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ARTIFICIAL BURROW USE BY BURROWING OWLS IN NORTHERN CALIFORNIA

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Abstract.—One common strategy to mitigate the loss of natural nest burrows for Burrowing Owls (*Athene cunicularia)* from ground-disturbing activities has been the installation of artificial burrows outside the disturbance area. I assessed the effectiveness of artificial burrows as a mitigation tool at two study sites in northern California. Parameters included nesting success at natural and artificial burrows; long-term occupancy rates of maintained and unmaintained artificial burrows; choice of burrow type (natural vs. artificial burrows) by owls raised in artificial burrows; and site fidelity and natal philopatry of Burrowing Owls raised in artificial burrows. I analyzed long-term datasets biologists collected from 1990 through 2012, including demographic data, band resightings, and burrow maintenance records. Nesting success at artificial burrows was significantly higher than at natural burrows at both study sites. At one site, nesting success at artificial burrows was 83% compared to 76% at natural burrows ($P = 0.035$); at the other site, nesting success at artificial burrows was 96% compared to 75% at natural burrows ($P = 0.036$). Artificial burrows that received annual surface maintenance were occupied for a significantly longer time (2.1 ± 1.9 yr; $n = 57$) than unmaintained artificial burrows (0.5 ±1.0 yr, $n = 51$; $U = 561$, $P < 0.001$) during the first 8 yr post-installation. Even with surface maintenance, occupancy rates declined from 44% ($n = 25$) of burrows occupied during the first year post-installation, to 28% ($n = 15$) of burrows occupied during the fourth year post-installation. Based on this decline, regular maintenance of the entire artificial burrow, including tunnel and nest chamber, may be crucial for longer-term use. Of 120 Burrowing Owls raised in maintained artificial burrows and resighted during subsequent breeding seasons, 70% occupied artificial burrows and 30% natural burrows. Only 3% of these owls occupied their natal burrow during the first nesting season post-fledging. Of those owls that were resighted during two or more nesting seasons, almost half (48%) occupied different artificial burrows from one year to the next; therefore, the number of artificial burrows at a management site should be sufficient to provide opportunities for Burrowing Owls to move between nest burrows from year to year.

Key Words: *Burrowing Owl*; Athene cunicularia; *artificial burrow*; *California*; *mitigation*; *natal philopatry*; *nest-site fidelity*.

USO DE MADRIGUERAS ARTIFICIALES DE *ATHENE CUNICULARIA* EN EL NORTE DE CALIFORNIA

Resumen.—Una estrategia habitual para mitigar la pérdida de madrigueras nido naturales para *Athene cunicularia* debido a actividades que modifican el suelo ha sido la instalación de madrigueras artificiales fuera del área de molestias. Evalué la efectividad de las madrigueras artificiales como una herramienta de conservación en dos áreas de estudio en el norte de California. Los parámetros estudiados incluyen el éxito de nidificación en madrigueras naturales y artificiales; las tasas de ocupación a largo plazo de las madrigueras artificiales con y sin mantenimiento; la elección del tipo de madriguera (madrigueras naturales versus artificiales) por los búhos criados en madrigueras artificiales; y la fidelidad al sitio y filopatría natal de individuos de *A. cunicularia* criados en madrigueras artificiales. Analicé bases de datos a largo plazo recolectadas por biólogos entre 1990 y 2012, incluyendo datos demográficos, re-avistamiento de anillas y registros de mantenimiento de madrigueras. El éxito de nidificación en las madrigueras artificiales fue significativamente mayor que en las madrigueras naturales en ambas áreas de estudio. En un área, el éxito de nidificación en las madrigueras artificiales fue del 83% comparado con el 76% en las madrigueras artificiales

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($P = 0.035$); en la otra área, el éxito de nidificación en las madrigueras artificiales fue del 96% comparado con el 75% en las madrigueras naturales ($P = 0.036$). Las madrigueras artificiales con mantenimiento anual de superficie fueron ocupadas por un periodo de tiempo significativamente mayor (2.1 ±1.9 años; $n = 57$) que las madrigueras artificiales sin mantenimiento (0.5 ± 1.0 años, $n = 51$; $U = 561$, $P < 0.001$), durante los primeros ocho años posteriores a su instalación. Incluso con mantenimiento de superficie, las tasas de ocupación disminuyeron desde un 44% ($n = 25$) de las madrigueras ocupadas durante el primer año pos-instalación, a un 28% ($n = 15$) de las madrigueras ocupadas durante el cuarto año pos-instalación. En base a esta disminución, el mantenimiento regular de toda la madriguera artificial, incluyendo el túnel y la cámara de nidificación, puede ser crucial para su uso a largo plazo. De los 120 individuos de *A. cunicularia* criados en madrigueras artificiales con mantenimiento y re-avistados durante las estaciones reproductivas subsecuentes, el 70% ocupó madrigueras artificiales y el 30% madrigueras naturales. Solo el 3% de estos búhos ocuparon sus madrigueras natales durante la primera estación reproductora posterior al abandono del nido. De los búhos que fueron re-avistados durante dos o más estaciones reproductoras, casi la mitad (48%) ocupó madrigueras artificiales diferentes de un año al siguiente; por lo tanto, el número de madrigueras artificiales en un lugar gestionado debería ser suficiente como para proporcionar oportunidades de movimiento de los individuos de *A. cunicularia* entre madrigueras nido de un año a otro.

[Traducción del equipo editorial]

The conversion of grasslands to urban areas or agriculture, and associated ground-disturbing activities (e.g., disking, trenching, and bulldozing) are among the factors that have contributed to the population decline of Burrowing Owls (*Athene cunicularia*) in many parts of their North American range over the last 30 yr (Haug et al. 1993, James and Espie 1997, Klute et al. 2003, DeSante et al. 2007). Burrowing Owls roost and nest in underground burrows, thus the availability of burrows is an essential habitat requirement (Plumpton and Lutz 1993, Poulin et al. 2005). Burrows are typically dug by other animals, especially colonial mammals, such as California ground squirrels (*Spermophilus beecheyi*) or prairie dogs (*Cynomys* spp.; Thomsen 1971, Zarn 1974). Since the 1990s, one common strategy to mitigate for the loss of these natural burrows has been the installation of artificial burrows outside the ground-disturbance area (Trulio 1995, Smith and Belthoff 2001a, Barclay 2008).

A number of studies have compared productivity of owls nesting in artificial and natural burrows (e.g., Botelho and Arrowood 1998, Smith and Belthoff 2001b, Smith et al. 2005, Barclay et al. 2011), and one study has examined the longevity of artificial burrows (Belthoff and Smith 2003). However, no studies have examined long-term effects of artificial burrows on the nest-site selection of owls, and whether Burrowing Owls raised in artificial burrows choose to nest in artificial burrows significantly more often than in natural burrows. To my knowledge, no studies have previously assessed nest-site fidelity (an individual occurring at the same location during successive nesting seasons) and natal philopatry (the tendency of an individual to stay in or return to its natal area [Newton 2008]) of Burrowing Owls raised in artificial burrows.

I analyzed data collected at two sites in northern California where artificial burrows were installed as mitigation for the loss of occupied natural burrows. Data were collected during a 22-yr period (1990–2011) at Norman Y. Mineta San Jose International Airport (SJC) and during a 16-yr period (1997–2012) at the Defense Logistics Agency's Distribution Depot San Joaquin – Sharpe Site (Sharpe Depot). I evaluated occupancy, the effects of surface-burrow maintenance on occupancy rates, and the effects of burrow type (artificial vs. natural) on nesting success. I also examined burrow-type choice, nest-site fidelity, and natal philopatry of Burrowing Owls raised in artificial burrows. This study provides information on the effectiveness of artificial burrows as a mitigation tool, and presents recommendations for artificial burrow maintenance that may enhance Burrowing Owl management over the long term.

METHODS

Study Areas and Artificial Burrows. The SJC airport is located in San Jose, Santa Clara County, California, USA (37°21′ N, 121°55′ W). The site was flat and encompassed about 425 ha, of which 134 ha were vegetated. The vegetated area consisted of 42 infields between paved runways and taxiways. Vegetation in the infields was a mixture of nonnative grasses and annual weedy, herbaceous plants characteristic of the California annual grassland series (Sawyer and Keeler-Wolf 1995). During the wet season, approximately November through March, vegetation was regularly mowed to a height of ≤10 cm.

Soil types were a mixture of clay (65%) and silt loam (35%; US Department of Agriculture [USDA] 2014), and in many areas, the soil had been modified and compacted from grading operations. California ground squirrels and their burrows were abundant in those areas where the soil was loose and porous. During 1990–2009, 113 artificial burrows were installed to replace natural burrows that had been closed intentionally in construction areas or near runways (Barclay 2007). Barclay (2008) described the artificial burrow design used at SJC. Seventy-one of the artificial burrows were installed with one entrance and 42 burrows with the optional second entrance (Barclay 2008).

The installation of artificial burrows was a dynamic process, starting with two burrows in late 1990 and incrementally increasing to a maximum of 71 artificial burrows in the ground and potentially available to owls. Some artificial burrows had to be abandoned and substituted at a new location, either because they were in the way of further construction or the previous placement was unsuitable (e.g., erosion). Substitute burrows received a new designation number; therefore, the total number of artificial burrow installations ($n = 113$) exceeded the maximum number of artificial burrows actually in the ground ($n = 71$). All artificial burrows were installed at the ends of the runways and between taxiways paralleling the runways where strike hazards to aircraft were lowest (Barclay 2007). Spacing between artificial burrows was irregular and interspersed with an ever-changing and unknown number of natural burrows. Data on natural burrow density and distribution were not collected.

The other study site, Sharpe Depot, was a principal military supply depot, located in Lathrop, San Joaquin County, California, USA (37°51′ N, 121°16′ W). The depot was generally flat and encompassed 293 ha, containing 11 large (1.2 –7.3 ha) warehouses, approximately 80 smaller buildings, and large barren storage areas. Areas between buildings consisted of compacted soil bisected by railroad tracks and unpaved roads.

In most areas (92%) of the depot, the native soil was modified and altered with fill (USDA 2014). Soil types in the remaining areas were a mix of sandy loam (7%) and loamy sand (1%; USDA 2014). Most of the ground surface was either barren or vegetated by invasive grasses and herbaceous plants characteristic of disturbed sites. The timing, frequency, and method of vegetation management varied from year to year, and included mowing and herbicide application. California ground squirrels occurred throughout the study site where the soil was loose and porous; natural burrows in those areas were abundant. In other areas of the depot, the soil was compacted and poorly drained, making it unsuitable for fossorial mammal activity. In February 1999, 51 artificial burrows were installed to replace natural burrows that had been closed intentionally for a large warehouse construction project. All artificial burrows were installed with a single entrance (Barclay 2008). Their spacing was irregular and interspersed with an ever-changing and unknown number of natural burrows. Data on natural burrow density and distribution were not collected.

Owl Surveys at Artificial and Natural Burrows. I analyzed data biologists collected at SJC in 1990–2011 and Sharpe Depot in 1997–2012. At SJC, surveys were conducted twice each month in conjunction with a year-round wildlife-monitoring program designed to detect wildlife (primarily bird) strike hazards and to comply with Federal Aviation Administration (FAA) safety regulations (Barclay 2008). At Sharpe Depot, surveys were conducted only during the breeding season.

Measurement of reproductive rate at SJC. Biologists conducted Burrowing Owl surveys weekly during the nesting season and twice each month throughout the rest of the year. Surveys were typically conducted from inside a parked motor vehicle with binoculars or a spotting scope. Biologists recorded all artificial and natural burrows occupied by nesting pairs, and observed nesting phenology at each occupied burrow. They classified a burrow as occupied if they observed reproductive behaviors at or near the burrow entrance (e.g., courtship, copulation, or prey delivery), or if they saw signs such as decoration, pellets, droppings, or prey remains, and they considered that a pair occupying a burrow had made a nesting attempt. A pair's nesting attempt at either burrow type was considered successful if at least one offspring emerged from the nest burrow. Nesting success was defined as the percent of occupying pairs that were successful.

All young raised in artificial burrows were banded with a standard USGS aluminum band on one leg and a blue metal band with a unique alphanumeric code (Acraft Sign and Nameplate Company, Alberta, Canada) on the other. Nestlings were caught by hand inside artificial burrows after removal of the nest chamber lid (Barclay 2008). A modified rubber garden hose was used to coax nestlings from artificial burrow tunnels into nest chambers (Barclay et al. 2011). Young were released into their burrow immediately after banding. Any adult captured incidentally inside an artificial nest burrow was also banded. Trapping and banding of adults and young at natural burrows was logistically unfeasible amid airport operations.

Opening artificial burrows for banding allowed biologists to count all owlets inside the burrow. Thus, productivity, defined as the number of young raised at each occupied burrow, represented a complete count for the artificial burrows. However, the number of young raised at each occupied natural burrow was an estimate based on the maximum number of 2–4-wk-old owlets observed at the burrow entrance during any survey. Productivities at artificial and natural burrows were therefore statistically not comparable because data were collected using different methods (Gorman et al. 2003).

Artificial burrow inspection and maintenance at SJC. All artificial burrows were inspected annually before the start of the nesting season, and their condition (e.g., tunnel open, tunnel partially filled with soil, or tunnel entrance buried) was recorded. If artificial burrows were detectable (i.e., not buried from erosion or fossorial mammal activity), they received annual surface maintenance. Vegetation and built-up soil were removed around the burrow entrance and the tunnel was inspected visually or with a probe to check if it was open. No special effort was made to clean the inside of the tunnel or the nest chambers. However, when nest chambers were opened to catch and band nestlings, excess nesting material and soil were removed.

Measurement of reproductive rate at Sharpe Depot. Burrowing Owl observations at Sharpe Depot were recorded during five survey visits, usually in the early evening, at the height of the nesting season each year from May through July. Burrowing Owls were observed from inside a parked motor vehicle with binoculars or a spotting scope. Each year, biologists recorded all artificial and natural burrows occupied by nesting pairs, as well as each pair's nesting success and productivity, following the same methods and definitions used at SJC, except that Burrowing Owls at Sharpe Depot were not banded and artificial burrows were not opened to count the number of young inside nest chambers.

Artificial burrow inspection at Sharpe Depot. All 51 artificial burrows were inspected superficially and their condition (e.g., tunnel open, tunnel partially filled with soil, or tunnel entrance buried) recorded once in 2005 and again in 2011. Unlike at SJC, artificial burrows at Sharpe Depot were not maintained.

Data Analysis. At both sites, each survey record of Burrowing Owl observations contained an observation date, burrow identification number (ID), sex (male, female, or unknown), and age class (nestling, juvenile, adult, or unknown). Burrow ID referred to a serial number assigned to each natural burrow, artificial burrow, or non-burrow location where owls were observed. Data recorded at SJC also included band status (banded, not banded, unknown) and band ID (if read).

I assumed that the detection rates of nesting success at artificial and natural burrows were comparable, within each site and between sites. For example, counting of nestlings inside artificial burrow nest chambers at SJC only occurred after at least one young was observed above ground, which was the same approach used to count young at natural burrows at both study sites, as well as artificial burrows at Sharpe Depot.

I quantified how many artificial and natural burrows were occupied by nesting pairs each year at both study sites, and determined how many breeding seasons each artificial burrow was occupied. I also reviewed the inspection records from 1990–2011 for each artificial burrow at both study sites to evaluate how many of these burrows were actually open and available for Burrowing Owl occupation. I used a two-tailed Mann-Whitney *U*-test to analyze whether occupancy rates during the breeding season were significantly different between maintained artificial burrows at SJC and unmaintained artificial burrows at Sharpe Depot. In this analysis, I included data for the first 8 yr post-installation for all burrows at Sharpe Depot ($n = 51$) and for those burrows that were in the ground for $\geq$8 yr at SJC ($n = 57$). I performed Fisher exact tests for each of the study sites to examine whether the nesting success differed significantly between artificial and natural burrows.

Twenty-eight adults and 803 juveniles were banded between 1996 and 2011, so I used resighting records of banded owls at SJC to evaluate nest-site fidelity and natal philopatry. I searched the database records for sightings of banded owls at burrows during the nesting season (i.e., March through August) to determine which owl nested at an artificial or natural burrow and whether it nested in the same burrow in subsequent years.

For owls banded as nestlings at SJC, I compared the rates at which they were sighted at artificial or natural burrows during subsequent nesting seasons, and assessed whether each occupied the same or a different burrow. In ArcGIS 10.1, I measured the distance of dispersal movement of each banded owl that was resighted at the airport. I measured natal dispersal distance as the straight-line distance between the natal burrow and the first known nest burrow after the owl reached breeding age, and measured breeding dispersal distance as the distance between the breeding sites of successive years (Korpimäki et al. 1987, Newton 2008). I reported all means with ±1 standard deviation (SD).

RESULTS

Burrow Occupancy and Maintenance. *SJC.* During the first 8 yr post-installation, maintained artificial burrows at SJC were occupied for a significantly (Mann-Whitney *U*-test, $U = 561$, $P < 0.001$) greater number of nesting seasons (2.1 ±1.9 yr, $n = 57$) than unmaintained artificial burrows at Sharpe Depot (0.5 ± 1.0 yr, $n = 51$). At SJC, 26% ($n = 15$) of the 57 artificial burrows were occupied for one nesting season, fewer were occupied for two or three seasons, and only 5% ($n = 3$) were occupied for four seasons (Fig. 1). Only one burrow (2%) was occupied for all eight years. This noteworthy artificial burrow was AB01, the first artificial burrow ever installed at SJC, and it was actually occupied for 14 of the 15 nesting seasons that it was available.

During 1990–2011, the sum of all artificial burrows in the ground each year at SJC totaled 858 burrow-years. Burrow entrances and tunnels were actually open for 687 (80%) burrow-years (Fig. 2). On average, 32% of open artificial burrows were occupied each nesting season, but occupancy fluctuated greatly over time (Fig. 2).

Sharpe Depot. At Sharpe Depot, occupancy rates of the 51 artificial burrows ranged from a high of 10% ($n = 5$) in 2000 and 2001 to a low, when occupied, of 4% ($n = 2$) in 2005, and no artificial burrow was occupied in 2002 and 2006–2012 (Fig. 3). Of all artificial burrows, 24% ($n = 12$) were occupied one nesting season, and just one burrow (2%) was occupied for five nesting seasons (Fig. 1). Artificial burrow inventories in 2005 and 2011 revealed that of the 51 burrows installed in 1999, 22 (43%) were still open by 2005 and only one (2%) by 2011 (Fig. 3).

Nesting Success and Burrow Choice (Artificial vs. Natural). Nesting success at artificial burrows was significantly higher than at natural burrows at both SJC (Fisher exact test, $P = 0.035$) and Sharpe Depot (Fisher exact test, $P = 0.036$; Table 1, 2). At SJC, 219 (58%) pairs occupied artificial burrows during the nesting seasons 1991–2011, while 158 (42%) occupied natural burrows (Fig. 2). The 120 Burrowing Owls raised in artificial burrows and resighted at SJC in subsequent years made a total of 182 nesting attempts: 127 (70%) in artificial burrows and 55 (30%) in natural burrows.

At Sharpe Depot, 205 (90%) pairs occupied natural burrows during nesting seasons 1999–2012, whereas 23 (10%) pairs occupied artificial burrows, with a maximum of 38% (5 out of 13) of pairs occupying artificial burrows in 2001 (Fig. 3). During those 6 yr that artificial burrows were occupied, 24% (23 out of 94) of pairs occupied artificial burrows. In 1999, during the first nesting season after installation, 50% (four of eight) of pairs occupied artificial burrows, declining to 11% (two of 18) in 2005 (Fig. 2).

Nest-site Fidelity and Natal Philopatry. Of the 803 Burrowing Owls raised in artificial burrows at SJC, 120 (15%) occupied burrows at the airport during the following nesting season. Four (3%) of these 120 owls used their natal burrow during their first breeding season (two males, one female, one unknown). One male owl was not sighted during his first breeding season post-fledging, but returned to his natal burrow for nesting the following year. Of those owls that used a burrow other than their natal burrow, 20% occupied a burrow within 499 m (203 ±142 m) of the natal burrow for their first nesting attempt, and 32% used a burrow 500–999 m (721 ±148 m) away. The remaining Burrowing Owls (48%) dispersed ≥1 km (1889 ± 635 m) within the boundaries of the airport.

Of all 803 Burrowing Owls raised in artificial burrows, only 46 (6%) were resighted at artificial burrows on the airport during two or more nesting seasons and 13 (2%) in natural burrows. Of those owls resighted in artificial burrows, 22 (48%) switched artificial burrows between years (11 males, 10 females, 1 unknown), 17 (37%) used the same artificial burrow between years (9 males, 7 females, 1 unknown), and seven (15%) did both: used the same artificial burrow for ≥2 yr and switched to other artificial burrows for ≥1 yr (4 males, 3 females). Of the 182 nesting attempts of 120 Burrowing Owls raised in artificial burrows, 14% (*n*

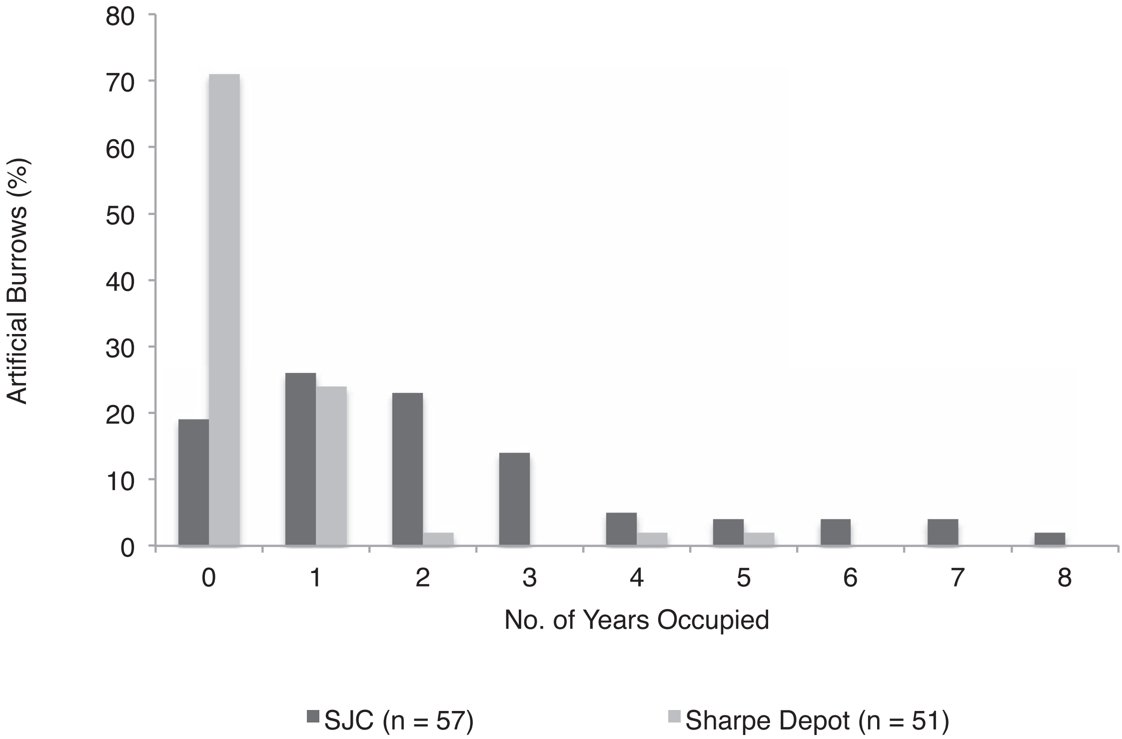

Figure 1. Number of years artificial burrows were occupied by nesting Burrowing Owls during the first 8 yr post-installation at Norman Y. Mineta San José International Airport (SJC) and Defense Logistics Agency's Distribution Depot San Joaquin – Sharpe Site (Sharpe Depot), California, USA, 1991–2012.

= 25) occurred at the same burrow (i.e., owls did not disperse from their natal burrow or previous nest burrow), while 86% (n = 157) used a different burrow than occupied the previous year.

DISCUSSION

Burrow Occupancy and Maintenance. The results of this study confirmed Collins' and Landry's (1977) initial observations that Burrowing Owls readily occupied newly installed artificial burrows, but that burrows may fill with soil from fossorial mammal activity, or erosion and silting during winter storms over time. Artificial burrows require some maintenance to be available for longer-term occupancy. Belthoff and Smith (2003) found that with periodic maintenance and cleaning, artificial burrows remained suitable for use by Burrowing Owls during their 5-yr study; however, they did not provide a specific maintenance protocol or schedule.

I found that artificial burrows receiving simple surface maintenance (i.e., removal of vegetation and built-up soil around the burrow entrance) annually, before the start of the breeding season, were occupied for a significantly greater number of nesting seasons than unmaintained artificial burrows. Nevertheless, even with surface maintenance, only 20% of artificial burrows were occupied for >4 nesting seasons, with considerable decline in occupancy from one year to the next post-installation. Based on this decline, maintenance of the entire artificial burrow (i.e., cleaning soil and debris from the tunnel and nest chamber) approximately every 5 yr appears to be crucial for longer-term use. This level of maintenance may involve unearthing the tunnel and nest chamber and then reinstalling the cleaned components.

In addition to burrow maintenance, other factors likely contributed to the difference in burrow occupancy between sites, including the difference in Burrowing Owl population size, soil types, vegetation management, and other habitat variables. Soil texture, for example, greatly affects the longevity of burrows and probably affects artificial and natural burrows similarly. Green and Anthony

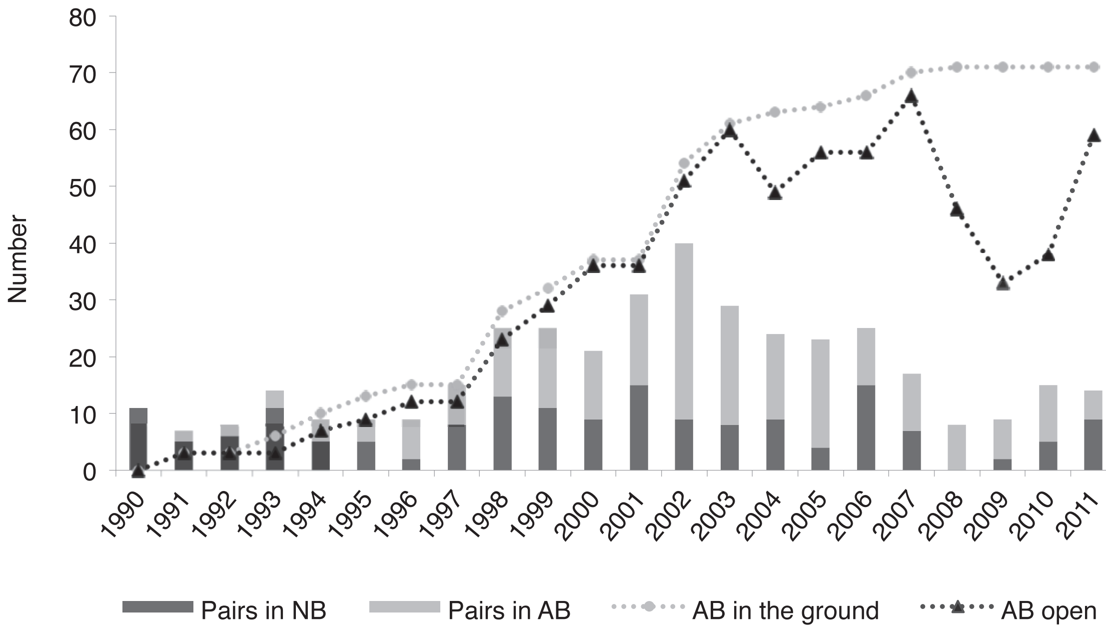

Figure 2. Number of artificial burrows (AB) present in the ground each year, compared to artificial burrows with entrance/tunnel open and available for use, and artificial burrows and natural burrows (NB) occupied by nesting Burrowing Owls at Norman Y. Mineta San Jose International Airport, California, USA, 1990–2011.

(1989) reported that 46% of natural burrows located in loamy sand were silted in by the next nesting season, but that none of 13 nest burrows in silty loam were. Holmes et al. (2003) found that natural burrows were available for owls the longest in sandy loam and collapsed most frequently in loamy sand. At SJC, where the soil types were a mixture of clay and silt loam, artificial burrows did not fill in as quickly as at Sharpe Depot, where the soil types included sandy loam and loamy sand. Drifting sand, water erosion, and ground squirrel activity around artificial burrows contributed to burrow tunnels and entrances filling up with soil at Sharpe Depot.

Rich (1984) reported that natural burrows in rock outcrops in Idaho were reused more often than burrows in soil mounds. Burrows in rock outcrops were never destroyed during his study period and he compared their durability to artificial burrows. Nonetheless, Rich (1984) found that even though burrows were not destroyed, they tended to be occupied for 1–3 yr followed by years of nonuse, indicating that other factors may lead to burrow abandonment, such as overwintering ectoparasite infestation (Smith and Belthoff 2001c), previous nest failure (Catlin et al. 2005), or changes in nearby prey/predator abundance (De Smet 1997, Wellicome et al. 1997). Rich's (1984) findings were consistent with observations at both of my study sites in northern California; of all artificial burrows that were ever occupied by a nesting pair, most were occupied for no more than three consecutive years.

Nesting Success and Burrow Choice (Artificial vs. Natural). I found that average nesting success at artificial burrows was significantly greater than at natural burrows at both study sites, whereas other studies report no significant difference in nesting success between the two burrow types (Botelho and Arrowood 1998, Smith and Belthoff 2001b, Smith et al. 2005). In addition, Burrowing Owls raised in artificial burrows at SJC nested in artificial burrows more frequently than in natural burrows. Riding and Belthoff (2015) report that at their study site in southwestern Idaho, Burrowing Owls rarely used natural burrows for nesting in areas where artificial burrows were present, possibly because of a shortage of suitable natural burrows. At SJC, however, natural burrows were abundant and seemingly not a limiting factor, suggesting that owls preferred artificial burrows. Nest-type imprinting (Brown and Collopy 2013) may occur to some degree, but clearly does not prevent occupancy of natural burrows by owls raised in artificial burrows.

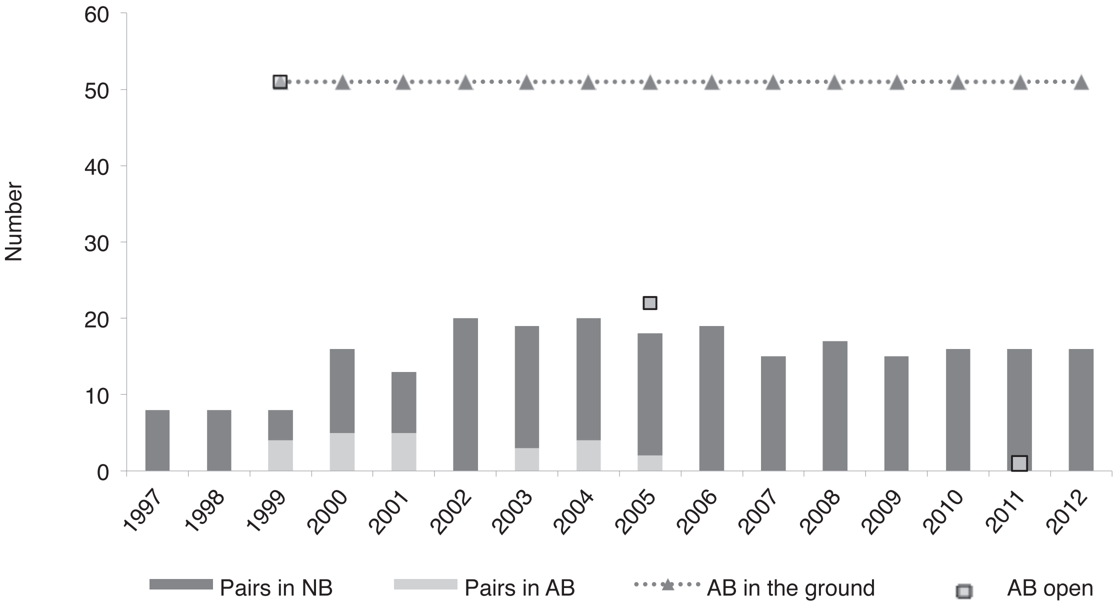

Figure 3. Number of artificial burrows (AB) present in the ground each year, compared to artificial burrows with entrance/tunnel open and available for use, and artificial burrows and natural burrows (NB) occupied by nesting Burrowing Owls at Defense Logistics Agency's Distribution Depot San Joaquin – Sharpe Site, California, USA, 1997–2012. Artificial burrows ($n = 51$) were installed in February 1999, and their condition (e.g., tunnel open, tunnel partially filled with soil, or tunnel entrance buried) inspected in 2005 and 2011.

Nest-site Fidelity and Natal Philopatry. The results of this study showed that Burrowing Owls nested in a different artificial burrow the following breeding season more often than in the same artificial burrow. Nest-site fidelity at SJC was not sex-biased as Martin (1973), Wellicome et al. (1997), and Millsap and Bear (1997) observed at their study sites, where males reused former nest territories more frequently than females. Lutz and Plumpton (1999) also did not find a strong sex bias. Similarly, natal philopatry at SJC did not appear to be sex-biased as suggested by Liberg and von Schantz (1985) and Wellicome et al. (1997), although the sample size in my study was too small for conclusive results. The 15% return rate

Table 1. Nesting success of Burrowing Owls in occupied natural and artificial burrows at Norman Y. Mineta San Jose International Airport, CA, USA, 1990–2011. Nesting success (bold values) is defined as the percentage of occupying pairs that raised at least one nestling to emerge from the nest burrow.

	BURROW TYPE	
REPRODUCTIVE OUTCOME	NATURAL BURROW *n* (%)	ARTIFICIAL BURROW *n* (%)
Successful	129 (**76**)	182 (**83**)
Unsuccessful	40 (24)	32 (15)
Unknown	0 (0)	5[a] (2)
Total	169	219

[a] In 2011, Albion Environmental, Inc., biologists recorded data only through June 30, at which time the reproductive outcome of five nests remained undetermined.

Table 2. Nesting success of Burrowing Owls in occupied natural and artificial burrows at Defense Logistics Agency's Distribution Depot San Joaquin – Sharpe Site, California, USA, during those years that artificial burrows were occupied, 1999–2001 and 2003–2005. Nesting success (bold values) is defined as the percentage of occupying pairs that raised at least one nestling to emerge from the nest burrow.

	BURROW TYPE	
REPRODUCTIVE OUTCOME	NATURAL BURROW *n* (%)	ARTIFICIAL BURROW *n* (%)
Successful	53 (**75**)	22 (**96**)
Unsuccessful	18 (25)	1 (4)
Total	71	23

of Burrowing Owls raised in artificial burrows at SJC and nesting at the airport during the subsequent breeding season was comparable to the 16% return rate observed for another nonmigratory population of Burrowing Owls in the Imperial Valley in California (Rosenberg and Haley 2004), and higher than the 8% rate reported for a migratory population in Colorado (Lutz and Plumpton 1999). In general, return rates are influenced by mortality and emigration, and migration might decrease the benefits of returning to a familiar nest site (Lutz and Plumpton 1999, Rosenberg and Haley 2004).

Understanding the extent of natal and breeding dispersal at managed sites is important because of its role in population dynamics and the colonization of unoccupied areas (Catlin and Rosenberg 2014). Of the owls that dispersed from their natal burrow at SJC, almost half were resighted nesting in a burrow $\geq$1 km from their natal burrow on the airfield for their first nesting attempt. Most owls that nested at SJC during subsequent breeding seasons did not disperse as far. Wellicome et al. (1997) reported similar results from Saskatchewan. However, banding studies, especially those based on resighting, are typically biased toward resighting within the study area, leading to artificially small dispersal distances.

Management and Conservation Implications. Although the installation of artificial burrows may be a useful short-term management tool, the presence and protection of fossorial mammals as the key provider of abundant natural burrows should remain a priority in any area managed for Burrowing Owls (Ronan 2002, Ronan and Rosenberg 2014). If natural burrows are absent, the number of artificial burrows at a management site must be sufficient to provide opportunities for Burrowing Owls to disperse and move between nest burrows from one year to the next.

Annual surface maintenance before the start of the breeding season at and around artificial burrow entrances appeared to enhance long-term occupancy by Burrowing Owls. Yet, even with annual surface maintenance, occupancy rates steadily declined from one year to the next. For longer-term occupancy, all components of the artificial burrow, including tunnel and nest chamber, may need to be cleaned approximately every 5 yr.

Soil texture greatly affects the longevity of artificial burrows (Rich 1984, Green and Anthony 1989, Holmes et al. 2003) and, in conjunction with the amount of precipitation, will influence the level, type, and timing of maintenance at different management sites. An evaluation of soil types may help to determine the appropriate maintenance regimen and design of artificial burrow installations. For instance, at management sites with sandy soils it may be best to install artificial burrows in a slight mound with the tunnel entrance facing away from the direction of the prevailing wind, so that the sand blows over the entrance rather than into it. If burrows are installed in artificial mounds above-grade, the added soil should be thoroughly compacted and should be mostly clay or loam, instead of erosion-prone sand or gravel (S. Menzel unpubl. data).

Although I did not specifically quantify vegetation management and its effect on artificial burrow occupancy, short vegetation (<30 cm) was an important prerequisite for the presence of Burrowing Owls at both study sites. Burrowing Owls require short vegetation around their nest burrows (Haug et al. 1993) and keeping an area surrounding artificial burrows mowed or grazed is essential for burrow occupancy. The optimal timing, method, and extent of vegetation management will vary at different management sites and from year to year.

This study showed that the installation of artificial burrows for Burrowing Owls can be an effective short-term mitigation tool. Burrowing Owls chose to occupy artificial burrows more frequently than natural burrows and nesting success was greater at artificial burrows than at natural burrows. However, annual surface maintenance and regular maintenance of the entire artificial burrow are essential for longer-term occupancy.

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