HABITAT PATCH SIZE AND LOCAL DISTRIBUTION OF BURROWING OWLS (*ATHENE CUNICULARIA*) IN ARGENTINA

Diego Villarreal[1], Marcela Machicote[1,2], Lyn C. Branch[1,2,3], Juan José Martinez[1], & Analía Gopar[1]

[1]Facultad de Ciencias Exactas y Naturales, Universidad Nacional de La Pampa, 6300 Santa Rosa, Argentina.
[2]Department of Wildlife Ecology and Conservation, Rm. 110 Newins-Ziegler Hall, University of Florida, Gainesville, Florida, USA 32611. *E-mail:* branchl@wec.ufl.edu.

Resumen. – Tamaño de los parches de hábitat y la distribución local de las Lechucitas de las Vizcacheras (*Athene cunicularia*). – La calidad del hábitat y la estructura del paisaje son factores claves en determinar la distribución de especies animales. Las características generales del hábitat de las Lechucitas de las Vizcacheras (*Athene cunicularia*) han sido bien estudiadas, pero poco se conoce de cómo la estructura del paisaje afecta a esta especie. En otros estudios se ha sugerido que los recursos alimenticios para las lechucitas deberían ser más abundantes en parches pequeños debido a la mayor proporción de borde y a la proximidad a la vegetación densa mientras que el riesgo de predación debería ser menor en parches grandes. En este trabajo, examinamos la relación entre la ocupación de parches por las lechucitas y el tamaño de los parches producidos por el pastoreo de un roedor colonial cavador, la vizcacha (*Lagostomus maximus*, Chinchillidae), en Argentina central. Se investiga la hipótesis que el tamaño del parche influencia la disponibilidad de presas para las lechucitas comparando la abundancia de artrópodos en parches de hábitat de diferentes tamaños. También se evalúa la relación entre el tamaño del parche de hábitat y las características de su vegetación. Las colonias de vizcachas ocupadas por las lechucitas tuvieron áreas pastoreadas significativamente más pequeñas que las colonias no ocupadas. La abundancia y biomasa de artrópodos no fueron diferentes entre tamaños de parche o entre zonas pastoreadas y no pastoreadas, sugiriendo que las lechucitas no escogen parches pequeños debido a la mayor disponibilidad de artrópodos como recurso alimenticio. La asociación de las lechucitas con colonias pequeñas puede ser explicada por una relación inversa entre el tamaño del parche y la calidad del hábitat, donde la baja calidad está vinculada a una alta cobertura de arbustos. Se requieren estudios adicionales para verificar esta hipótesis y dilucidar el rol de los mamíferos en general en la provisión de hábitat para las Lechucitas de las Vizcacheras en América del Sur.

Abstract. – Habitat quality and landscape structure are key factors that determine the distributions of animals. The general characteristics of the habitat of Burrowing Owls (*Athene cunicularia*) have been well studied, but little is known about how landscape structure affects this species. Other studies have suggested that food resources for owls should be higher in small patches because of increased edge and proximity to dense vegetation, and predation risk should be lower in large patches. We examined the relationship between patch occupancy by owls and the size of habitat patches produced by grazing of colonial, burrowing rodents, plains vizcachas (*Lagostomus maximus*, Chinchillidae), in central Argentina. We investigated the hypothesis that patch size influences prey availability for owls by comparing arthropod abundance in habitat patches of different sizes. We also examined the relationship between habitat patch size and vegetation characteristics of the patch. Vizcacha colonies occupied by owls had significantly smaller grazed areas than unoccupied colonies. Abundance and biomass of arthropods were not different among patch sizes or

---

[3]*Corresponding author.*

between grazed and ungrazed areas, suggesting that owls are not choosing small patches because they have more arthropods as food resources. Association of owls with small colonies may be explained by an inverse relationship between patch size and habitat quality, with low quality linked to high shrub cover. Additional studies are required to test this hypothesis and to elucidate the role of mammals, in general, in providing habitat for Burrowing Owls in South America. *Accepted 7 July 2005.*

INTRODUCTION

Burrowing Owls (*Athene cunicularia*) occur in grasslands and shrublands from Canada to southern Argentina (Haug *et al.* 1993). Vegetation structure has been identified as a key factor defining habitat quality for these owls (Rich 1986, Plumpton & Lutz 1993a, Machicote *et al.* 2004). In most of North America and parts of South America, Burrowing Owls are strongly associated with burrowing mammals, e.g., prairie dogs (*Cynomys* spp.) in the western prairies of North America and plains vizcachas (*Lagostomus maximus*) in southern South America. Through grazing, these mammals produce the open habitat preferred by owls, characterized by low stature grasses and forbs, and they also provide burrows for owl nests (Desmond *et al.* 2000, Machicote *et al.* 2004).

Although numerous studies have characterized the habitat surrounding Burrowing Owl nests (e.g., Rich 1986, Green & Anthony 1989), much less is known about how owls are affected by landscape structure (e.g., habitat patch size, patch shape, and distance between patches; Fahrig & Merriam 1994). In some areas, owls are most abundant in large habitat patches, but in other areas owls occupy small patches and are associated with high landscape heterogeneity (Pezzolesi 1994, Biddle 1996, Warnock & James 1997, Orth & Kennedy 2001). Reduced risk of predation is assumed to be the major benefit of large open patches for owls because predators are easier to detect in large open areas and larger patches are more difficult for predators to

search (Clayton & Schmutz 1999). In some areas, owls are limited to small patches because of lack of habitat, but food availability also may contribute to the occupancy of small patches by owls (Warnock & James 1997). Burrowing Owls are opportunistic foragers. They capture arthropods during the day, and forage for arthropods and small mammals after dark (Green *et al.* 1993, Plumpton & Lutz 1993b, Thompson & Anderson 1998). Increased food availability has been proposed as a benefit of fragmented habitats and small patches because of the proximity of dense vegetation and habitat edges; however, this food availability hypothesis has not been evaluated extensively (Haug & Oliphant 1990, Biddle 1996, Orth & Kennedy 2001). In this paper, we examine habitat patch size, arthropod abundance, and vegetation characteristics in mammal colonies occupied by Burrowing Owls in central Argentina. In general, the relationship between burrowing owls and burrowing mammals in South America has received little attention, even though these mammals may provide the critical habitat for owls in some regions (Machicote *et al.* 2004).

In the semiarid shrublands of central Argentina, Burrowing Owls reside most frequently in habitat patches with open understory created by grazing of the plains vizcacha, a large colonial, burrowing rodent (Machicote *et al.* 2004). Like prairie dogs, vizcachas are considered an agricultural and range pest and have been exterminated over vast parts of their former range (southern Paraguay through central Argentina, Jackson

et al. 1996), potentially reducing the availability of Burrowing Owl habitat. Despite the close association between owls and vizcachas and the potential for declining habitat for owls, many vizcacha colonies are not occupied by owls. In our study area, occupation of vizcacha colonies by owls is not limited by colony isolation (Machicote *et al.* 2004). The role of other components of landscape structure in influencing occupancy patterns is unknown.

In this study, we examine the relationship between the presence of owls and habitat patch size, defined as the size of the grazed area of the vizcacha colony. The grazed area at a vizcacha colony comprises a central patch within the landscape mosaic used by a pair of owls, but not the entire foraging area of the owls. Because burrowing owls are central place foragers, energetic costs of foraging increase and time spent foraging decreases with distance from the nest (Gervais *et al.* 2003). Thus, resources in the habitat patch surrounding the nest site may be particularly important. Also, areas with open understory are considered preferred habitat for owls (Green & Anthony 1989, Clayton and Schmutz 1999). In this landscape dominated by dense bunchgrass and shrubs, vizcacha colonies generally represent the only natural areas with open understory, except for burned areas that rapidly return to dense bunch grasses (Machicote *et al.* 2004).

We examine two hypotheses that may explain an observed relationship between the distribution of Burrowing Owls and habitat patch size: 1) abundance of arthropods, which are numerically important as prey for owls (Haug *et al.* 1993, Rosenberg & Haley 2004), varies with patch size; 2) patch size is correlated with the vegetation structure, which is known to influence habitat selection in Burrowing Owls (Green & Anthony 1989, Clayton and Schmutz 1999, Machicote *et al.* 2004). We compared the arthropod abundance in

patches of different sizes and also compared the arthropod abundance in open areas created by vizcachas with that in adjacent ungrazed areas with tall, dense grass. No data are published on Burrowing Owl diets from shrublands of central Argentina. However, arthropods are numerically dominant prey in diets of Burrowing Owls in a wide variety of habitats (Haug *et al.* 1993, Bellocq 1997, York et al. 2002, Rosenberg & Haley 2004) and preliminary data suggest that this may be the case for our site (Romero & Machicote unpubl.), though small mammals often comprise more biomass (Jaksic & Marti 1981, Silva *et al.* 1995). Arthropods may be particularly important during the breeding season when owls are feeding near the nest and energetic demands are high. Second, we examine the relationship between habitat patch size and vegetation characteristics in the patches. A multivariate habitat model developed for Burrowing Owls in our study area indicates that there is a negative association between the presence of owls in vizcacha colonies and shrub size, shrub density, and cover and height of perennial grasses at the colony (Machicote *et al.* 2004). If patch size is correlated with these variables, then vegetation structure could contribute to any association detected between occupancy patterns by owls and patch size.

METHODS

Study area. The study was conducted from May 2000 to February 2001 on Los Valles Ranch (7500 ha, 39°11'S, 63°42' W), a typical cattle ranch in the semiarid scrub of La Pampa Province, Argentina. The study area covered approximately 3000 ha. Annual precipitation in this area is 480 ± 23 mm (mean ± SE, 1971–1998, Río Colorado Meteorological Station located 60 km W of Los Valles, unpubl.). Rainfall during our study was above average (annual total for 2000, 556 mm). Vegetation is dominated by creosote bush (*Larrea*

divaricata) with mixed shrub patches (e.g., *Condalia microphylla, Geoffroea decorticans,* and *Prosopis flexuosa*) and an understory of bunch grasses (e.g., *Stipa* spp.) and forbs (mean shrub density $\pm$ SE = 994 $\pm$ 111 shrubs/ha, shrub height = 176 $\pm$ 10 cm, n = 25 0.04-ha plots, Machicote *et al.* 2004).

Vizcacha colonies. Each vizcacha colony is comprised of a principal burrow system (approximately 150 m^2) occupied by a kin group of vizcachas (c. 10–30 animals), an intensively grazed area surrounding the burrow system, and satellite burrows scattered throughout the grazed area, which are used for temporary shelter by vizcachas. The grazed areas surrounding vizcacha burrows form distinct patches on the landscape, characterized by low-growing forbs, short grasses and bare ground, imbedded in a landscape matrix with tall, dense bunch grass and shrubs (Branch *et al.* 1996). Satellite burrows are the primary nest sites for Burrowing Owls in our study area, though owls occasionally nest in burrows of other species such as the hairy armadillo (*Chaetophractus villosus*) (Machicote *et al.* 2004). Typically only one pair of owls resides in a vizcacha colony. Home ranges of owls have not been examined in our study area, but we have observed owls foraging in vizcacha colonies and in the surrounding landscape. Burrowing Owls are non-migratory in this area, and pairs occupy the same territory throughout the year (Machicote *et al.* 2004).

Surveys for Burrowing Owls and assessment of landscape structure. We searched the study area for vizcacha colonies and owls by traversing the area on foot and horseback. A vizcacha colony was classified as occupied by owls when a pair was seen at least five times in the area and a burrow showed signs that a breeding attempt occurred (Millsap & Bear 2000). In order to examine the relationship between patch size and presence of Burrowing Owls, we estimated the size of the patch modified by vizcacha grazing at each colony by measuring the distance from the center of the principal burrow system to the edge of the grazed area along three random compass bearings. The average of these radii was used to estimate patch size as a circle. We performed log transformations to obtain normally distributed data (Shapiro/Wilk test, Zar 1984) and compared mean patch sizes of vizcacha colonies that were occupied and unoccupied by owls using a t-test adjusted for inequality of variances (SPSS 1999).

Arthropod biomass and abundance. We assessed the abundance (number of individuals/trap-day) and biomass (mg dry weight/trap-day) of arthropods in the grazed patches of vizcacha colonies (size range, 0.02–1.22 ha, mean $\pm$ SE = 0.30 $\pm$ 0.19 ha, n = 5) and in adjacent ungrazed areas at these colonies, which were chosen at random from colony sites with Burrowing Owls (n = 14). Initial sampling of vegetation with sweep nets produced few insects. Therefore, we focused our sampling on pitfall trapping. At each site, we placed pitfall traps at 20 random locations within a 10 x 10-m plot located in the area grazed by vizcachas and in a similar plot in the ungrazed area. Plots in grazed areas were established along randomly chosen bearings and at randomly chosen distances between 5–25 m from the principal burrows. Plots in ungrazed areas were placed along similar random bearings at distances randomly chosen between 5–25 m beyond the edge of the open patches created by vizcachas. Each trap consisted of a 1-liter plastic cup, leveled with the ground, and filled with brine as preservative (Braid & Panizzi 1994).

We sampled arthropods during seven trap sessions between late August and early December 2000. This period encompasses about 9 weeks prior to initiation of nesting by

owls, incubation, and the first 3 weeks of feeding chicks. Traps remained open continuously for 5 days during each session and insects were collected at the end of the sampling period. All five colonies were sampled simultaneously. During each session, some traps were destroyed by vizcachas and cows and had to be replaced. As a result, the mean number of trap-days ($\pm$ SE) was 549 $\pm$ 25 for each zone (grazed or ungrazed) at a colony over the seven sessions.

Arthropods were identified at the taxonomic level of order except larvae, which were combined into a single category. Ants and other insects less than 3 mm in length were excluded from the study. Samples were dried and weighed, and samples from each vizcacha colony were pooled for the entire period of study for analysis. Data were normally distributed (Shapiro/Wilk test, SPSS 1999). Arthropod biomass and abundance were compared between grazed and ungrazed areas using paired t-tests, and Pearson's correlations were used to examine the relationships between these variables and patch size. All statistical analyses were performed using SPSS (SPSS 1999). Data are presented as means $\pm$ SE.

Vegetation. Vegetation was sampled using the circular sample-plot method with one 0.04-ha plot at each vizcacha colony (James & Shugart 1970, see Machicote *et al.* 2004 for details). Plots were centered on the owl nest in vizcacha colonies occupied by owls (n = 14) and on a randomly chosen satellite burrow in colonies without owls (n = 24). We placed two 22.5-m transects in random directions within the plot, estimated height and cover of perennial grasses, cover of perennial herbs, cover of annual herbs and grasses, and cover of litter and bare soil every 2 m along the transects, and averaged all measures to obtain a single value for each variable for each colony. We also counted all shrubs with at least one stem

inside a 1.8-m strip along each transect, averaged counts for the two transects, and calculated shrub density. Mean shrub height for each plot was determined from measurements of heights of 20 shrubs chosen randomly in each 0.04-ha plot. Correlations between habitat variables were calculated using Pearson's correlation coefficient, and one of each pair of highly correlated variables (r $\geq$ 0.7) was removed from further analyses (Machicote *et al.* 2004). Univariate logistic regression models were constructed for remaining variables to test whether each variable was associated with selection of vizcacha colonies by burrowing owls and significant variables were entered into a multifactor logistic regression model (Neter *et al.* 1989). The model that included percent cover and height of perennial grasses and height and density of shrubs resulted in the model with the best fit with the fewest parameters (see Machicote *et al.* 2004 for details). All four variables were related negatively to the presence of owls. Here, we examine correlations between these four variables and patch size using Pearson's correlations following arcsine transformations of grass cover and square-root transformations of grass height and shrub data.

RESULTS

We located 38 active vizcacha colonies in the study area. Fourteen were occupied by owls. Vizcacha colonies with Burrowing Owl nests had significantly smaller patch sizes (0.18 $\pm$ 0.07 ha) than those without owl nests (0.60 $\pm$ 0.11 ha; t = 3.32, df = 35, *P* = 0.002).

We captured 9296 arthropods from 12 orders in pitfall traps (Table 1). Coleoptera were the most abundant arthropods captured, accounting for 76.7 $\pm$ 1.8% of the individuals and 56.6 $\pm$ 6.8% of the biomass in grazed areas, and 61.1 $\pm$ 6.9% of the individuals and 46.6 $\pm$ 7.9% of the biomass in ungrazed areas.

TABLE 1. Abundance (number of individuals/100 trap-days) and biomass (mg dry weight/100 trap-days) of arthropods captured in 1-liter pitfall traps in areas grazed by vizcachas and in adjacent ungrazed areas. Data are grand means ($\pm$ SE) for five vizcacha colonies and adjacent areas.

Groups	Grazed areas		Ungrazed areas	
	Abundance	Biomass	Abundance	Biomass
Arachnids[1]	6.94 (1.24)	0.08 (0.03)	9.89 (1.25)	0.14 (0.05)
Coleoptera	146.22 (16.42)	1.74 (0.39)	108.03 (58.32)	1.89 (0.51)
Diptera	2.67 (0.57)	0.02 (0.007)	1.08 (0.54)	0.16 (0.009)
Heteroptera	4.35 (2.34)	0.04 (0.02)	2.14 (0.48)	0.02 (0.004)
Hymenoptera	6.25 (2.97)	0.07 (0.008)	5.69 (1.33)	0.08 (0.19)
Lepidoptera	2.45 (0.67)	0.05 (0.01)	0.35 (0.15)	0.006 (0.003)
Orthopteroids[2]	6.27 (1.37)	0.48 (0.15)	8.33 (0.59)	0.92 (0.36)
Larvae[3]	13.92 (1.65)	0.41 (0.13)	14.83 (3.99)	0.80 (0.29)
TOTAL	189.07 (17.71)	2.89 (0.47)	150.34 (60.22)	4.01 (0.51)

[1]Includes Araneae, Opiliones, and Scorpiones.

[2]Includes Blattaria, Mantodea, Orthoptera, and Phasmida.

[3]Includes Coleoptera and Lepidoptera larvae.

Patch size did not have a significant influence on abundance or biomass of arthropods (all species combined or for Coleoptera only, n = 5, all $P > 0.70$). Also, abundance and biomass of arthropods were not significantly different between patches grazed by vizcachas and ungrazed areas surrounding vizcacha colonies (t = 0.55, df = 4, $P = 0.61$; t = 1.28, df = 4, $P = 0.27$, respectively, Table 1). Similarly, abundance and biomass of Coleoptera were not significantly different between these areas (t = 0.65, df = 4, $P = 0.55$; t = 0.27, df = 4, $P = 0.79$, respectively).

The size of grazed patches at vizcacha colonies (n = 38) was correlated positively with shrub height (mean shrub height $\pm$ SE = 189 $\pm$ 12 cm, r = 0.48, $P < 0.003$) and shrub density (mean shrub density $\pm$ SE = 500 $\pm$ 63 shrubs/ha, r = 0.41, $P < 0.01$). Patch size and cover of perennial grasses were not related strongly (mean grass cover $\pm$ SE = 5 $\pm$ 1.6%, r = -0.28, $P = 0.08$) and patch size and height of perennial grasses were not correlated (mean grass height $\pm$ SE = 32.8 $\pm$ 5.0 cm, r = 0.07, $P = 0.81$).

DISCUSSION

In our study area, Burrowing Owls nest in small patches relative to the range of patch sizes produced by vizcacha grazing. Similarly, in Saskatchewan, Canada, Burrowing Owls nest in small open patches but forage in areas with more dense herbaceous vegetation (Haug & Oliphant 1990). In large prairie dog colonies, Burrowing Owls nest in clusters located at the colony edge (Desmond *et al.* 1995). Numerous studies have shown that insects and rodents are more abundant in areas with dense cover and along habitat edges (Webb & Hopkins 1984, Ellis *et al.* 1997). Occupancy of small patches by owls could represent a trade off between the need for open habitat for nesting and access to dense vegetation for foraging. However, at our site, we did not detect differences in the abundance and biomass of arthropods between open patches produced by vizcacha grazing and ungrazed areas surrounding these patches, and these variables were not related to patch size. Thus, our data do not support

the hypothesis that small patches provide more abundant food resources than do large patches. However, we did not sample rodents, which generally are less numerous in the diet of Burrowing Owls than insects but often constitute a greater proportion of the biomass (Green *et al.* 1993, Silva *et al.* 1995, Thompson & Anderson 1998). Also, we only sampled insects during spring and summer, but this sampling incorporated a period of high energetic demand and restricted foraging when owls were feeding young. Food resources that we did not measure could influence the selection of habitat patches by owls and merit further investigation.

An alternative explanation for the association of owls with small patches is that patch size and habitat quality are related inversely (Warnock & James 1997). Owls occupy vizcacha colonies characterized by short shrubs (< 180 cm height; range in sample plots, 50–310 cm) and low shrub density (< 575 shrubs/ha; range in sample plots, 0–1450 shrubs/ha, Machicote *et al.* 2004). In our study area, size of the grazed area in a vizcacha colony is positively correlated with the height and density of shrubs. Colonies with large grazed areas may not represent habitat patches for owls. Association of Burrowing Owls and vizcacha colonies with small grazed patches may result from habitat selection for areas without large shrubs, rather than selection for small grazed patches. In North America, burrowing owls avoid dense shrub habitat for foraging and encroachment of woody plants is detrimental to owl populations (Rich 1986, Uhmann *et al.* 2001). Differences in vegetation structure with patch size also may influence predation risk. In grasslands, large open patches created by grazing may facilitate detection of predators. In contrast, in vizcacha colonies with large grazed areas, the understory is open but the shrub canopy often is tall and dense. Owls may be more effective at detecting predators in small

grazed patches with little woody vegetation than in large grazed patches with abundant large shrubs. Predation on burrowing owls has not been studied in Argentina and, thus, the major predators at different life stages of owls have not been identified. However, the predator community in our study area is diverse and predators are abundant, including four species of native cats (*Herpailurus yaguarondi*, *Oncifelis colocolo*, *Oncifelis geoffroyi*, and *Puma concolor*), pampas fox (*Pseudalopex gymnocercus*), grison (*Galictis cuja*), and numerous snakes and raptors that could take owls.

In conclusion, our study shows that Burrowing Owls nest in small vizcacha colonies and suggests that selection of small habitat patches may be related to factors other than increased abundance of arthropod prey. We hypothesize that the presence of owls in small colonies is explained by higher habitat quality linked to low shrub cover in these patches, but further research is needed to test this hypothesis and elucidate underlying mechanisms, as well as to fully test the food hypothesis. Throughout much of North America, populations of Burrowing Owls are in serious decline (Holroyd *et al.* 2001). Threats include loss, fragmentation, and degradation of habitat and reduction in mammal populations that provide open habitat and burrows for owls (Haug *et al.* 1993). The conservation status of Burrowing Owls is unknown in South America, but many of the same factors are likely to impact owl populations (Bellocq 1997). Recent studies with mitochondrial DNA suggest that this owl may be a different species than the North American Burrowing Owl and thus may merit more conservation attention (Desmond *et al.* 2001). As Burrowing Owl habitat continues to decline in North and South America, studies that integrate measures of habitat quality and landscape structure will become increasingly important for understanding factors that influence dynamics and long-term persistence of these owls (Clay-

ton & Schmutz 1999, Orth & Kennedy 2001). In addition, the role of mammals in providing habitat for Burrowing Owls in South America deserves more attention.

ACKNOWLEDGMENTS

REFERENCES

Bellocq, M. I. 1997. Ecology of the Burrowing Owl in agroecosystems of central Argentina. J. Raptor Res. Rep. 9: 52–57.

Biddle, P. B. 1996. Do landuse patterns influence Burrowing Owl nest site selection in northeastern Colorado? M.Sc. thesis, Colorado State Univ., Fort Collins, Colorado.

Braid, M. R., & K. T. C. Panizzi. 1994. The pitfall trap: a review of types and their uses for invertebrate collection. J. Ala. Acad. Sci. 65: 171–193.

Branch, L. C., D. Villarreal, J. L. Hierro, & K. Portier. 1996. Effects of local extinctions of the plains vizcacha (*Lagostomus maximus*) on vegetation of the semi-arid scrub of central Argentina. Oecologia 106: 389–399.

Clayton, K. M., & J. K. Schmutz. 1999. Is the decline of Burrowing Owls *Speotyto cunicularia* in prairie Canada linked to changes in Great Plains ecosystems? Bird Conserv. Int. 9: 163–185.

Desmond, M. J., J. A. Savidge, & T. F. Seibert. 1995. Spatial patterns of Burrowing Owl (*Speotyto cunicularia*) nests in black-tailed prairie dog (*Cynomys ludovicianus*) towns. Can. J. Zool. 73: 1375–1379.

Desmond, M. J., J. A. Savidge, & K. M. Eskridge. 2000. Correlations between Burrowing Owl and black-tailed prairie dog declines: a 7-year analysis. J. Wildl. Manage. 64: 1067–1075.

Desmond, M. J., T. J. Parson, T. O. Power, & J. A. Savidge. 2001. An initial examination of mitochondrial DNA structure in Burrowing Owl populations. J. Raptor Res. 35: 274–281.

Ellis, B. A., J. N. Mills, J. E. Childs, M. C. Muzzini, K. T. McKee, Jr., D. A. Enria, & G. E. Glass. 1997. Structure and floristics of habitats associated with five rodent species in an agroecosystem in Central Argentina. J. Zool. 243: 437–460.

Fahrig, L., & G. Merriam. 1994. Conservation of fragmented populations. Conserv. Biol. 8: 50–59.

Gervais, J. A., D. K. Rosenberg, & R. G. Anthony. 2003. Space use and pesticide exposure risk of male Burrowing Owls in an agricultural landscape. J. Wildl. Manage. 67: 155–164.

Green, G. A., & R. G. Anthony. 1989. Nesting success and habitat relationships of Burrowing Owls in the Columbian Basin, Oregon. Condor 91: 347–354.

Green, G. A., R. E. Fitzner, R. G. Anthony, & L. E. Rodgers. 1993. Comparative diets of Burrowing Owls in Oregon and Washington. Northwest Sci. 67: 88–93.

Haug, E. A., & L. W. Oliphant. 1990. Movements, activity patterns, and habitat use of Burrowing Owls in Saskatchewan. J. Wildl. Manage. 54: 27–35.

Haug, E. A., B. A. Millsap, & M. S. Martell. 1993. Burrowing Owls (*Speotyto cunicularia*). *In* Poole, A., & F. Gill (eds.). The birds of North America, No. 61. The Birds of North America, Inc., Philadelphia, Pennsylvania.

Holroyd, G. L., R. Rodriguez-Estrella, & S. R. Sheffield. 2001. Conservation of the Burrowing Owl in western North America: issues, challenges, and recommendations. J. Raptor Res. 35: 399–407.

Jackson, J. E., L. C. Branch, & D. Villarreal. 1996. *Lagostomus maximus.* Mammalian Species No. 543, American Society of Mammalogists,

Lawrence, Kansas.

Jaksic, F. M., & C. D. Marti. 1981. Trophic ecology of *Athene* owls in mediterranean-type ecosystems: a comparative analysis. Can. J. Zool. 59: 2331–2340.

James, F. C., & Shugart, H. H. 1970. A quantitative method of habitat description. Audubon Field Notes 24: 727–736.

Machicote, M., L. C. Branch, & D. Villarreal. 2004. Burrowing Owls and burrowing mammals: are ecosystem engineers interchangeable as facilitators? Oikos 106: 527–535.

Millsap, B. A., & C. Bear. 2000. Density and reproduction of Burrowing Owls along an urban development gradient. J. Wildl. Manage. 64: 33–41.

Neter, J., W. Wasserman, & M. H. Kutner. 1989. Applied linear regression models. Irwin, Homewood, Illinois.

Orth, P. B., & P. L. Kennedy. 2001. Do land-use patterns influence nest-site selection by Burrowing Owls (*Athene cunicularia hypugaea*) in northeastern Colorado? Can. J. Zool. 79: 1038–1045.

Pezzolesi, L. S. W. 1994. The western Burrowing Owl: increasing prairie dog abundance, foraging theory, and nest site fidelity. M.Sc. thesis, Texas Tech Univ., Lubbock, Texas.

Plumpton, D. L., & R. S. Lutz. 1993a. Nesting habitat use by Burrowing Owls in Colorado. J. Raptor Res. 27: 175–179.

Plumpton, D. L., & R. S. Lutz. 1993b. Prey selection and food habits of Burrowing Owls in Colorado. Great Basin Nat. 53: 299–304.

Rich, T. 1986. Habitat and nest-site selection by Burrowing Owls in the sagebrush steppe of Idaho. J. Wildl. Manage. 50: 548–555.

Rosenberg, D. K., & K. L. Haley. 2004. The ecology of Burrowing Owls in the agroecosystem of the Imperial Valley, California. Stud. Avian Biol. 27: 120–135.

Silva, S. I., I. Lazo, E. Silva-Aranguiz, F. M. Jaksic, P. L. Meserve, & J. R. Gutiérrez. 1995. Numerical and functional response of Burrowing Owls to long-term mammal fluctuations in Chile. J. Raptor Res. 29: 250–255.

SPSS. 1999. SPSS: for Windows, version 10.05. SPSS, Inc., Chicago, Illinois.

Thompson, C. D., & S. H. Anderson. 1998. Foraging behavior and food habits of Burrowing Owls in Wyoming. Prairie Nat. 20: 23–28.

Uhmann, T. V., N. C. Kenkel, & R. K. Baydack. 2001. Development of a habitat suitability index model for Burrowing Owls in the eastern Canadian prairies. J. Raptor Res. 35: 378–384.

Warnock, R. G., & P. C. James. 1997. Habitat fragmentation and Burrowing Owls (*Speotyto cunicularia*). Pp. 477–486 *in* Duncan, J. R., D. H. Johnson, & T. H. Nicholis (eds.). Biology and conservation of owls of the northern hemisphere. USDA Forest Service General Technical Report NC-190. North Central Research Station, Forest Service, U.S. Department of Agriculture, St. Paul, Minnesota.

Webb, N. R., & P. J. Hopkins. 1984. Invertebrate diversity on fragmented *Calluna* heathland. J. Appl. Ecol. 21: 921–933.

York, M, D. K. Rosenberg, & K. K. Sturm. 2002. Diet and food-niche breadth of burrowing owls (*Athene cunicularia*) in the Imperial Valley, California. Western North American Naturalist 62: 280–287.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey.