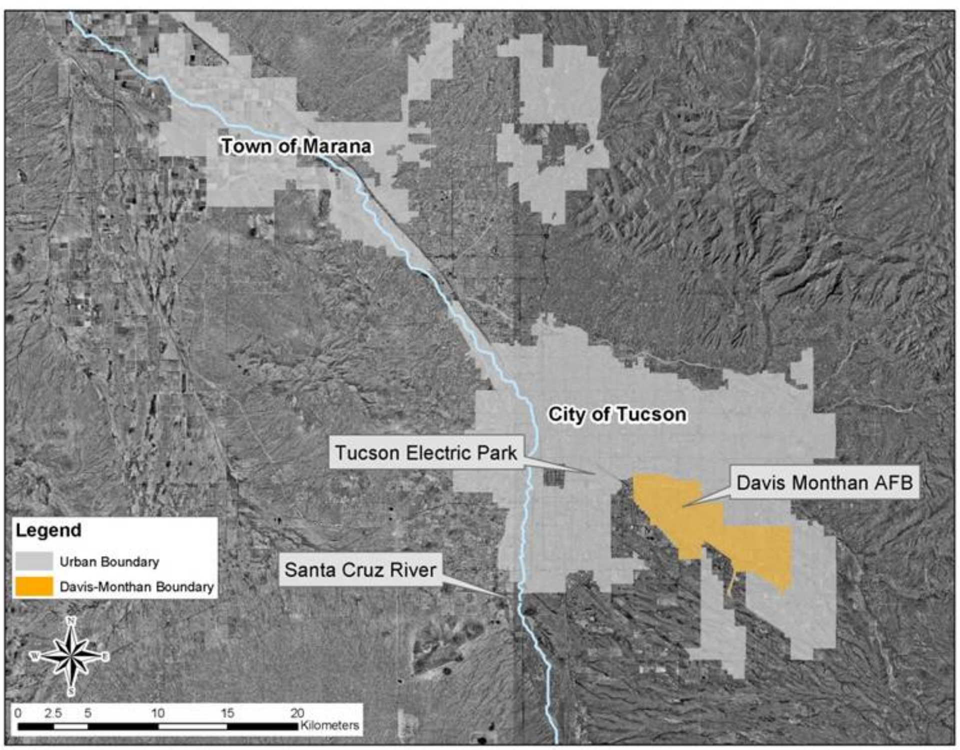


Figure 1. Study area and sampling locations for burrowing owls during the 2004 and 2005 breeding season in southeastern Arizona, USA.

The City of Tucson is located within the Basin and Range Physiographic Province which occupies much of the western and southwestern United States, including most of Nevada, western Utah, southeastern California, and southern Arizona. The Tucson area is characterized by broad alluvial fans, dissected upland bajadas, and four major mountain ranges - Santa Catalina Mountains, Tucson Mountains, Santa Rita Mountains, and Rincon Mountains - which form the boundary of the Tucson Basin. Average precipitation ranges between 11 and 12 inches per year, although actual precipitation varies locally within the basin. Summer temperatures range from 71° F to 101° F (NOAA 1997). The City of Tucson supports as human population of approximately 500,000 residents. Land use within the Tucson Basin includes residential, commercial, industrial, military, and recreational open space. The City of Tucson is currently developing a Habitat Conservation Plan and has identified the burrowing owl as a covered species (Liberti and Wyneken 2006). As a result, they are currently developing conservation measures to minimize the impacts of future development on burrowing owls.

Davis-Monthan Air Force Base is located within the city limits of Tucson, Arizona. Potential burrowing owl habitat on the base includes landscaped areas associated with the urban/residential sections of the base, Aerospace Maintenance and Regeneration Group (AMARG), the golf course, and areas around the runway (flight line). Vegetation on the runway is limited to short grasses, though most of the ground is devoid of vegetation. This area has been shown to support a high density of burrowing owls that is thought to benefit from the limited human disturbance, maintenance of short vegetation, predator control, and the availability of prey resources such as arthropods and small mammals. The availability of burrows may contribute to high burrowing owl density around the runways as well. Davis-Monthan Air Force Base supports a high density of breeding burrowing owls and maintains a large year-round population of owls. During the 2004 breeding season, approximately 198 adult burrowing owls were detected on the base and 183 juveniles were banded (Conway and Ogonowski 2005). During the 2004 - 2005 Winter, approximately 49% of the burrowing owls detected during the 2004 breeding season over-wintered on the base (Conway and Ogonowski 2005).

The Tucson Electric Park is part of the Kino Sports Complex located within the urbanized boundary of Tucson, Arizona. The facility is largely managed for recreational purposes including baseball and soccer fields, playgrounds, and the Sam Lena Park on the north side of Ajo Way. The complex also includes a 50-acre riparian restoration area containing upland and wetland habitat. Artificial burrowing owl habitat has also been established as part of this restoration effort. Surrounding land use is primarily residential to the north and commercial and industrial to the south.

The Santa Cruz River originates in the San Rafael Valley (located southeast of Tucson), flows southwest into Mexico and reenters Arizona east of Nogales. The Santa Cruz River runs north from Nogales, crosses through Tucson and meets the Gila River southwest of Phoenix. This river is characterized as an intermittent desert stream that contains perennial and effluent dominated reaches. Most of the section of river flowing through Tucson contains protected embankments (e.g., soil cement) although areas of unimproved banks exist. Erosion along these unimproved, and largely unvegetated sections of the river create burrows that are often used by burrowing owls for both nesting and non-nesting habitat. Land use along the Santa Cruz River includes residential, commercial, industrial, dedicated rights-of-way, and recreational open space such as urban parks and trail systems.

The Town of Marana is rapidly growing municipality north of Tucson. Marana's population is estimated at 30,000 and is expected to double by 2020. Historic land use has been primarily agricultural although within recent years residential growth in Marana has resulted in conversion of agricultural fields to housing developments. The Town of Marana is currently developing a Habitat Conservation Plan that identifies the burrowing owl as a covered species and is therefore incorporating conservation strategies for to minimize impacts of future development on burrowing owls and their habitat.

METHODS

Standardized Surveys. All areas that met the vegetation structure characteristics of potential nesting habitat (i.e., open, treeless areas with low vegetation density and presence of fossorial mammals) were surveyed during the 2004 and 2005 breeding seasons. Surveys were conducted by walking a series of transects spaced at 50 meter intervals. Surveyors recorded the location of all burrows within 25 meters of each transect. Burrows were designated as 'active' if owls were detected or if fresh sign was observed at burrow entrances. During the 2005 survey, burrows were categorized by their potential to support burrowing owls. Specifically, we assessed the size of the burrow entrance (height 8 – 20 cm; width 8 – 28 cm), burrow depth (> 1 meter), and evidence of past use (e.g., fresh pellets, prey remains, owl feathers, and ornamentation). Category 1 burrows were large enough to accommodate burrowing owls but exhibited no evidence of use. Category 2 burrows showed evidence of previous use, but that use was not recent (e.g., old whitewash, old pellets, cobwebs, or debris at burrow entrances). Category 3 burrows showed sign of recent use (e.g., fresh whitewash, fresh pellets, feathers, or nest ornamentation). The location of all suitable burrows was recorded and mapped. We then examined the number of burrow detections in each of four land use categories (flight line, golf course, AMARG, and residential). However, because survey effort varied between years, we converted the number of detections in each category to proportions for comparison (Zar 1999).

Juvenile Movement. We captured burrowing owls using two-way box traps, mist nets, and bow nets. We determined age (adult or juvenile) based on plumage characteristics (Priest 1997). Juveniles weighing > 110 g were fitted with necklace style transmitters (4.4 g, Holohil Systems Ltd., Ontario, Canada). Owls were tracked using a 3-element yagi antenna (ATS, Inc., Isanti, MN) and a TRX2000S receiver (Wildlife Materials, Carbondale, IL). We used fixed-wing aircraft equipped with radio-telemetry equipment to supplement ground efforts to locate owls that had made long-distance movements. We relocated individuals weekly. Burrowing owl locations were plotted using ArcGIS 9.2 and movement pattern analysis was conducted with the Animal Movements Extension (Beyer 2004).

Dispersal Habitat. We defined dispersal as a movement outside of a 600 m radius buffer centered on the individual's natal burrow without returning. This distance represents the maximum distance that breeding male burrowing owls traveled from nest burrows during the breeding season and beyond which juveniles were considered independent (Arizona Game and Fish Department, unpublished data). Juveniles that moved beyond 600 m from their nest burrow were considered dispersers. All juvenile locations within 600 m of a nest burrow were excluded from dispersal habitat analyses. Although juvenile burrowing owl locations were acquired over a period of seven months, individuals were consistently relocated at few unique locations. This reduced the number of locations that could be sampled without re-sampling the same location repeatedly. Therefore, repeated owl locations were only sampled once (Thomas and Taylor 2006) and we did not allow sampling plots to overlap in order to avoid autocorrelation. However, due to the lack of unique locations, we pooled location data for all individuals for our analysis of habitat characteristics. Using the location estimate, rather than the individual, as the sampling unit constitutes pseudo-replication (i.e., samples are not independent) because variation among individuals is not accounted for (Aebischer et al. 1993, Otis and White 1999). However we were limited by the fact that burrowing owls are closely tied to a specific feature, specifically the shelter site (e.g., burrow, culvert, etc.) and few unique locations to sample from. Despite this limitation, we believe that it is informative to describe the habitat used by dispersing juvenile burrowing owls in an urbanized landscape to gain a better understanding of the urban ecology for this species. Therefore, we present the results of this analysis in a qualitative fashion and caution that their utility for making inferences regarding habitat use is limited.

The characteristics of habitat features for juvenile burrowing owls were examined at two scales because animals are thought to select habitat in a hierarchical fashion (Johnson 1980). The first level of analysis examined vegetation characteristics in the immediate vicinity of the burrowing owl location. We used 30 m radius circular plots to measure habitat characteristics thought to influence burrowing owl habitat use. We recorded the frequency of all shrubs and trees within the plot. We also estimated percent cover and vegetation height using the line intercept method (Canfield 1941). We examined habitat characteristics at known locations and randomly chosen locations nearby. For each known use plot, we randomly selected a second plot by generating a random bearing and random distance between 100 and 200 m.

The second level of analysis assessed land use patterns in the landscape surrounding owl locations. We examined land use composition of the Tucson Basin with the mean habitat compositions of individual owl radiolocations. Our analysis examined land use composition within a 466 m diameter buffer (17.06 ha) centered on juvenile burrowing owl locations (n = 30). We chose this buffer size *a posteriori* to capture surrounding land use complexity while keeping the buffer within the range of observed daily movement distances for the owls in our study. The mean distance between juvenile burrowing owl locations on consecutive days (n = 105) was 465.5 m (SE = 67.61 m). Other studies have documented retreat distances for burrowing owls ranging from 75 m (Fisher et al. 2004) to 200 m (Belthoff and King 2002) indicating that owls are knowledgeable regarding the habitat within this distance (Belthoff and King 2002). This buffer size allowed us to examine the land use mosaic used by dispersing juvenile burrowing owls.

We summarized land use using the 2001 National Land Cover Data (Homer et al. 2004). This data set models sixteen classes of land cover at a 30 m cell size with a 1 acre minimum mapping unit. We included the nine land use categories that fell within the study area (Appendix A). We calculated the percent area of each land use category at each sample location to describe land use composition. We then generated a land use polygon to represent the compositional availability of land use for dispersing owls within the Tucson Basin. The boundaries of this "polygon of availability" were defined *a posteriori* by a buffer with radius equal to the mean net dispersal distance (7176.6 m) centered on banding (i.e., nest) locations. Random points were generated within this polygon using the Animal Movement Extension (Beyer 2004) for ArcGIS 9.2.

Juvenile Survival. We used the staggered entry Kaplan-Meier estimator (Pollock et al. 1989) to assess weekly juvenile survival rates. When mortality could be verified, we assumed that death occurred at the midpoint between the last day that the owl was known to be alive and the date of detecting its death. Individuals, whose fates were unknown, were censored on the midpoint between the last day that the owl was located and first date that the owl was not detected using ground or aerial telemetry techniques (Winterstein et al. 2001).

RESULTS

Standardized Surveys. A total of 1,187.05 and 1,657.12 hectares were surveyed during survey efforts in 2004 and 2005, respectively. A total of 92 and 298 burrows were detected in 2004 and 2005, respectively (Table 1; Appendix B). Burrows were detected in all parts of the installation, although the majority of burrows were detected within the flight line and on AMARG (Figure 2).

Table 1. Summary of standardized burrow surveys conducted during 2004 and 2005 on Davis-Monthan Air Force Base, Tucson, Arizona, USA. Category 1 burrows were large enough to accommodate burrowing owls but exhibited no evidence of use. Category 2 burrows showed evidence of previous use, but that use was not recent (e.g., old whitewash, old pellets, cobwebs, or debris at burrow entrances). Category 3 burrows showed sign of recent use (e.g., fresh whitewash, fresh pellets, feathers, or nest ornamentation).

Survey Year	Total Burrows	Total Active Burrows	Category 1	Category 2	Category 3
2004	92	56	.	.	.
2005	298	62	174	40	84

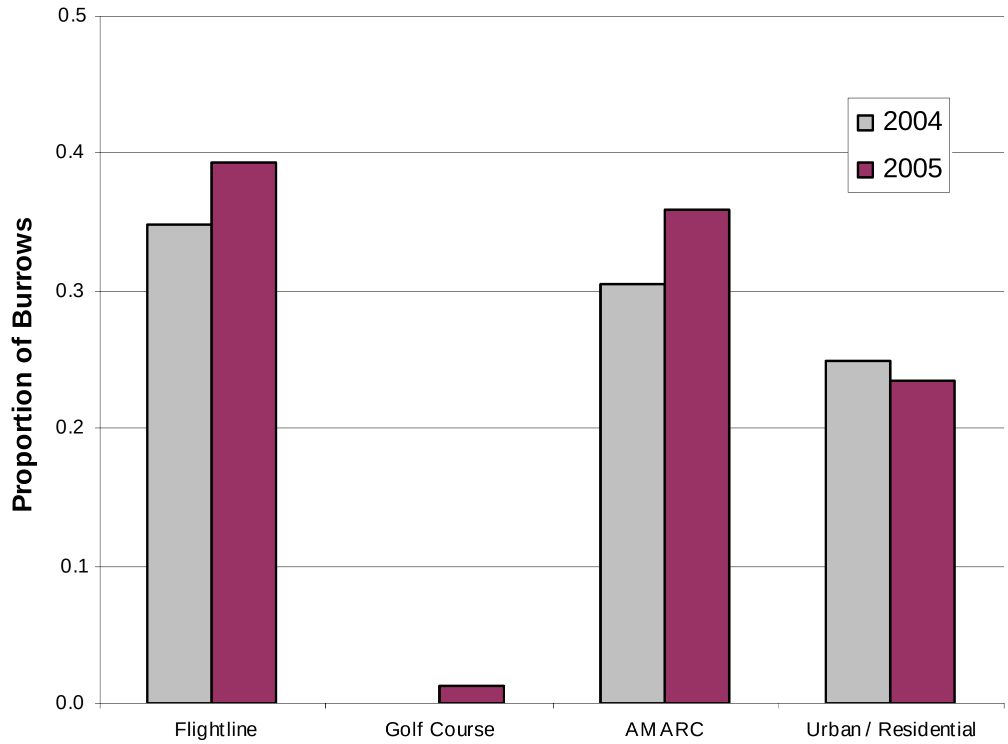


Figure 2. Proportion of burrows detected within four land use categories on Davis-Monthan Air Force Base, Tucson, Arizona, USA.

Juvenile Movement. We captured and radio-marked 18 juvenile burrowing owls between 26 July and 24 August 2004 (Table 2). However, one individual was eliminated from the sample due to its disappearance shortly after being released. Burrowing owls were monitored until 23 February 2005 over an average of 30 weeks (range: 7 to 52 weeks). The number of locations beyond 600 m for the individuals included in our analysis ranged between 10 and 111.

Table 2. Juvenile burrowing owls captured and radio-marked during 2004 in southeastern Arizona, USA. Universal Transverse Mercator coordinates were collected using North American Datum 1927. Long distance dispersal (LDD) was defined as movement in excess of 1 kilometer straight-line-distance from the natal burrow. If a juvenile died during the monitoring period, 'Died' = 1.

Location	Nest ID	UTMe	UTMn	Band ID	Weight (g)	# Locs	Weeks Monitored	LDD	Died
DMAFB	SUNG 01	511024	3561386	844-79707	127	72	39	0	0
DMAFB	CRAY 01A	511713	3561293	844-79709	141	81	46	1	0
DMAFB	AMARG 6	514715	3559744	844-79723	124	10	7	1	0
DMAFB	AMARG 10	514966	3558536	844-79803	144	11	10	1	1
DMAFB	AMARG 10	514966	3558536	844-79806	150	51	31	1	0
DMAFB	YUMA 03A	513382	3557675	844-79820	124	58	37	1	0
SANTA CRUZ	DREX 05A	499545	3557647	844-79868	133	83	39	1	1
SANTA CRUZ	DREX 01F	499356	3556973	844-79922	121	63	33	0	0
SANTA CRUZ	DREX 01F	499356	3556973	844-79923	119	52	30	0	0
SANTA CRUZ	DREX 01F	499356	3556973	844-79924	139	111	52	0	0
SANTA CRUZ	DREX N	499499	3557535	934-05003	128	49	27	1	0
DMAFB	AMARG 14	512633	3558718	934-05005	112	17	17	1	0
TEP	TEP W	505928	3559857	934-05006	130	84	47	1	0
TEP	TEP W	505928	3559857	934-05007	127	39	24	1	0
MARANA	WATER S	473329	3591670	934-05010	138	104	44	0	0
SANTA CRUZ	SANTA CRUZ	500632	3557806	934-05012	135	17	7	0	1
SANTA CRUZ	SANTA CRUZ	500632	3557806	934-05013	134	48	21	1	1

Fourteen of the 18 radio-marked juveniles dispersed more than 600 m from natal burrows during the monitoring period and eleven made post-fledgling movements of over 1 kilometer straight-line-distance from natal burrows (Table 2; Figure 3). Dispersal distance was not correlated to the length of time that individuals were monitored ($r^2 = 0.18$, $p = 0.09$). Two individuals made long-distance movements of more than 30 kilometers (Appendix C). One of these individuals traveled north and the other south; both appeared to follow the path of the Santa Cruz River. A brief description of each juvenile's movements relative to the burrow at which they were captured is provided in Appendix C.

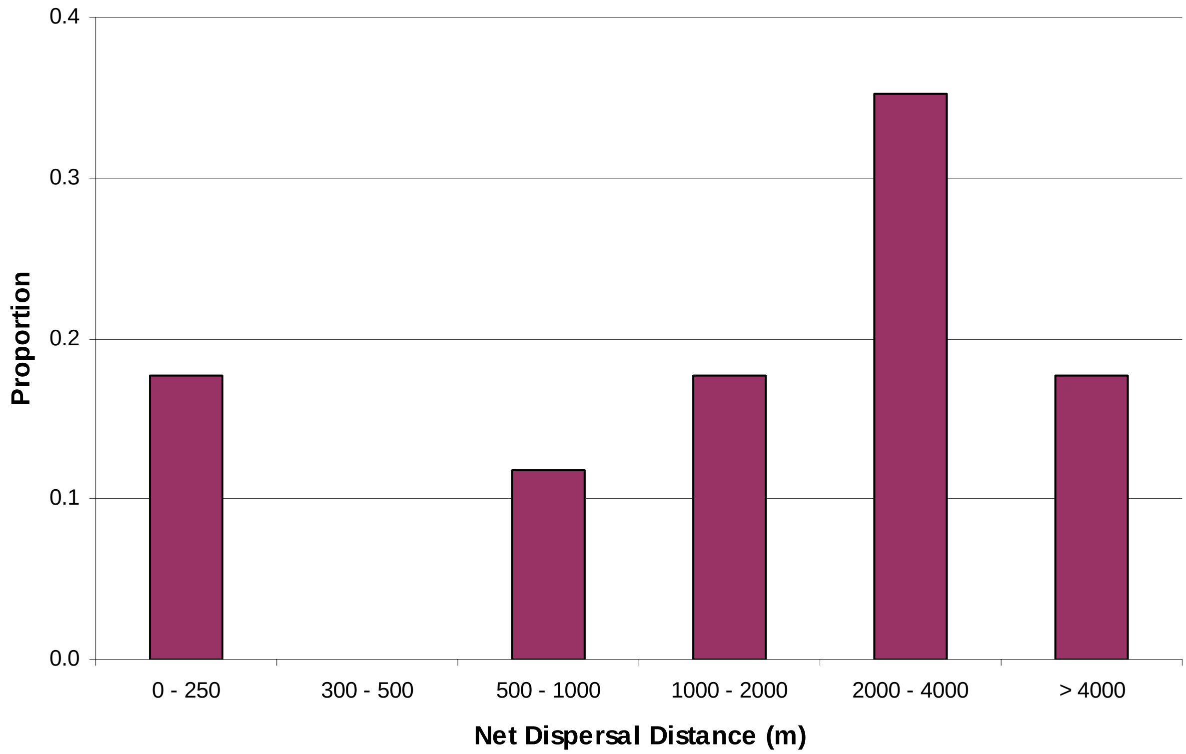


Figure 3. Distribution of juvenile burrowing owl (*Athene cunicularia*) net dispersal distance during 2004 in southeastern Arizona, USA. Data are presented as the proportion of owls that dispersed a distance within a given interval

Dispersal Habitat. Due to low sample size and lack of dependence among burrowing owl locations we were unable to make specific inferences regarding habitat use or selection during juvenile dispersal events. Qualitatively, dispersal habitat at the plot level was characterized by moderate levels of bare ground, low vegetation height, and low densities of shrubs and trees (Table 3). Shelter sites used by dispersing juveniles included: natural burrows constructed by roundtail ground squirrels (*Citellus tereticaudus*), badgers (*Taxidea taxus*), coyotes (*Canis latrans*); human structures such as cement culverts, and drain pipes; and erosion burrows along the banks of the Santa Cruz River (Figure 4).

Figure 4. Juvenile burrowing owl shelter sites used during post-fledging dispersal in 2004 in southeastern Arizona, USA. Clockwise from upper left: erosion burrow along the Santa Cruz River; coyote burrow in a mesquite bosque south of Green Valley; round-tailed ground squirrel burrow on Davis-Monthan Air Force Base; drain pipe in Tucson.

Table 3. Habitat characteristics measured at dispersal locations of juvenile burrowing owls (Athene cunicularia) captured and radio-marked during 2004 in the Tucson Basin, Tucson, Arizona, USA.

Habitat Metric	Unit	Mean	Standard Error
Bare Ground	Percent	0.509	0.0276
Vegetation Height	Meter	0.146	0.0230
Shrub Density	# / Plot	0.154	0.0236
Tree Density	# / Plot	0.004	0.0006

A minimum of 30 locations were acquired for 13 of the 18 individuals (Table 2), yielding a total of 30 unique samples for assessing land use composition. Qualitatively, dispersing juvenile burrowing owls were located in areas where scrub habitat, barren space, and herbaceous land use categories occurred in higher proportion than they occurred in the landscape (Figure 5). The proportional composition of all other land use categories was lower at dispersal locations than they occurred in the landscape. Dispersing juveniles were located within landscapes where scrub habitat dominated the landscape (mean = 0.552; SE = 0.055) and where low intensity development made up a significant proportion of the surrounding landscape (mean = 0.171; SE = 0.030). All other land use categories made up less than 10% of the surrounding landscape (Figure 5).

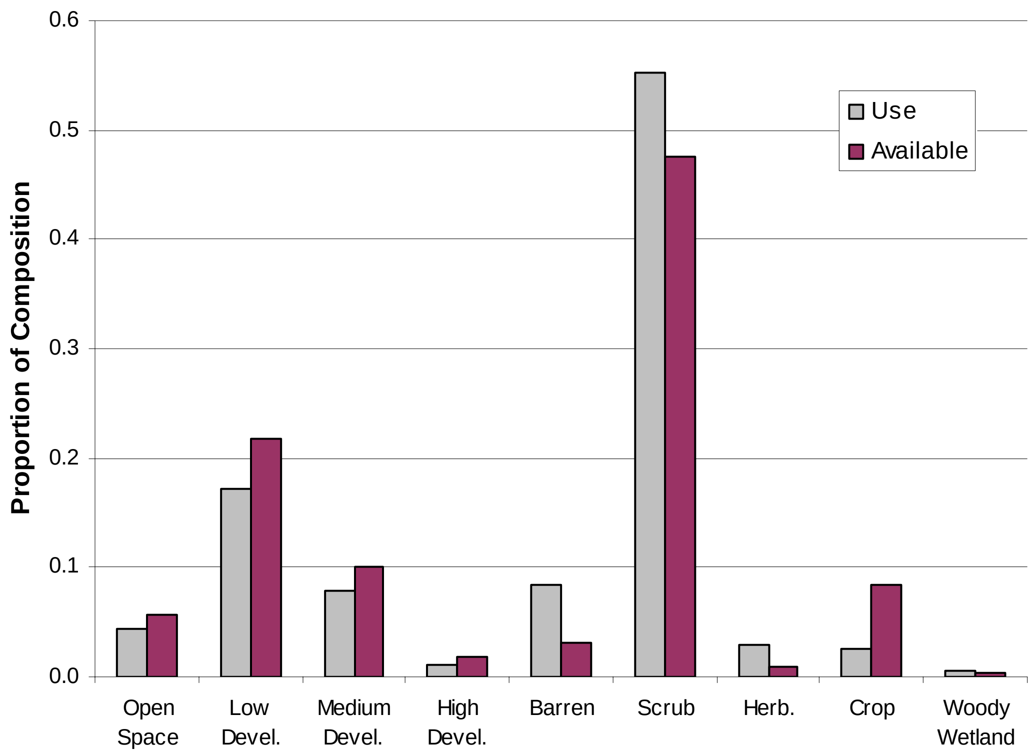


Figure 5. Proportional composition (i.e., land use composition within a 466 m radius buffer centered of individual owl locations) for 13 dispersing juvenile burrowing owls during 2004 in the Tucson, Basin, Arizona, USA.

Juvenile Survival. Four owls were recovered dead and we verified that two transmitters failed based on visual observations of those radio-marked individuals. Of the four owls that died, three showed signs of predation and the cause of the fourth was unclear. Cumulative weekly survival at the end of 30 weeks of monitoring was 70% (Figure 6).

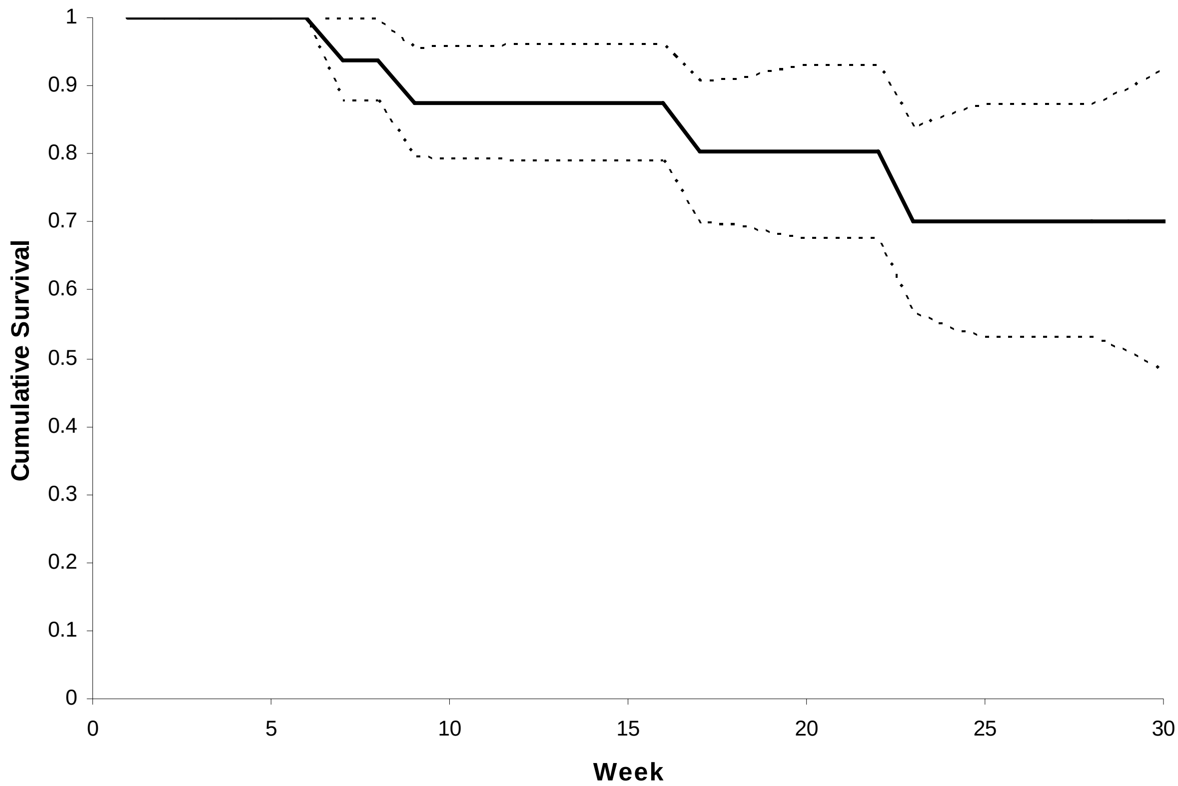


Figure 6. Kaplan-Meier survival curve for juvenile burrowing owls radio-marked during 2004 post-fledging period in the Tucson, Basin, Tucson, Arizona, USA.

DISCUSSION

Davis-Monthan Air Force Base provides a large contiguous area of breeding habitat that benefits from regular maintenance (e.g., mowing along the flight line and AMARG) and reduced levels of human disturbance. Surveys of the base have documented between 28 and 98 active nest burrows during the breeding season (Estabrook and Mannan 1998, Ellis et al. 2004, this study). Given the fact that 3 of the 7 juveniles radio-marked on the base dispersed beyond its borders suggests that Davis-Monthan may support a source population for other parts of the Tucson Basin. In addition, observations of burrowing owls banded on the base in other parts of the Tucson Basin (M. Ogonowski, *pers. comm.*, D. Grandmaison, *pers. obs.*) indicate that at least some of the resident owls in the Tucson Basin originate on the base.

Likewise, the Santa Cruz River provides a linear corridor of burrowing owl habitat that, along with Davis-Monthan Air Force Base, supports the majority of active burrows in the Tucson Basin (Estabrook and Mannan 1998). The juvenile burrowing owls that we tracked in the Santa Cruz River channel were consistently relocated along the channel and movement patterns indicate that these owls followed the channel north and south during the post-fledging period. Although this corridor is heavily influenced by surrounding land use, some of these impacts (e.g., vegetation management by Pima Flood Control) benefit burrowing owl habitat. However, plans to revegetate and soil-cement portions of the river may conflict with efforts to maintain this area as breeding habitat for burrowing owls. Long-distance dispersal events documented for two juveniles banded on Davis-Monthan Air Force Base suggest the Santa Cruz River is may also be an important geographic corridor for burrowing owl movements during migration.

Our results indicate that successful juvenile dispersal is possible given the current proportional composition of land use in the Tucson Basin. Vegetation characteristics of dispersal locations generally conformed to the classic definition of burrowing owl habitat (Haug et al. 1993, Klute et al. 2003). That is, dispersal habitat consisted of a dominance of bare ground, low vegetation height, and low shrub and tree density. However, some interesting exceptions were observed. For example, one dispersing juvenile utilized a coyote burrow in a mesquite bosque south of Green Valley (Figure 4). In addition, burrowing owls were documented in areas of undisturbed native vegetation dominated by creosote bush. These results suggest dispersing owls are more plastic in habitat use than previously believed, and undisturbed creosote flats may be important dispersal habitat.

Dispersal locations, while exhibiting classic habitat characteristics, were embedded in a landscape mosaic consisting of both undeveloped and developed land use categories. Although burrowing owls displayed an apparent preference for undeveloped land use categories, scrub habitat (shrub canopy greater than 20% of the total vegetative cover) comprised a majority of the proportional land use composition at dispersal points, while barren land and herbaceous cover were much lower. Undoubtedly, this relates to the availability of these land use categories in the landscape. However, the fact that scrub habitat occurred in higher proportion at dispersal locations than it occurred in the landscape further suggests that the classic definition of burrowing owl habitat may not be adequate for non-breeding or dispersal habitat. Developed land use types, including developed open space (e.g., parks and golf courses), comprised a lower proportion of the landscape at dispersal locations than available in the urban matrix. This suggests that while developed areas are used by dispersing owls, they may not be preferred. The variety of shelter sites provided by these areas may be the reason that burrowing owls will use them during dispersal.

Previous research in a grassland ecosystem estimated juvenile survival during the post-fledging period at approximately 55% (Todd et al. 2003) whereas survival rates in our study were estimated at 70%. In both cases, predation was considered the primary cause of juvenile mortality. The higher survival estimates for this urban dispersal study may be a result of lower predator diversity within the urban matrix and the lower density of burrowing owls within the urban matrix relative to intact grassland systems. Relatively high survival estimates for juveniles in the Tucson Basin suggest that successful dispersal within the urban matrix is possible, given the current proportional land use composition.

Reduction in the proportion of undeveloped land use types resulting from the rate of development predicted for the Tucson Basin could impede future dispersal success. Continued fragmentation and isolation of existing dispersal habitat within the Tucson Basin will most likely serve to concentrate burrowing owls, and their predators, in small, isolated patches thereby resulting in elevated mortality rates. Likewise, without adequate dispersal habitat, owls traversing the urban landscape are more likely to fall prey to human induced mortality (e.g., automobile collisions, burrow destruction, etc.). Careful planning for dispersal corridors and the strategic location of artificial burrow structures within the urban matrix may help maintain a viable population of burrowing owls in the Tucson Basin by facilitating movement, providing shelter sites, and protecting burrowing owls from predation.

LITERATURE CITED:

Aebischer, N. J., P. A. Robertson, and R. E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313-1325.

Alanen, M. 2004. Town of Marana 2003-2004 Burrowing Owl Surveys: Final Report. Arizona Game and Fish Department, Research Branch, Phoenix, Arizona.

Arizona Game and Fish Department. 2004. *Cynomys ludovicianus*. Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ.

Belthoff, J. R., and R. A. King. 2002. Nest-site characteristics of burrowing owls (*Athene cunicularia*) in the Snake River Birds of Prey Natural Conservation Area, Idaho, and applications to artificial burrow installation. Western North American Naturalist 62:112-119.

Bendire, C. E. 1892. Western burrowing owl. *In*: Bent, C.A. (ed.). U.S. National Museum Bulletin No. 170, Life Histories of North American Birds. Part 2. Government Printing Office, Washington DC, US, pp. 384-396.

Beyer, H. L. 2004. Hawth's analysis tools for ArcGIS. Available at http://www. spatialecology. com/htools.

Brown, D. E., and C. H. Lowe, Jr. 1980. Biotic communities of the American southwest (map). USDA Forest Service and University of Utah, Salt Lake City, UT, USA.

Brown, N. L. 2001. The howdy owls of Arizona: a review of the status of *Athene cunicularia*. Journal of Raptor Research 35:344-350.

Brown, N. L., and R. W. Mannan. 2002. Status of burrowing owls in Arizona. Heritage Report. Arizona Game and Fish Department, Phoenix, Arizona.

Canfield, R. H. 1941. Application of the line-intercept method in sampling range vegetation. Journal of Forestry 39:388-394.

Conway, C. J., and M. S. Ogonowski. 2005. Determining migratory status of burrowing owls in the Tucson Basin. Final Report to the Arizona Bird Conservation Initiative. Wildlife Research Report #2005-06, U. S. Geological Survey, Arizona Cooperative Fish and Wildlife Research Unit, Tucson, AZ.

Desmond, M. J., and J. A. Savidge. 1996. Factors influencing Burrowing Owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between burrowing owl and black-tailed prairie dog declines: a seven-year analysis. Journal of Wildlife Management 64:1067-1075.

Ellis, L. A., C. J. Conway, and M. S. Ogonowski. 2004. Demography of urban-nesting burrowing owls (*Athene cunicularia*) in southern Arizona. Report to the Arizona Game and Fish Department State Wildlife Grant Program, Phoenix, AZ, USA.

Estabrook, T. S., and R. W. Mannan. 1998. Urban habitat selection by burrowing owls: final report. Heritage Grand U96006. Arizona Game and Fish Department, Phoenix, AZ.

Fisher, R. J., R. G. Poulin, L. D. Todd, and R. M. Brigham. 2004. Nest stage, wind speed, and air temperature affect the nest defense behavior of burrowing owls. Canadian Journal of Zoology 82:707-713.

Grandmaison, D. D., and L. Urreiztieta. 2006. The City of Tucson HCP: Burrowing owl occupancy surveys within the City of Tucson's Avra Valley properties. Arizona Game and Fish Department, Research Branch, Phoenix, AZ.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing owl (*Speotyto cunicularia*). No. 611 in A. Poole and F. Gill, editors. The Birds of North America. The Academy of Natural Sciences, Philadelphia, Pennsylvania, USA.

Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan. 2004. Development of a 2001 National Landcover Database for the United States. Photogrammetric Engineering and Remote Sensing, Vol. 70, No. 7, July 2004, pp. 829-840.

James, P. C., and R. H. M. Espie. 1997. Current status of the burrowing owl in North America: an agency survey. Pages 3-5 *in* J.L. Lincer and K. Steenhof, editors. The Burrowing Owl: Its Biology and Management. Raptor Research Report No. 9.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Klute, D.S., L.W. Ayers, M.T. Green, W.H. Howe, S.L. Jones, J.A. Shaffer, S.R. Sheffield, and T.S. Zimmerman. 2003. Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States. U. S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R6001-2003, Washington, D.C.

Latta, M. J., C. J. Beardmore, and T. E. Corman. 1999. Arizona Partners in AMARG Bird Conservation Plan. Version 1.0. Nongame and Endangered Wildlife Program Technical Report 142. Arizona Game and Fish Department, Phoenix, Arizona.

Liberti, L., and M. W. Wyneken. 2006. City of Tucson Habitat Conservation Plan, Preliminary Draft. City of Tucson, Arizona.

NOAA Climate Prediction Center (CPC). http://www.ispe.arizona.edu/climas/forecasts/jan2006figs/09_prec_outlook.html.

Otis, D. L., and G. C. White. 1999. Autocorrelation of location estimates and the analysis of radiotracking data. Journal of Wildlife Management 63:1039-1044.

Phillips, A., J. T. Marshall, Jr., and G. Monson. 1964. T*he Birds of Arizona*. University of Arizona Press, Tucson, AZ, USA.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Priest, J. E. 1997. Age identification of nestling burrowing owls. Journal of Raptor Research 9:125-127.

Sonoran Desert Conservation Plan. 2002. http://www.co.pima.az.us/cmo/sdcp.

Thomas, D. L., and E. J. Taylor. 2006. Study designs and tests for comparing resource use and availability II. Journal of Wildlife Management 70:324-336.

Todd, L. D., R. G. Poulin, T. I. Wellicome, and R. M. Brigham. 2003. Post-fledging survival of burrowing owls in Saskatchewan. Journal of Wildlife Management 67:512-519.

U.S. Fish and Wildlife Service. 2002. Birds of Conservation Concern. U. S. Department of the Interior, Fish and Wildlife Service, Administrative Report, Arlington, Virginia.

Wellicome, T. I., and E. A. Haug. 1995. Second update of status report on the burrowing owl (SPEOTYTO CUNICULARIA) in Canada. Committee on the Status of Endangered Wildlife in Canada, Canadian Wildlife Service, Environment Canada, Ottawa, Ontario.

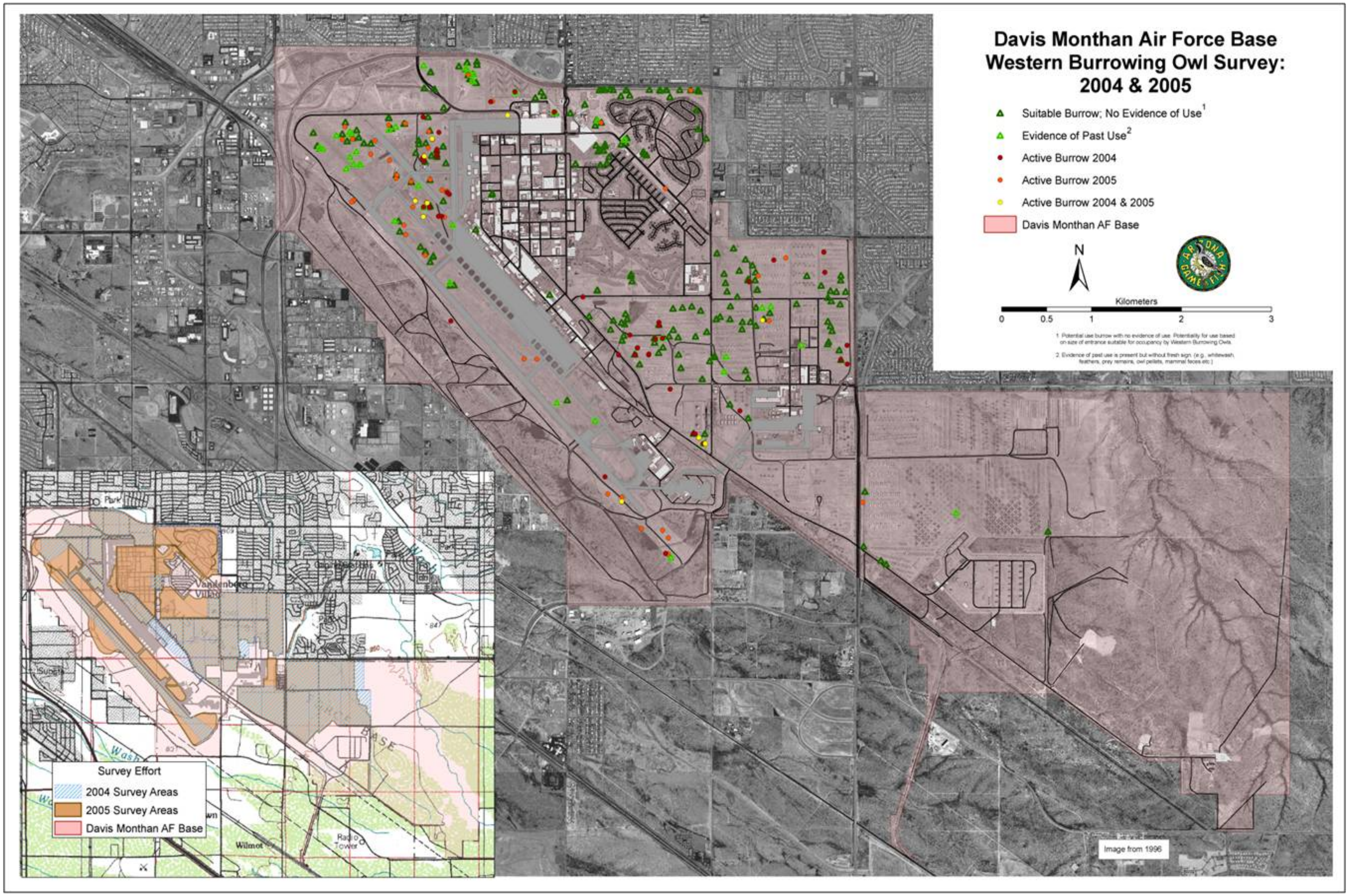
Winterstein, S. R., K. H. Pollock, and C.M. Bunck. 2001. Analysis of survival data from radiotelemetry studies. In: Millspaugh, J.J., and J.M. Marzluff (eds.). *Radio Tracking and Animal Populations*. Academic Press, San Diego, CA, USA, pp. 351-380.

Zar, J. H. 1999. *Biostatistical Analysis*. Prentice Hall, Upper Saddle River, New Jersey, USA.

Appendix A. Land use categories used to characterize juvenile burrowing owl dispersal habitat in the Tucson Basin, Arizona. Source: http://www.mrlc.gov/nlcd_definitions.asp

Land Use Category	Definition
Developed, Open Space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot-single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed, Low Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of the total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
Developed, High Intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 8-100 percent of the total cover.
Barren Land	Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally vegetation accounts for less than 15% of total cover.
Scrub/Shrub	Areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
Herbaceous	Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation.
Cultivated Crops	Areas used for the production of annual crops. Crop vegetation accounts for greater than 20% of total vegetation.
Woody Wetland	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Appendix B**.** Map of burrows detected on Davis-Monthan Air Force Base during surveys conducted in 2004 and 2005.



Appendix C. Descriptions of individual juvenile burrowing owl movement patterns.

Seven juveniles were captured and radio-marked on Davis-Monthan Air Force Base (Figure C.1). Five of these individuals remained within close proximity of the base while two made long-distance movements of more than 30 kilometers. Juvenile 844-79707 was banded at a burrow located along E. Sunglow Rd. and was subsequently detected in close proximity to a burrow located in an open area adjacent to a gravel road and a parking lot. Over the next five months, this individual would be consistently relocated near this burrow with the exception of two exploratory movements that were detected; one along a drainage 270 meters northwest of the burrow and the other near a hanger along the AMARG line, approximately 900 meters to the southwest. Juvenile 844-79709 was captured and radio-marked at a burrow located next to a gravel road and parking lot. This individual would spend the next 7 weeks making short, exploratory movements between its capture location and an area 285 meters to the northwest (Figure C.1). In early October, the juvenile was relocated in a parking lot within the urban/residential portion of the base 430 meters southwest of its capture location. Subsequent locations were made on the southern boundary of the golf course. Juvenile 844-79723 was

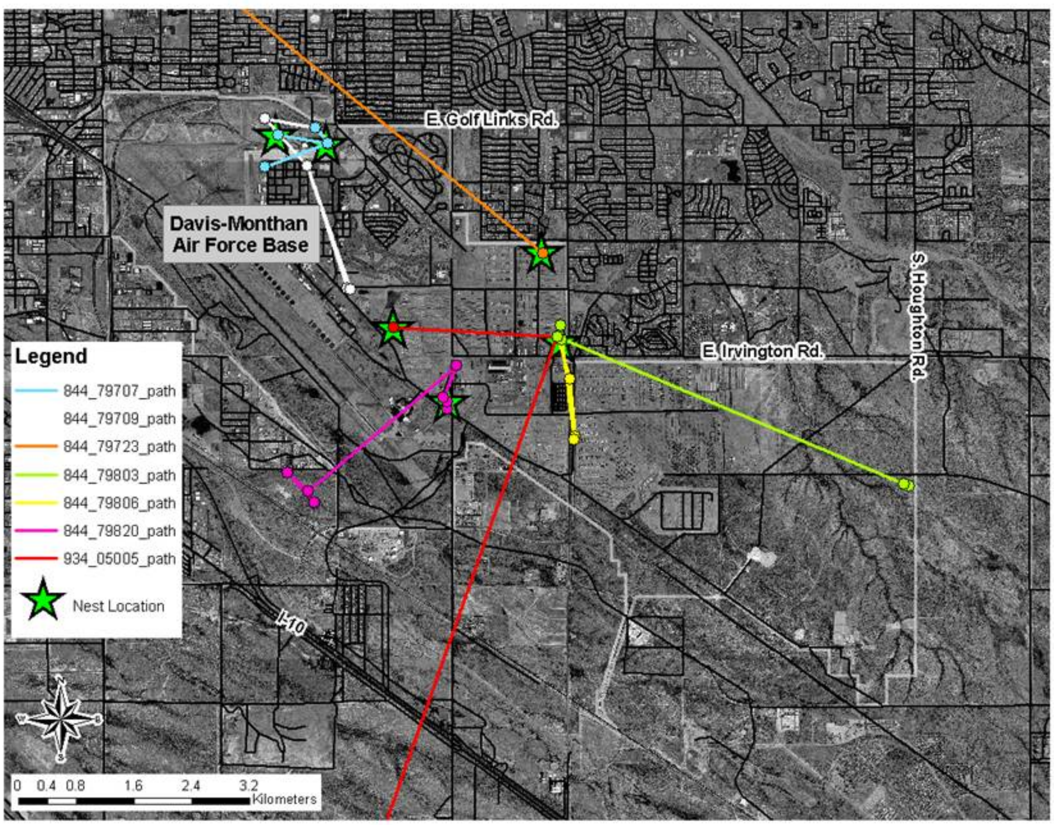


Figure C.1. Movement maps for seven juvenile burrowing owls banded at Davis-Monthan Air Force Base and radio-tracked during 2004 in Tucson, AZ, USA.

banded on AMARG in late July. This individual was relocated in close proximity to its natal burrow for two weeks, after which, it was relocated approximately 30.5 kilometers to the northwest along the Santa Cruz River (Figure C.2). After three consecutive days of tracking in

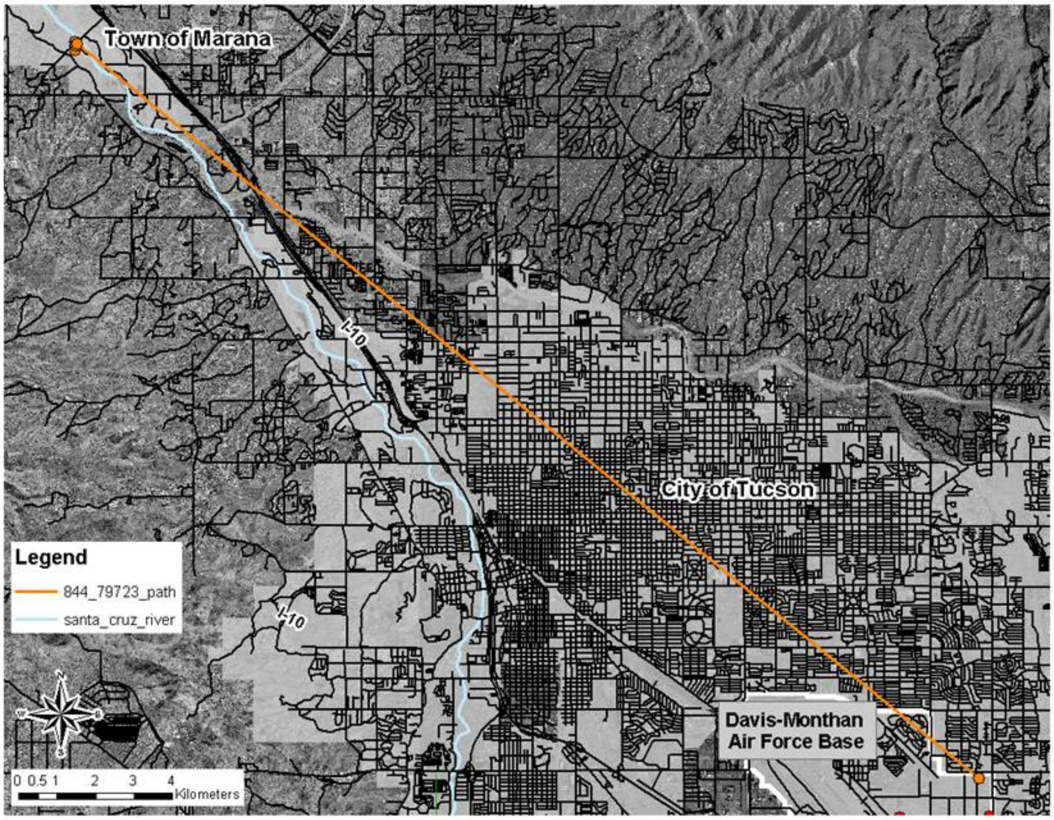


Figure C.2. Long-distance dispersal for a juvenile burrowing owl banded on Davis-Monthan Air Force Base and radio-tracked during 2004 in Tucson, AZ, USA.

this area, the individual's signal was lost and we were unable to relocate it again. Juvenile 884-79803 was banded and radio-marked on 30 July in the northwest portion of AMARG (Figure C.1). In early September, this individual moved to the eastern AMARG boundary where it utilized a ground squirrel burrow. During the next tracking session, technicians discovered this individual's transmitter hanging from a paloverde branch. Burrowing owl feathers at the base of the tree suggest predation by an avian predator. Juvenile 844-79803 was banded and radio-tagged on 30 July in the northwest portion of AMARG and remained in close proximity to its capture location, utilizing three ground squirrel burrows within 200 meters. In early November, this individual was detected making exploratory movements along a wash adjacent to S. Kolb Rd. The owl utilized two erosion burrows along this wash, and made at least one visit to its capture location before the transmitter expired. Juvenile 844-79820 was banded and radio-marked on 2 August at a nest burrow along the western boundary of AMARG. This individual remained near the natal burrow until mid-October, after which it had moved west, across the AMARG line area and into a vacant lot outside the western boundary of the base. Here, the owl was located in close proximity to a badger burrow for the remaining lifetime of the transmitter.

Juvenile 934-05005 was banded and radio-marked on 29 July at a nest burrow on AMARG. Shortly after being banded, this individual moved approximately 2.3 kilometers east to the AMARG boundary where it utilized two ground squirrel burrows until early September.

On 23 September this individual was relocated approximately 43.4 kilometers southwest of Davis-Monthan Air Force Base along the Santa Cruz River (Figure C.3). A week later, this individual was relocated an additional 23.4 kilometers to the south where it utilized a coyote burrow in a mequite bosque near the Santa Cruz River. Attempts to relocate this individual south of this location were unsuccessful.

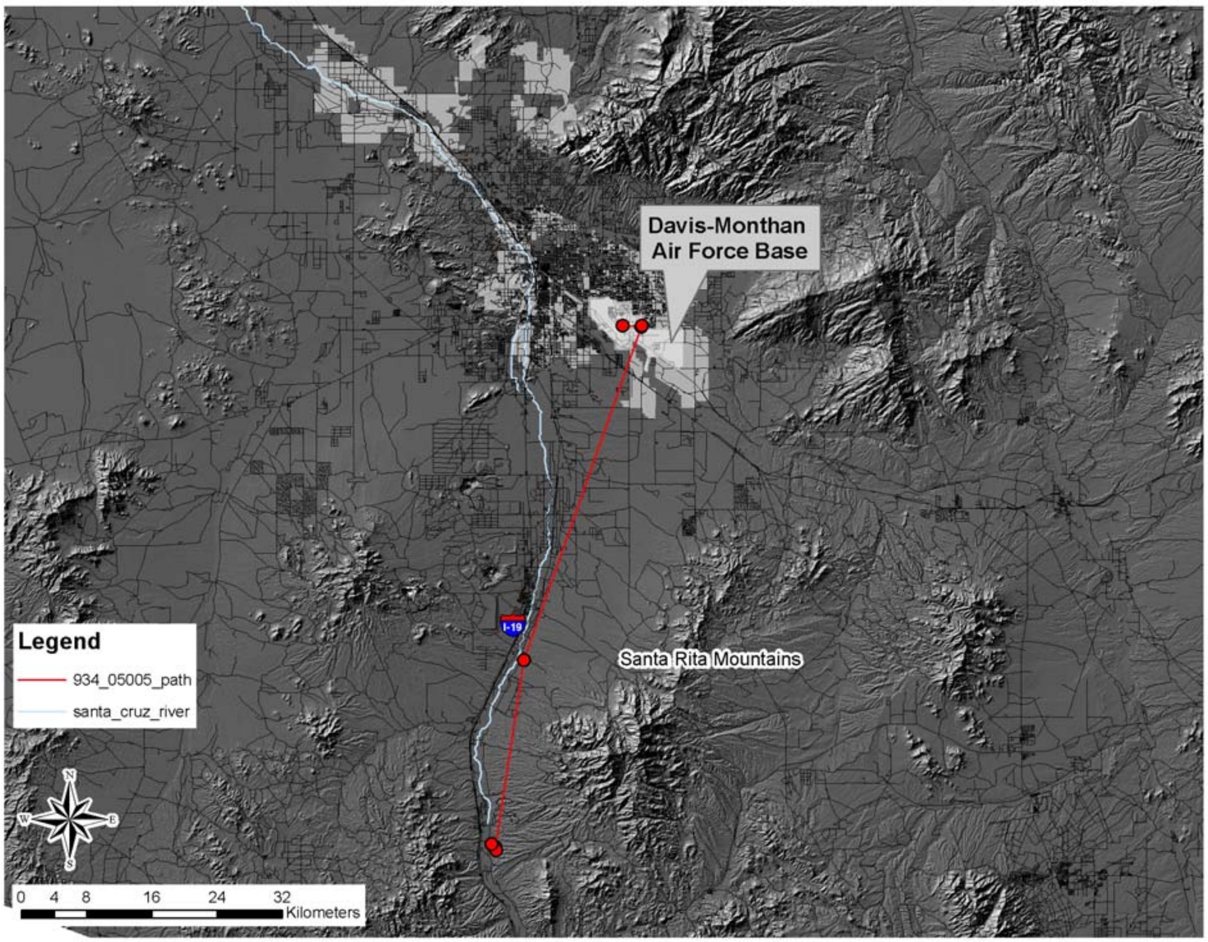


Figure C.3. Long-distance dispersal for a juvenile burrowing owl banded on Davis-Monthan Air Force Base and radio-tracked during 2004 in Tucson, AZ, USA.

Two juveniles were radio-tagged at the Tucson Electric Park. One of these individuals (934-05006) was first detected making significant movements away from the nest burrow approximately one month after it was captured. (Figure C.4). This individual spent time moving between two main activity areas over the next five months. The first activity area was centered on a natural burrow in a vacant lot approximately 1 kilometer south of the nest burrow and on the south side of the interstate (I-10). This activity area was characterized by bare ground interspersed with creosote bush (*Larea tridenta*) and triangle leaf bursage (*Ambrosia deltoidia*) encompassing approximately 0.16 square kilometers. The second activity area, roughly 2 kilometers southeast of the nest burrow fell on both sides of S. Palo Verde Rd., just north of the interstate. This area consisted primarily of industrial development and vacant lots vegetated with creosote bush, acacia (*Acacia* sp.) and mesquite (*Prosopis* sp.). On seven occasions, this juvenile was observed using drain pipes near industrial buildings for shelter.

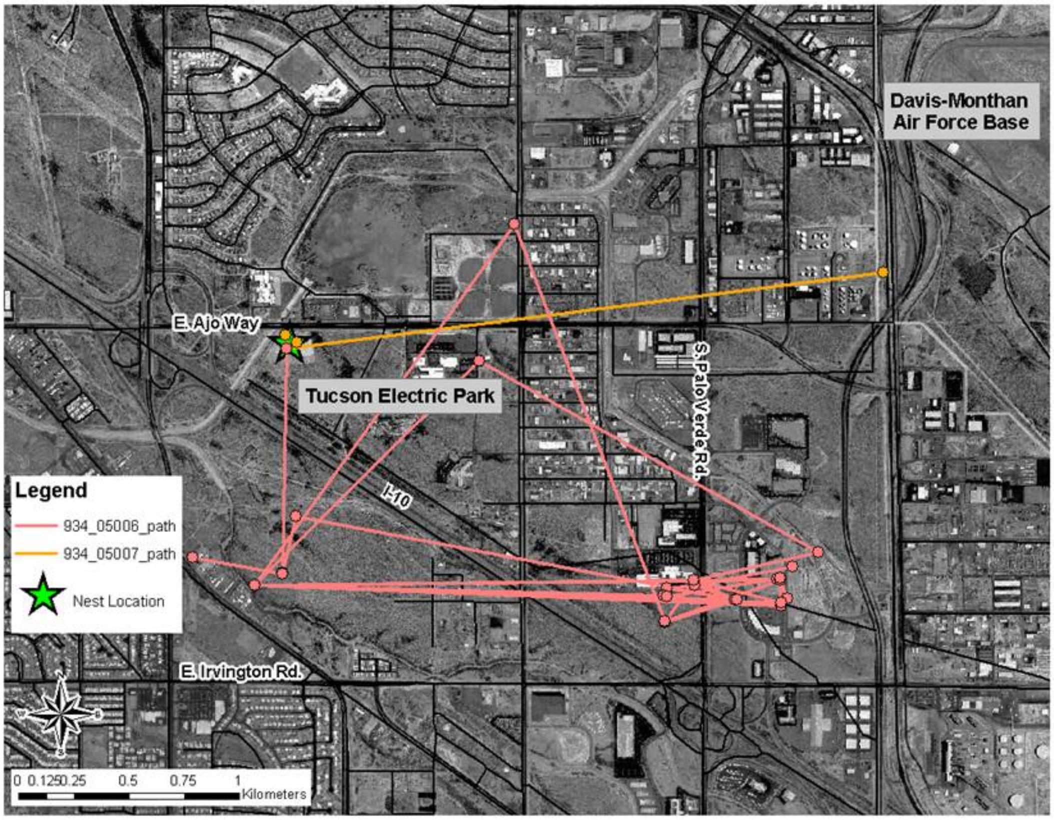


Figure C.4. Movement maps for two juvenile burrowing owls banded at the Tucson Electric Park and radio-tracked during 2004 in Tucson, AZ, USA.

The second individual (934-05007) spent August through October within 65 meters of its natal burrow. In late November this individual was detected on the western boundary of Davis-Monthan Air Force Base (Figure C.4).

Seven juveniles were captured and radio-tagged along the Santa Cruz River (Figure C.5). Movement patterns displayed by these individuals were generally linear and located along the Santa Cruz River or the west branch of the Santa Cruz River. Juvenile 844-79868 spent two months in close proximity to its natal burrow on the west branch of the Santa Cruz River. In late September this individual made its first significant movement to the main channel of the Santa Cruz River, approximately 1.5 kilometers from its natal burrow. For three months, this individual was consistently relocated at three erosion burrows along the Santa Cruz River, just south of W. Drexel Rd. until being discovered dead in a vacant lot south of a nearby residential development. The carcass was found intact, with very few feathers missing and no additional sign of injury indicating possible predation by a domestic house cat. Juvenile 844-79922 remained near its natal burrow on the west branch of the Santa Cruz River until late September when it made a 1.6 kilometer movement to the main channel where it remained in close proximity to an erosion burrow for two weeks (Figure C.5). This individual was later found approximately 3.1 kilometers to the south where it utilized a drain culvert for shelter in a vacant lot on the west bank of the Santa Cruz River. Juvenile 844-79923 was captured in a nest located inside an erosion burrow on the west branch of the Santa Cruz River. This individual continued to utilize this burrow until early November when it began moving south along the river. The last location for this owl was along the river at the W. San Xavier Rd. alignment. Juvenile 844-79924

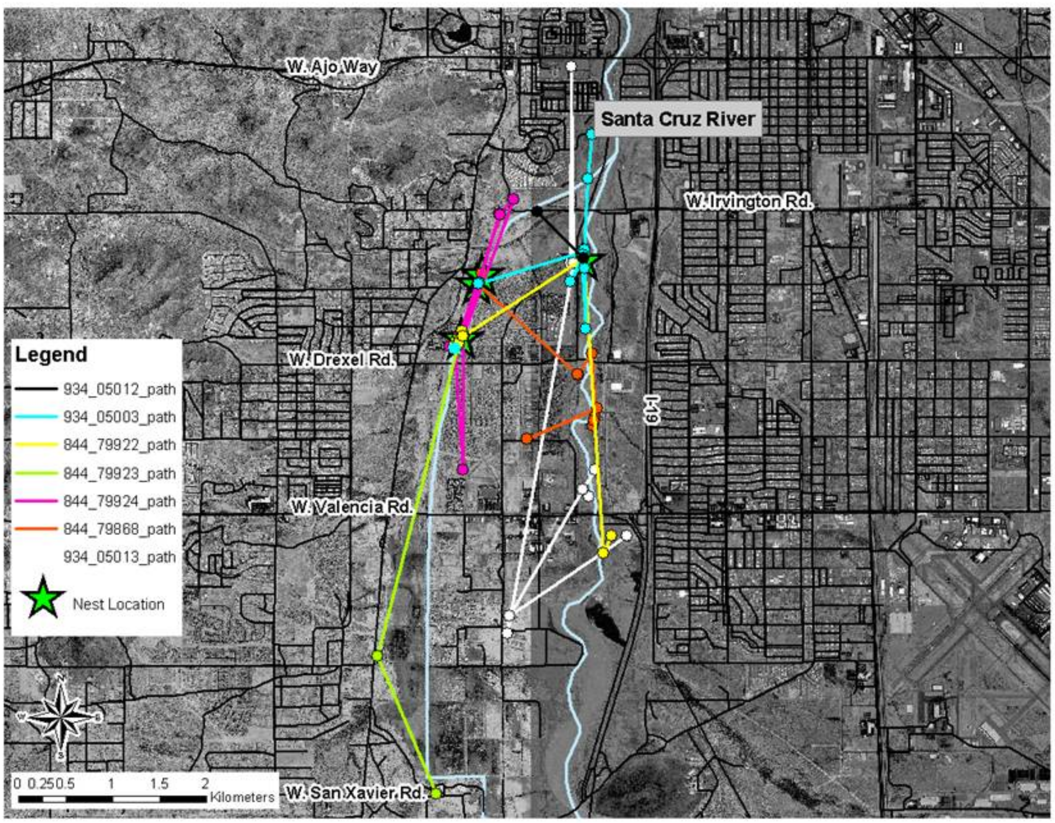


Figure C.5. Movement maps for seven juvenile burrowing owls banded along the Santa Cruz River and radio-tracked during 2004 in Tucson, AZ, USA.

generally remained in close proximity to its natal burrow with the exception of three significant exploratory movements, two to the north and one to the south (approximately 1.6, 1.5, and 1.4 kilometers from the natal burrow, respectively). In between the exploratory movements, this individual would return to its natal area, occupying several nearby erosion burrows (Figure C.5). All of this individual's movements were within the west branch of the Santa Cruz River. Juvenile 934-05003 was captured and radio-tagged in an erosion burrow on the west branch of the Santa Cruz where it remained for two weeks before moving to an erosion burrow on the main channel. It used this burrow for the next two months, making periodic exploratory trips south and southwest of this burrow. In mid-October, this individual began moving north, using a sparsely vegetation buffer area along the west bank along the Santa Cruz. Juvenile 934-05012 was consistently re-located at its natal erosion burrow for one month after which it was discovered dead in a sparsely vegetated buffer along the west branch of the Santa Cruz River, just north of W. Irvington Rd. (Figure C.5). The cause of death could not be determined for this individual. Juvenile 924-05013 was banded and radio-marked in an erosion burrow along the main channel the Santa Cruz River in late August and spent approximately two weeks in close proximity to its natal burrow before traveling 3 km south to a second erosion burrow. This individual spent the following two months occupying several erosion burrows in this southern activity area before being discovered dead along the bank of the river. Evidence suggested that this individual was killed by an avian predator.