1-1-2002

Nest-Site Characteristics of Burrowing Owls (*Athene Cunicularia*) in the Snake River Birds of Prey National Conservation Area, Idaho, and Application to Artificial Burrow Installation

James R. Belthoff
Boise State University

R. Andrew King
Boise State University

Western North American Naturalist 62(1), © 2002, pp. 112–119

NEST-SITE CHARACTERISTICS OF BURROWING OWLS (*ATHENE CUNICULARIA*) IN THE SNAKE RIVER BIRDS OF PREY NATIONAL CONSERVATION AREA, IDAHO, AND APPLICATIONS TO ARTIFICIAL BURROW INSTALLATION

James R. Belthoff[1] and R. Andrew King[1,2]

ABSTRACT.—Burrowing Owl (*Athene cunicularia*) populations are declining in many portions of their range, and research and management efforts into stemming declines are underway. One tool with promise is the artificial burrow, which can supplement nesting opportunities and play a role in research, mitigation, translocation, and reintroduction studies. However, few studies directly assess important burrow and surrounding topographic features upon which owls choose sites and then construct and install artificial burrows accordingly. In this study we (1) measure physical, vegetative, and topographic characteristics of Burrowing Owl nest sites in the Snake River Birds of Prey National Conservation Area (SRBPNCA); (2) compare used and unused burrows to determine features important in nest-site selection; and (3) use this information to help guide current and future construction and placement of artificial burrows in the SRBPNCA. Owls nested in abandoned American badger (*Taxidea taxus*) burrows in areas with more than one burrow, close to roads and irrigated agricultural fields, and characterized by sparse and low vegetation dominated by nonnative plant species. Only one feature studied, tunnel entrance angle, corresponded with choice by owls; odds of burrow use decreased 17% with each 1° increase in slope of the tunnel entrance. Owls nesting near irrigated agricultural fields also had higher productivity. We discuss applications of our results to construction and placement of artificial burrows in the SRBPNCA and similar shrub-steppe environs in western North America.

Key words: Burrowing Owl, Athene cunicularia, *nest-site selection, artificial burrows, southwestern Idaho, Snake River Birds of Prey National Conservation Area.*

Burrowing Owl (*Athene cunicularia*) populations are declining in many portions of their range (Wellicome et al. 1997, Kirk and Hyslop 1998, Clayton and Schmutz 1999), including western North America (James and Espie 1997, Sheffield 1997). These declines are attributed to control measures aimed at burrowing mammals; loss of habitat to cultivation, development, and other land use activities; predation; human persecution; and other factors (Rich 1986, Haug et al. 1993, Sheffield 1997). Because of declines, resource agencies in the United States and Canada determined Burrowing Owls require management or special attention (James and Espie 1997).

Artificial burrows are one promising management technique (Collins and Landry 1997). These structures enhance nesting opportunities in areas where natural burrows are limited (Trulio 1995, Botelho and Arrowood 1998) and allow accurate assessment of reproductive output (e.g., Olenick 1990, Wellicome 1997, Wellicome et al. 1997). They also are useful for relocation of nesting owls when nesting Burrowing Owls conflict with human developments (Trulio 1995, 1997, Delevoryas 1997, Feeney 1997, Smith and Belthoff 2001) and in owl transplant programs (Martell 1990). However, few studies have directly assessed natural nest burrow features or surrounding vegetation in an attempt to determine owl preferences prior to construction and proper placement of the artificial burrows thereafter. Thus, our objectives in the present study were threefold: (1) to measure physical, vegetative, and topographic characteristics of Burrowing Owl nest sites in the Snake River Birds of Prey National Conservation Area (SRBPNCA); (2) to determine potentially important features for nest-site selection by Burrowing Owls in the SRBPNCA by comparing features of used and unused burrows; and (3) to use this information to help guide future construction and placement of artificial burrows within the rangelands in and near the SRBPNCA. We also assessed relationships between productivity

[1]Department of Biology and Raptor Research Center, Boise State University, Boise, ID 83725.
[2]Present address: USFWS, Bloomington Field Office, 620 S. Walker Street, Bloomington, IN 47403-2102.

(number of fledglings) and attributes of the burrow, surrounding vegetation, and topography to gain insight into features important for successful reproduction.

METHODS

Study Area

We studied Burrowing Owls nesting in and near the SRBPNCA located in southwestern Idaho (Ada and Elmore counties; May–September 1996 for this analysis). The SRBPNCA (formerly Snake River Birds of Prey Area) is more than 196,000 ha in size and was established to provide conservation, protection, and enhancement of raptor populations and habitats. The Bureau of Land Management (BLM) currently manages the SRBPNCA. Despite diverse land uses (ranching, row crop and hay production, recreation, military training, residential, and power generation), the area contains an exceptionally high diversity of raptors. Fifteen species, including Burrowing Owls, nest in the Snake River Canyon or in surrounding uplands, while another 10 species use the area during migration or in winter (U.S. Department of the Interior 1996). Burrowing Owls in the SRBPNCA are annual migrants (personal observation); they generally arrive in early March and leave by October (often earlier) of each year, although a few owls of unknown origin winter in the area as well.

The SRBNCA is characterized by a mosaic of big sagebrush (*Artemisia tridentata*) and other shrublands, and disturbed grasslands dominated by cheatgrass (*Bromus tectorum*), tumble mustard (*Sisymbrium altissimum*), and other nonnative plant species. Surrounding areas contain irrigated agricultural fields (primarily alfalfa, mint, and sugar beets); sparsely scattered residential homes; dirt, gravel, and paved roads; rangelands (grazed primarily by cattle and sheep); and several dairy farms. The topography of the area is flat to slightly rolling with a few isolated buttes and rock outcroppings. A relatively high density of burrows excavated (mainly) by American badgers (*Taxidea taxus*) exists in the area in which Burrowing Owls nested, cached prey, or sought shelter throughout the breeding season.

Capturing and Monitoring Burrowing Owls

Owls were captured at each nest using Havahart® traps, noose rods and carpets, and one-way door traps as described in Belthoff et al. (1995) and King (1996). Most trapping occurred between 1600 and 0200 hours MST, and we attempted to capture both adults and each of their young. After capture, we fitted each owl with a U.S. Geological Survey aluminum leg band and 3 plastic, colored leg bands for future identification.

During a minimum of 2–3 follow-up visits per week, we recorded number of young owls of fledging age (~30 days) observed at entrances to nest burrows, from which we calculated number of young produced. Because of the subterranean nature of nests, some young may go undetected in natural burrows despite intensive observation; thus, we considered maximum number of young observed at the entrance to a burrow as the minimum number of young that nesting pairs produced. Because juveniles have been observed moving on foot to other nest burrows (e.g., Henny and Blus 1981, Johnson 1997), there is a chance that an estimate of reproductive output for a pair misrepresents its genetic contribution. However, we never observed color-banded owls in a nest of another pair in this study, even when we banded them as early as 12 days after hatching.

Nesting Habitat Quantification

To determine features upon which owls selected nest sites, we recorded physical attributes and surrounding vegetation for nest burrows and the nearest, seemingly suitable (unobstructed entrances and tunnels, suitably sized openings), unused burrow within 200 m. This distance is within the range adult owls fly when flushed from their nests (personal observation), and our observations suggest that owls are keenly aware of burrow locations within their immediate home range (i.e., within this distance). Thus, owls likely could have selected these comparison burrows as nests but apparently rejected them; therefore, differences between nest and comparison burrows may give clues to features important for nest site selection. A comparison burrow within 200 m of one nest was unavailable, thus accounting for the lower sample size for unused burrows in results.

BURROW CHARACTERISTICS.—We measured tunnel entrance height and width, mound height near the burrow entrance (mounds form by excavated dirt and/or accumulation of nesting debris; measured from level ground to highest point of mound), angle of burrow entrance (deviation from horizontal; the larger the angle, the steeper the entrance tunnel, Fig. 1), number of apparently suitable burrows within 10 m, and compass orientation of en- trance of each burrow (nest and comparison burrows). We reasoned that each feature (or combinations of them) could influence site choice as follows. Entrance height and width could affect access to burrows by either owls or potential nest predators. Entrance angle may alter the ease with which owls can move in or out of nests to feed young or seek cover from predators. Compass orientation of en- trance, height of mound, and entrance angle also could affect exposure to climatic elements. Finally, number of suitable burrows within 10 m affects access to satellite burrows in which owls cache prey, roost, or seek cover during both the breeding and post-fledging dispersal periods (King and Belthoff 2001). Importantly, these variables, if desired, can be manipulated when placing artificial burrows for management purposes.

SURROUNDING VEGETATION.—We also measured surrounding vegetation and topographic features of nests and comparison burrows. To determine if cover type is important for site selection, we estimated relative proportion of the following cover types within a circle (100-m diameter) centered on the nests or comparison burrows: (1) cheatgrass, (2) rabbitbrush (*Chrysothamnus* sp.), (3) irrigated agriculture, (4) tumble mustard, (5) rock, (6) annual wheatgrass (*Eremopyrum triticeum*), (7) sagebrush, (8) bare ground, (9) clasping pepperweed (*Lipidium perfoliatum*), and (10) all others.

We measured vegetation within 2 m of the burrow entrance to determine vegetation height near burrows. Burrowing Owls often nest in areas with sparse or low vegetation (MacCracken et al. 1985, Rich 1986, Green and Anthony 1989). We measured distance to nearest road and irrigated agriculture to determine if owls avoided roads because of potential vehicular disturbance (Plumpton and Lutz 1993) or nested nearer irrigated agriculture because of abundant prey, for example (Rich 1986, Leptich 1994). Finally, because owls frequently use perches near nests (personal observation), and taller perches may afford increased visibility and early detection of predators (e.g., Green and Anthony 1989), we recorded distances to and height of the nearest perch for nest and comparison burrows.

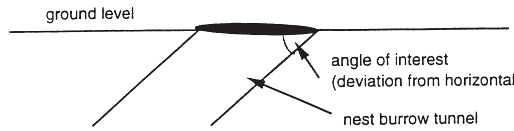

Fig. 1. Illustration depicting tunnel entrance angle and its measurement, i.e., deviation (in degrees) from horizontal.

Data Analyses

We divided analyses into tests of (1) burrow characteristics, which provide information useful for artificial burrow construction, and (2) vegetation/topographic measurements, which will help guide future placement of artificial burrows. We used multivariate analysis of variance (MANOVA) to examine differences between types of burrow and to determine if cover classes differed between used and comparison burrows; when significant effects existed, we examined results of univariate (ANOVA) analyses to determine variables contributing to differences. Percentage data from cover type measurments were arcsine transformed prior to analysis (Zar 1999), and this MANOVA included only the first 9 categories of cover, because the 10th was not independent of the first 9 (i.e., knowing the percentages of the first 9 categories would determine the 10th). We also modeled burrow use with logistic regression, which calculated odds of use of a site in relation to burrow or vegetation/topographic parameters entered into the model. Finally, we explored whether burrow or vegetation/topographic characteristics were related to productivity (maximum number of fledging-age young at burrow entrance) using Spearman's rank correlation analyses. Data derived from circular distributions (burrow entrance orientation) were analyzed separately using circular statistics following Zar (1999). We used SAS® (Version 6.12, SAS Institute, Inc., Cary, NC) for all statistical analyses except circular statistics, which were performed using Oriana (Version 1.0, Kovach Computing, Anglesey, Wales). We present means as $\bar{x} \pm s_{\bar{x}}$ and considered results significant when $P < 0.05$. Finally, a range fire burned areas surrounding 2 nest sites before we measured some variables, which explains sample size differences for some variables.

RESULTS

Productivity of Nesting Pairs

Of 32 Burrowing Owl nests studied, all but 2 produced fledglings (93.8% successful). Successful nests produced 5.1 ± 0.3 young (range: 2–10). We were unable to determine cause for nest failures.

Nest-Site Habitat

Burrow and habitat features were measured at 32 nests and 31 comparison burrows. Distances between nest and comparison burrows averaged 15.8 ± 3.3 m (range: 2–64 m, $n = 31$).

BURROW CHARACTERISTICS.—There was a significant difference between nest and comparison burrows when considering burrow characteristics (MANOVA: Wilks' $\lambda = 0.808$, $F_{5,57} = 2.70$, $P = 0.029$). Examination of univariate results (Table 1) indicates that only tunnel angle differed significantly; comparison burrows had tunnels with greater slopes than nest burrows. We also rejected the null hypothesis that all explanatory variables in the logistic regression of burrow features had coefficients equal to zero ($\chi^2 = 13.83$, df = 5, $P = 0.017$), and tunnel angle was the only significant explanatory variable in this analysis. For each 1° increase in slope of tunnel angle, there was a 17% reduction in odds of use by nesting Burrowing Owls (Table 2). None of the burrow characteristics was correlated with productivity (Table 1). Directions of burrow openings were not significantly oriented for either nest (74.7 ± 47.0°, $r = 0.15$, Rayleigh's test of uniformity, $P = 0.48$) or comparison burrows (5.2 ± 50.4°, $r = 0.08$, Rayleigh's test, $P = 0.81$). Burrow opening direction did not differ between used and comparison burrows (Watson-Williams test: $F_{1,61} = 3.37$, $P = 0.07$).

VEGETATION AND TOPOGRAPHIC CHARACTERISTICS.—Vegetation height and topographic measurements (distance to nearest perch, perch height, distance to irrigated agriculture and roads) did not differ significantly between nest and comparison sites (MANOVA: Wilks' $\lambda = 0.991$, $F_{5,53} = 0.10$, $P = 0.992$; Table 1). We also could not reject the null hypothesis that all explanatory variables had coefficients

TABLE 1. Characteristics ($\bar{x} \pm s_{\bar{x}}$) of Burrowing Owl nest burrows and nearest, apparently suitable unoccupied (Comparison) burrows in the Snake River Birds of Prey National Conservation Area, Idaho, and results of univariate (ANOVA) comparisons. See text for results of MANOVAs. Also indicated is the correlation between attributes and productivity at nest burrows.

Attribute	Nest burrows (Range)	Comparison burrows (Range)	F[a]	P	r_s[b] (P)
Burrow characteristics					
Entrance angle (degrees)	27.4 ± 1.1 (20–41)	32.3 ± 1.1 (12–50)	9.80	0.003	–0.146 0.424
Entrance height (cm)	14.8 ± 0.7 (8–24)	14.2 ± 0.7 (9–25)	0.39	0.535	–0.253 0.162
Entrance width (cm)	20.2 ± 0.5 (12–28)	19.7 ± 0.6 (13–28)	0.32	0.573	–0.276 0.126
Height of mound (cm)	8.4 ± 0.9 (0–20)	8.0 ± 0.9 (0–22)	0.10	0.749	–0.071 0.699
Number of burrows within 10 m	2.1 ± 0.4 (0–11)	2.3 ± 0.4 (0–7)	0.09	0.763	0.097 0.604
Vegetation/Topographic characteristics					
Vegetation height 2 m from burrow (cm)	38.9 ± 3.1 (16–70)	39.6 ± 3.1 (16–70)	0.02	0.888	0.034 0.859
Distance to perch (m)	26.1 ± 4.4 (0.5–115)	24.2 ± 4.4 (1.5–67)	0.10	0.757	0.284 0.114
Height of perch (m)	99.5 ± 7.7 (0.5–145)	92.5 ± 7.9 (10–70)	0.40	0.530	0.223 0.220
Distance to irrigated agriculture (m)	165.0 ± 29.8 (36.5–580)	169.5 ± 30.3 (25–601)	0.01	0.916	–0.387 0.028
Distance to road (m)	95.9 ± 26.2 (8.4–600)	94.9 ± 26.6 (5–603)	0.01	0.978	0.161 0.378

[a]1,61 dfs for ANOVAs related to burrow characteristics; 1,57 dfs for ANOVAS related to vegetation/topographic characteristics.
[b]Spearman rank correlation coefficient; $n = 32$ except number of burrows where $n = 31$ because no comparison burrow within 200 m of nest, and vegetation height where $n = 30$ because range fire precluded measurement (see text).

TABLE 2. Results of logistic regression analyses of (A) burrow characteristics (n = 32 and 31 for nests and comparison burrows, respectively) and (B) surrounding vegetation/topographic (n = 30 and 29) features of Burrowing Owl nest and comparison burrows in the Snake River Birds of Prey National Conservation Area, Idaho. See Table 1 for variable names and units of measurement.

Variable	df	Parameter estimate	$s_{\bar{x}}$	Wald χ^2	P	Odds ratio
(A) Burrow characteristics						
Intercept	1	2.313	1.981	1.36	0.243	
Angle	1	–0.179	0.058	9.41	0.002	0.836
Height	1	0.116	0.095	1.49	0.222	1.123
Width	1	0.071	0.108	0.43	0.513	1.073
Mound height	1	0.021	0.060	0.12	0.731	1.021
No. of burrows	1	–0.092	0.130	0.49	0.480	0.912
(B) Vegetation/Topographic characteristics						
Intercept	1	–0.199	0.965	0.04	0.836	
Vegetation height 2 m	1	–0.005	0.020	0.05	0.815	0.995
Distance to perch	1	–0.002	0.014	0.01	0.896	0.998
Height of perch	1	0.005	0.008	0.43	0.511	1.005
Distance to perch	1	–0.001	0.002	0.07	0.791	1.000
Distance to road	1	0.001	0.003	0.05	0.823	1.000

equal to zero in the logistic regression analysis that examined predictors of nest and comparison burrows (χ^2 = 0.55, df = 5, P = 0.990; Table 2). However, despite similarities between nest and comparison burrows, productivity was significantly related to distance from agriculture (Table 1); owls nesting closer to irrigated fields had greater productivity. Among the other vegetation and topographic features we measured, productivity was most closely related to distance to perch (Table 1).

VEGETATION TYPES SURROUNDING BURROWS.—The most common vegetation around Burrowing Owl nests included cheatgrass, tumble mustard, and annual wheatgrass (Fig. 2). No difference in cover classes between nest and comparison burrows existed (MANOVA: Wilks' λ = 0.899, $F_{9,51}$ = 0.64, P = 0.762).

DISCUSSION

Vegetation and topographic variables differed little between used and comparison burrows in the SRBPNCA. Some of these similarities may have occurred as a result of the sampling protocol, in that comparison burrows generally were in close proximity to nest burrows. Nonetheless, other studies have produced similar results. For example, Schmutz (1997) found no differences among a small suite of microhabitat variables near Burrowing Owl nests and unoccupied sites in Alberta, Canada. Others report differences between only a few variables (Rich 1986, Green and Anthony 1989, Plumpton and Lutz 1993), although experimental designs differed from our study. Similarities in aboveground features suggest that owls may be keying on belowground characteristics of burrows (e.g., chamber/tunnel configuration and dimensions) during nest-site selection, although we know of no studies that have compared underground features of used and unused burrows. Tunnel angle was the only variable that differed significantly between used and comparison burrows in our study, but this feature and productivity were not significantly related.

Relationships Between Nest-site Characteristics and Productivity

Previous studies found relationships between nest locations and perch distances or height (Fehler 1998). Additionally, perch height was one of the important variables discriminating occupied and potential nest sites in cheatgrass habitats in Oregon (Green and Anthony 1989). Apparently, taller perches increase visibility and predator detection. We found a weak positive relationship between productivity and distance to perch. However, there was a stronger (negative) relationship between productivity and distance to irrigated agriculture. Associations with irrigated agriculture apparently provide increased access to montane voles (*Microtus montanus*), an important prey item

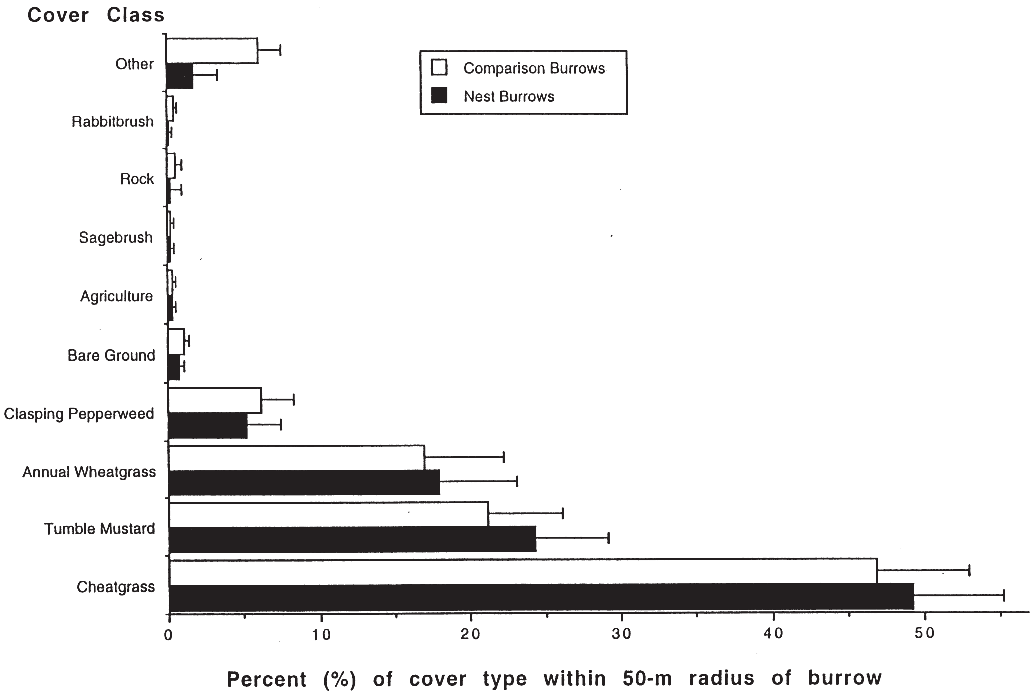

Fig. 2. Mean ($\pm s_{\bar{x}}$) percentage of 10 cover types within 50-m radius of used (n = 31) and comparison burrows (n = 30) for Burrowing Owls in the Snake River Birds of Prey National Conservation Area, Idaho (see text for plant scientific names).

(Rich 1986, personal observation). An untested alternative hypothesis is that greater productivity near farmland may result from decreased predation, perhaps as a result of higher densities of nesting owls and the increased vigilance that results (J. Belthoff unpublished; but see Haug et al. 1993 for areas with intensive agriculture).

Applications to Artificial Burrow Construction and Placement

Artificial burrow systems have been widely used for reintroduction, translocation, relocation, research, and management studies of Burrowing Owls (e.g., Martell 1990, Olenick 1990, Dyer 1991, Trulio 1995, Delevoryas 1997, Wellicome 1997, Botelho and Arrowood 1998). However, few studies systematically determined prior to installation how to correctly configure and place the artificial structures so that they meet the requirements or preferences of nesting Burrowing Owls. Our results suggest placement of nest burrows generally near agriculture and open areas like those near gravel and paved roads, and in areas with low shrub cover and short vegetation. Artificial burrows placed in disturbed grassland/shrub interspersed with irrigated agricultural areas would attract nesting owls and perhaps result in greater reproduction. However, increased exposure to pesticides (James and Fox 1987, Gervais et al. 2000) may be one drawback of the latter protocol. For example, we suspect pesticide poisoning in at least one recent owl death in the SRBPNCA (J. Belthoff unpublished). Moreover, Haug et al. (1993) note that intensive agriculture results in loss of burrows, loss of foraging habitat, creation of suboptimal nesting habitat, and increased vulnerability to predation. Therefore, care should be taken to place burrows in areas where irrigated agriculture comprises only a small component of the landscape.

Data from the present study suggest that odds of nest burrow use decrease with each 1° increase in tunnel angle. Thus, tunnel angle of the entrance on artificial burrows should be limited to gradual slopes (occupied burrows averaged 27°). Opening sizes of used burrows were variable enough to suggest that tunnels of various sizes (e.g., heights of 8–24 cm) would be used. Recent studies indicate that tunnels nearer the smaller end of the range (10 cm) are actually preferred by owls when nesting in artificial burrows (Smith 1999). Finally, because owls routinely use refuge (satellite) burrows both during the nesting and dispersal periods (e.g., King and Belthoff, 2001), more than one artificial burrow should be installed in an owl's range.

In conclusion, we measured attributes of Burrowing Owl nests in the SRBPNCA to determine features owls use when selecting nest sites. This information is intended to guide future artificial burrow construction and placement. Areas harboring nesting owls generally had abundant burrows (e.g., an average of 2.2 burrows within 10 m) and were close to roads and irrigated agricultural fields. Vegetation was characteristically sparse and dominated by nonnative plant species, such as cheatgrass, tumble mustard, and annual wheatgrass. We are planning to use and are using artificial burrows (constructed using specifications suggested here) in agricultural and nonagricultural areas, which will test some of the notions we raised here.

ACKNOWLEDGMENTS

We thank S. Fonley, B. Smith, and L. Townley for assistance with fieldwork. We captured, marked, and banded owls under U.S. Geological Survey Permit #22174 and Idaho Fish and Game Permit SCP 930810 issued to J. Belthoff. Financial and logistical support was provided through grants from the BLM to J. Belthoff, Department of Biology and Raptor Research Center at Boise State University, and the former Raptor Research and Technical Assistance Center (now Snake River Field Station, Forest and Rangeland Ecosystem Science Center, Biological Resources Division, U.S. Geological Survey, Boise, Idaho). J. Clark, J. Doremus, and J. Sullivan facilitated work in and near the SRBPNCA, and M. Fuller, director of the Raptor Research Center, Boise State University, was very helpful in numerous ways. Finally, we thank L. Bond, A. Dufty, J. Munger, B. Smith, and N. Woffinden for discussions about data analyses or helpful comments on the manuscript.

LITERATURE CITED

BELTHOFF, J.R., R.A. KING, J. DOREMUS, AND T. SMITH. 1995. Monitoring post-fledging Burrowing Owls in southwestern Idaho. Technical Bulletin 95-8, U.S. Bureau of Land Management, Idaho State Office.

BOTELHO, E.S., AND P.C. ARROWOOD. 1998. The effect of burrow site use on the reproductive success of a partially migratory population of western Burrowing Owls (*Speotyto cunicularia hypugaea*). Journal of Raptor Research 32:233–240.

CLAYTON, K.M., AND J.F. SCHMUTZ. 1999. Is the decline of Burrowing Owls *Speotyto cunicularia* in prairie Canada linked to changes in Great Plains ecosystems? Bird Conservation International 9:163–185.

COLLINS, C.T., AND R.E. LANDRY. 1977. Artificial nest burrows for Burrowing Owls. North American Bird Bander 2:151–154.

DELEVORYAS, P. 1997. Relocation of Burrowing Owls during courtship period. Journal of Raptor Research Report 9:138–144.

DYER, O.N. 1991. Reintroduction of Burrowing Owls (*Athene cunicularia*) to the South Okanagan Valley, British Columbia (1983 to 1988). Pages 231–235 *in* G.L. Holroyd, G. Burns, and H.C. Smith, editors, Proceedings of the Second Endangered Species and Prairie Conservation Workshop, Provincial Museum Alberta Natural History Occasional Paper 15.

FEENEY, L.R. 1997. Burrowing Owl site tenacity associated with relocation efforts. Journal of Raptor Research Report 9:132–137.

FEHLER, N.A. 1998. Owls of the Idaho National Engineering and Environmental Laboratory (INEEL). Master's thesis, South Dakota State University, Brookings.

GERVAIS, J.A., D.K. ROSENBERG, D.M. FRY, L. TRULIO, AND K.K. STURM. 2000. Burrowing Owls and agricultural pesticides: evaluation of residues and risks for three populations in California, USA. Environmental Toxicology and Chemistry 9:337–343.

GREEN, G.A., AND R.G. ANTHONY. 1989. Nesting success and habitat relationships of Burrowing Owls in the Columbia Basin, Oregon. Condor 91:347–354.

HAUG, E.A., B.A. MILLSAP, AND M.S. MARTELL. 1993. Burrowing Owl (*Speotyto cunicularia*). *In:* A. Poole and F. Gill, editors, The birds of North America, No. 61. Academy of Natural Sciences, Philadelphia, and American Ornithologists' Union, Washington, DC.

HENNY, C. J., AND L. J. BLUS. 1981. Artificial burrows provide new insight into Burrowing Owl nesting biology. Journal of Raptor Research 15:82–85.

JAMES, P.C., AND R.H.M. ESPIE. 1997. Current status of the Burrowing Owl in North America: an agency survey. Journal of Raptor Research Report 9:3–5.

JAMES, P.C., AND G.A. FOX. 1987. Effects of some insecticides on productivity of Burrowing Owls. Blue Jay 45:65–71.

JOHNSON, B.S. 1997. Reproductive success, relatedness, and mating patterns of colonial Burrowing Owls. Journal of Raptor Research Report 9:64–67.

KING, R.A. 1996. Post-fledging dispersal and behavioral ecology of Burrowing Owls in southwestern Idaho. Master's thesis, Boise State University, Boise, ID.

KING, R.A., AND J.R BELTHOFF. 2001. Post-fledging dispersal of Burrowing Owls in southwestern Idaho: characterization of movements and use of satellite burrows. Condor 103:118–126.

KIRK, D.A., AND C. HYSLOP. 1998. Population status and recent trends in Canadian raptors: a review. Biological Conservation 83:91–118.

LEPTICH, D.J. 1994. Agriculture development and its influence on raptors in southern Idaho. Northwest Science 68:167–171.

MACCRACKEN, J.G., D.W. URESK, AND R.M. HANSEN. 1985. Vegetation and soils of Burrowing Owl nest sites in Conata Basin, South Dakota. Condor 87:152–154.

MARTELL, M.S. 1990. Reintroduction of Burrowing Owls into Minnesota: a feasibility study. Master's thesis, University of Minnesota, Minneapolis.

OLENICK, B.E. 1990. Breeding biology of Burrowing Owls using artificial nest burrows in southeastern Idaho. Master's thesis, Idaho State University, Pocatello.

PLUMPTON, D.L., AND R.S. LUTZ. 1993. Nesting habitat use by Burrowing Owls in Colorado. Journal of Raptor Research 27:175–179.

RICH, T. 1986. Habitat and nest-site selection by Burrowing Owls in the sagebrush steppe of Idaho. Journal of Raptor Research 50:548–555.

SCHMUTZ, J.K. 1997. Selected microhabitat variables near nests of Burrowing Owls compared to unoccupied sites in Alberta. Journal of Raptor Research Report 9:80–83.

SHEFFIELD, S.R. 1997. Current status, distribution, and conservation of the Burrowing Owl (*Speotyto cunicularia*) in midwestern and western North America. Pages 399–407 *in* J.R. Duncan, D.H. Johnson, and T.H. Nichols, editors, Biology and conservation of owls of the Northern Hemisphere, Second International Symposium. General Technical Report NC-190, USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN.

SMITH, B.W. 1999. Nest-site selection, ectoparasites, and mitigation techniques: studies of Burrowing Owls and artificial burrow systems in southwestern Idaho. Master's thesis, Boise State University, Boise, ID.

SMITH, B.W., and J.R. Belthoff. 2001. Burrowing Owls and development: results of short-distance nest burrow relocations to minimize construction impacts. Journal of Raptor Research 35:385–391.

TRULIO, L.A. 1995. Passive relocation: a method to preserve Burrowing Owls on disturbed sites. Journal of Field Ornithology 66:99–106.

______. 1997. Burrowing Owl demography and habitat use at two urban sites in Santa Clara County, California. Journal of Raptor Research Report 9: 84–89.

U.S. DEPARTMENT OF THE INTERIOR. 1996. Effects of military training and fire in the Snake River Birds of Prey National Conservation Area. BLM/IDARNG Research Project Final Report, USGS, Biological Resources Division, Snake River Field Station, Boise, ID. 130 pp.

WELLICOME, T.I. 1997. Reproductive performance of Burrowing Owls (*Speotyto cunicularia*): effects of supplemental food. Journal of Raptor Research Report 9:68–73.

WELLICOME, T.I. G.L. HOLROYD, K. SCALISE, AND E.R. WILTSE. 1997. The effects of predator exclusion and food supplementation on Burrowing Owl (*Speotyto cunicularia*) population change in Saskatchewan. Pages 487–497 *in* J.R. Duncan, D.H. Johnson, and T.H. Nichols, editors, Biology and conservation of owls of the Northern Hemisphere, Second International Symposium. General Technical Report NC-190, USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN.

ZAR, J.H. 1999. Biostatistical analysis. 4th edition. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Received 27 March 2000
Accepted 2 October 2001