Burrowing owl nesting productivity: a comparison between artificial and natural burrows on and off golf courses

by Matthew D. Smith, Courtney J. Conway, and Lisa A. Ellis

Abstract Burrowing owl (*Athene cunicularia)* populations are declining in many portions of their range, and lack of suitable nesting burrows is thought to be one reason for observed declines. Burrowing owls are attracted to golf courses because the birds generally nest and forage in short-grass, open areas, yet golf courses seldom have suitable nesting burrows. We examined the efficacy of installing artificial nesting burrows on golf courses as a way to help restore local burrowing owl populations. From 2001–2004 we monitored over 175 natural burrows off golf courses, 14 natural burrows on golf courses, 86 artificial burrows off golf courses, and 130 artificial burrows on golf courses. Owls located and used 8 of the 130 artificial burrows installed on golf courses (4 were used as nests). Owls selected burrows that were closer to existing natural burrows, farther from maintained areas (areas receiving turf maintenance by golf course staff), and farther from sprinkler heads. All 4 of the artificial burrows used as nests successfully fledged young, and annual site fidelity for owls nesting on golf courses was higher than for owls nesting off golf courses. However, annual fecundity of owls nesting on golf courses was lower than that of owls nesting off golf courses. If golf courses have sufficiently large nonmaintained areas and there are nesting owls nearby, course managers potentially can help in restoring local burrowing owl populations by installing artificial nesting burrows on the periphery of the course. However, the low fecundity on golf courses reported here should be more thoroughly examined before artificial burrows are used to attract owls to golf courses.

Key Words artificial nest, *Athene cunicularia*, burrowing owl, golf courses, nest-site selection, south-central Washington

Pesticide application, high water consumption, and disruption of local wildlife through the alteration of native ecosystems are among the environmental concerns associated with golf courses (Murata and Takahashi 1991, Terman 1997). There are approximately 15,000 golf courses in the United States alone, covering an estimated

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8,000 km^2 (National Golf Course Foundation 2004). The popularity of golf continues to rise; over the last 10 years an average of 296 new courses were built per year in the United States (National Golf Course Foundation 2004). Thus, biologists, resource managers, and conservation organizations should attempt to work with the golf industry to reduce impacts. Golf course designers seldom consider ways to minimize adverse effects on local wildlife during the layout and construction of courses. Thus, managers of existing facilities should be encouraged to mitigate any negative environmental effects of their courses on endemic wildlife.

Efforts to benefit wildlife also may benefit local courses because golfers value seeing rare or charismatic wildlife during a round of golf. Burrowing owls (*Athene cunicularia*) are a good example of a species that might benefit from targeted mitigation efforts on existing golf courses. Burrowing owls are attracted to short-grass open areas (Haug et al. 1993), and often are seen foraging on courses (Thomsen 1971).

Burrowing owls have suffered range contractions and population declines in many portions of their North American range (Dechant et al. 1999, Wellicome and Holroyd 2001). Burrowing owls currently are listed as an endangered species in Canada and are a species of national conservation concern in the United States (James and Espie 1997, United States Fish and Wildlife Service [USFWS] 2002). Many state management agencies are concerned about current population declines, but large-scale conservation programs are lacking. Burrowing owls are obligate cavity-nesters, and most owls depend on burrows abandoned by fossorial mammals (e.g., prairie dogs, *Cynomys* spp; badgers, *Taxidea taxus;* ground squirrels, *Spermophilus* spp.; coyotes, *Canis latrans*; Haug et al. 1993). A decline in fossorial animals (and hence a lack of suitable nesting burrows) is thought to be one factor contributing to burrowing owl population declines (Desmond and Savidge 1996). To offset elimination of natural burrows, managers and researchers have used artificial burrows to provide nesting sites for burrowing owls (Collins and Landry 1977, Trulio 1995, Smith and Belthoff 2001*a*). Artificial burrows are effective because they provide nest sites that are resistant to collapse and can therefore be used for many years, thus allowing high rates of reoccupancy for owls (Belthoff and Smith 2003).

Golf courses might have appropriate foraging habitat for burrowing owls, but they often lack suitable nesting burrows. Our study examined the efficacy of installing artificial nesting burrows on golf courses as a way to help restore local burrowing owl populations. We compared breeding biology of burrowing owls that occupied 4 different burrow types: 1) natural burrows on golf courses, 2) natural burrows off golf courses, 3) artificial burrows on golf courses, and 4) artificial burrows off golf courses. We examined: a) whether burrowing owls would locate and occupy artificial burrows placed on golf courses, and, if so, b) which course features influenced the probability that owls used an artificial burrow, c) whether occupied artificial burrows on golf courses were as successful as other burrow types, and d) whether there was a difference in annual site fidelity between burrows on and off golf courses.

[A]rtificial burrows require periodic upkeep. The substrate around an artificial burrow entrance can erode or blow away, and owls often will dig under the tunnel tubing.

Study area

Field research was conducted from 1 February to 31 August 2001–2004 in south-central Washington (WA), USA. The study site covered approximately 518 km^2 in Franklin and Benton counties. Land use in this area included urban, suburban, industrial, agricultural, and horse and cattle grazing. Natural nests used for this study occurred within all types of land use (except dense urban areas) and were predominantly located in industrial areas with moderately disturbed habitat but little human presence. A number of natural nests also occurred in undisturbed shrub–steppe. Artificial burrows off golf courses were installed in short-grass, open areas with few trees–shrubs, on both public and private lands. Artificial burrows on golf courses were installed on our 8 participating golf courses: Meadow Springs Golf and Country Club and Canyon Lakes Golf Course located in Kennewick, WA; Sun Willows Golf Course located in Pasco, WA; Horn Rapids Golf Course and Columbia Point Golf Course located in Richland, WA; Buckskin Golf Course and West Richland Municipal Golf Course located in West Richland, WA; and Moses Pointe Golf Course located in Moses Lake, WA (Table 1). Prior to our study, active nests in natural burrows existed on Sun Willows and Horn Rapids golf courses.

Methods

Study burrows

At the outset of our study, we approached all of the major golf courses in south-central Washington. All

Table 1. Distribution of the 130 artificial nesting burrows installed on golf courses in south-central Washington 2000–2001.

	Participating golf course								
	Canyon Lakes	Columbia Point	Horn Rapids	Meadow Springs	Buckskin	West Richland	Sun Willows	Moses Pointe	Total
# of artificial burrows installed	19	10	30	7	8	8	30	18	130
# in maintained areas	16	10	12	7	4	5	13[a]	7	74
# in nonmaintained areas	3	0	18[b]	0	4	3	17[c]	11	56

[a] 1 burrow used by an unpaired male in 2002.

[b] 1 burrow used as a nest in 2002 and 2 in 2001, 2 burrows used as roost burrows in 2001 and 1 in 2000.

[c] 1 burrow used as a nest in 2002; 4 burrows used by an unpaired male in 2002 and 1 in 2001; 1 burrow used as a roost burrow in 2002, 4 in 2001, and 1 in 2000.

agreed to allow at least some artificial burrows to be created there. At each course we attempted to install artificial burrows in a variety of locations, but superintendents were given final say in placement (a necessity of their cooperation).

We monitored over 175 natural burrows off golf courses, 14 natural burrows on golf courses, 86 artificial burrows off golf courses, and 130 artificial burrows on our participating golf courses (sometimes a new burrow was found; other times a previously monitored burrow collapsed or was destroyed by construction; see Table 2 for yearly fluctuations in number of burrows monitored). We monitored all of our burrows (regardless of whether they were occupied by owls) throughout the course of the study. We located natural burrows off golf courses to monitor using 3 sources: 1) Washington Department of Fish and Wildlife historical records of burrowing owl nest burrows, 2) word-of-mouth (from local residents and members of the Lower Columbia Basin Audubon Society), and 3) standardized walking and driving surveys (Conway and Simon 2003). We monitored natural burrows on golf courses at 2 of our 8 courses (Sun Willows and Horn Rapids). Artificial burrows for this study were constructed by digging a tunnel that dropped ~ 45º to a depth of 1 m, then turned 90º and traveled an additional 2 m to the nest chamber. Ten-cm (4-inch)-diameter, slotted irrigation tubing was used for the tunnel. The nest chamber was constructed using a 22-liter (5-gallon) bucket buried upside-down, and drilled with 18 small holes (for moisture evaporation) and one 10-cm hole for the tunnel connection (Figure 1). Prior to 2001 volunteers from the Lower Columbia Basin Audubon Society installed the artificial off-course burrows by selecting both public and private land that appeared to be suitable for burrowing owls (i.e., short-grass, open areas that had ≥1 active burrowing owl nest nearby or areas with few trees–shrubs). From February 2000–February 2001, we installed 130 artificial nest burrows on our 8 golf courses at various distances from common golf course features (e.g., tee box, tree, sprinkler; Table 1, 3). Distance to next nearest artificial burrow varied from 12–300 m. Distance between artificial burrows to nearest natural burrow varied from 58 m to >800 m. For each artificial burrow, we placed the tunnel entrance flush with the ground to allow

Table 2. Occupancy and reproductive success of burrowing owls in artificial and natural burrows both on and off golf courses (gc) in south-central Washington 2001–2002.

	2001				2002			
	Artificial burrows		Natural burrows		Artificial burrows		Natural burrows	
	on gc	off gc	on gc	off gc	on gc	off gc	on gc	off gc
Burrows monitored	130	86	14	186	123	82	14	256
Burrows w/unpaired male	1	10	2	14	4	2	0	17
(% of monitored)	(1%)	(12%)	(14%)	(8%)	(3%)	(2%)	(0%)	(7%)
Nesting burrows	2	6	7	56	2	5	9	72
(% of monitored)	(2%)	(7%)	(50%)	(30%)	(2%)	(6%)	(64%)	(28%)
Mean ± SE young/	2.5 ± 1.5	2.3 ± 1.4	2.3 ± 0.7	2.7 ± 0.3	2.0 ± 0.0	2.6 ± 1.2	0.9 ± 0.4	2.2 ± 0.3
nesting attempt (*n*)	(2)	(6)	(7)	(56)	(2)	(5)	(9)	(72)
Successful nests[a] (%)	2 (100%)	3 (50%)	6 (86%)	39 (70%)	2 (100%)	4 (80%)	4 (44%)	44 (61%)
Mean ± SE young/	2.5 ± 1.5	4.7 ± 2.0	2.7 ± 0.8	3.9 ± 0.3	2.0 ± 0.0	3.3 ± 1.3	2.0 ± 0.8	3.7 ± 0.3
successful nest (*n*)	(2)	(3)	(6)	(39)	(2)	(4)	(4)	(44)

[a] We considered a nest successful if ≥1 young owls were observed outside of the burrow on any visit.

Table 3. Mean (±SE) distance (m) to 10 landscape features comparing (one-tailed Mann-Whitney U-tests) artificial burrows not used by burrowing owls (unoccupied burrows; n = 120) with burrows occupied by owls (n = 8) and burrows used as nests (n = 4) on golf courses in south-central Washington 2001–2002.

	Unoccupied burrows	Nest burrows			Occupied burrows		
Landscape feature	$\bar{x}$ ± SE	$\bar{x}$ ± SE	U	P	$\bar{x}$ ± SE	U	P
Distance to maintained area	18 ± 3	48 ± 24	49	0.003	34 ± 15	208	0.004
Distance to cart path	41 ± 3[a]	55 ± 33	223	0.45	39 ± 16	367	0.16
Distance to rough	15 ± 2	57 ± 33	85	0.01	34 ± 18	307	0.04
Distance to fairway	35 ± 3	74 ± 34	125	0.05	47 ± 19	426	0.30
Distance to sprinkler	23 ± 2	60 ± 26	78	0.01	43 ± 14	243	0.01
Distance to green	104 ± 6	106 ± 31	230	0.44	98 ± 17	467	0.45
Distance to tee box	82 ± 6	88 ± 33	221	0.39	90 ± 23	454	0.40
Distance to tree	17 ± 1	14 ± 5	231	0.45	21 ± 5	364	0.13
Distance to nearest natural burrow	579 ± 25	149 ± 68	56	0.002	180 ± 43	125	0.001
Distance to next artificial burrow	45 ± 4b	72 ± 26	157	0.12	57 ± 15	395	0.21

[a] n = 116.
[b] n = 119.

mowing equipment to pass over the burrow without disturbing the entrance. We also left a 45-cm^2 patch of dirt at the tunnel entrance to mimic a natural burrow mound (to serve as a potential search-image for owls; Figure 1).

Occupancy and reproductive success

We recorded occupancy and burrowing owl reproductive success of the 4 different burrow types by using repeated nest visits and an infrared fiberscope. We visited all burrows every 2–4 days from 1 February to 31 August, 2001–2004. During these nest visits, we recorded number of adults and juveniles visible, and any signs of depredation. Nest visits consisted of approaching each burrow and stopping 100 m away to look for owls through binoculars. We then continued to approach the burrow, stopping every 25 m to look for owls. If we observed an owl, we looked for and recorded the presence of any additional owls nearby (i.e., mates or juveniles). We also recorded the exact location and behavior of all owls (because behavior can provide clues about stage of the nesting cycle). If no owl was observed, we proceeded to the burrow entrance and noted any signs of occupancy (e.g., feathers, pellets, tracks, or feces). We then removed all burrowing owl signs from the immediate area so that presence of sign on future visits would indicate recent use of the burrow. We also used an infrared fiberscope (Peeper Video Probe, Sandpiper Technologies, Manteca, Calif.) once every 7–10 days to look inside the burrow for incubating females, eggs, or nestlings. Each year we recorded whether burrows were 1) used as nests, 2) occupied by an unpaired male, 3) used temporarily by owls (i.e., we never detected owls but observed pellets or feathers indicating a satellite burrow or use by dispersing birds), or 4) not used by owls.

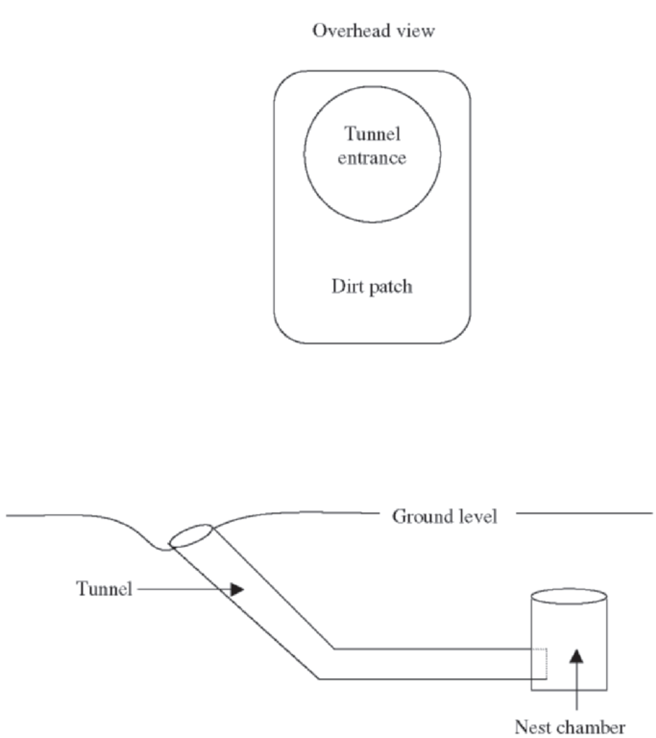

Figure 1. Design of artificial nesting burrows used for burrowing owls in south-central Washington, 2001–2004. Tunnel was 3 m long and nest chamber was 1 m underground. Detail shows overhead view of tunnel entrance and the 25 × 35-cm dirt patch.

Factors influencing occupancy

To test which golf course features influenced occupancy and reproductive success, we placed artificial burrows at a variety of locations on each of the 8 courses (Table 1). At the request of course managers, we attempted to distribute artificial burrows evenly across each course. We selected locations for installation by first deciding whether a burrow was to be near to or far from a particular feature and then by choosing a maintained area or a nonmaintained area to install the burrow. We attempted to install a similar number of burrows in each of those 4 categories for each feature and to include substantial variation in distance from each feature (however, superintendents were given final discretion in burrow locations).

At each artificial burrow, we measured the distance to each of the following golf course features: 1) cart path, 2) tree, 3) existing natural burrow, 4) another artificial burrow, 5) rough, 6) fairway, 7) tee-box, 8) green, 9) sprinkler-head, 10) maintained area, and 11) nonmaintained area. Maintained areas were those with frequent mowing, watering, and golfer traffic. We calculated Spearman rho correlation coefficients to examine relationships among the 10 golf course features. We used one-tailed Mann-Whitney *U*-tests to examine differences in the 10 golf course features between used and unused artificial burrows on courses. We chose nonparametric tests for these comparisons because we had disparate sample sizes, and nonparametric tests make no assumptions about equality of variance. We used one-tailed tests because we assumed a priori that owls would select burrows that were closer to or farther from a given course feature (e.g., farther from tee boxes, closer to nonmaintained areas). We also used logistic regression to examine which features influenced occupancy. We conducted binary logistic regression analysis using a backward stepwise selection process with burrow status (occupied or unoccupied) as the dependent variable and the 10 course features as independent variables.

Annual site fidelity

To compare annual site fidelity between burrows on and off golf courses, we attempted to band all adult owls on our study site. In 2000–2003, we banded each owl with a USFWS band and also with a uniquely numbered color band (Acraft Bird Bands, Edmonton, Alberta, Canada). We conducted re-sight surveys at all monitored burrows in 2001–2004 to locate owls that returned to our study site. We considered a bird to have "returned" if it was detected in a subsequent breeding season (regardless of where it nested relative to golf courses). All "re-sighting" was done at occupied burrows. Burrowing owl nests were relatively rare in our study area, and we believe we located a large proportion of the nests within our study area each year. We visited all known burrows in our study area regularly throughout each breeding season and followed the same explicit nest monitoring and re-sight protocol each year; we visited all burrows every 2–4 days from early February through the end of August of each year. Thus, neither the re-sight effort nor the area searched for each burrow differed, and we have no reason to think that detection probability differed between these 2 groups of birds. We used a contingency table analysis to compare the proportion of banded owls that returned to breed in a subsequent year between owls originally banded on golf courses vs. those banded at burrows off courses. We chose to use a contingency table analysis rather than a Jolly-Cormack-Seber approach because we had a small sample of owls banded on golf courses during any one year (i.e., 7 in 2000 and 11 in 2001) and we had no reason to think that detection probability differed between birds originally banded on courses and those originally banded off courses.

Results

Occupancy

Burrowing owls occupied and nested in all 4 burrow types. We found most of them in natural burrows off golf courses (Table 2). While we found more owls in natural burrows off courses, we found that owls used a higher percent of the natural burrows on golf courses (86% compared to 58% for natural burrows off courses; average for both years). During our study owls used artificial burrows only on 2 of the 8 participating golf courses. Of the 130 artificial burrows installed on golf courses, 4 different burrows were used as nests and 4 others were occupied by unpaired males (Table 2; one of these burrows was used as a nest in 2001, but was occupied by an unpaired male in 2002 and is considered only as a nest burrow in our analyses). Burrowing owls used a smaller proportion of the artificial burrows on golf courses (7%; average for both years) compared to artificial burrows off golf courses (18%; average for both years). However, we were not surprised that owls were reluctant to use burrows near a green or fairway. Indeed, burrowing owls used 12.5% of the artificial burrows in nonmaintained areas and only 1 artificial burrow in maintained areas. Owls occupied 35% of the 23 artificial burrows installed within 200 m of a natural nest burrow.

Burrowing owls on golf courses. In the year prior to installation of artificial burrows (2000), there were 10 nests on golf courses (all in natural burrows). In 2001 there were 9 nests (2 in artificial burrows and 7 in natural burrows), and in 2002 there were 11 nests (2 in artificial burrows and 9 in natural burrows) (Table 2). Hence, the total number of nests on golf courses increased by only 1 after the installation of artificial burrows. After installation, total number of adults on golf courses (both paired and unpaired males) increased by 24% (from 21 to 26). Although the number of adult owls using golf course burrows did not increase the first year after installation (21 in 2000 and 2001), some adults used the newly installed artificial burrows (5 owls; Table 2). Then in 2002 there was an increase in the number of adults occupying both artificial (8 owls) and natural (18 owls) burrows (Table 2). Additionally, the percent of owls on golf courses that occupied artificial burrows increased from 24% in 2001 to 31% in 2002.

Table 4. Correlation (Spearman's *rho*) among 10 landscape features associated with 128 artificial burrows installed on golf courses in south-central Washington 2000–2001.

	Distance (m) to:								
Distance (m) to:	Cart path	Rough	Fairway	Sprinkler	Green	Tee box	Tree	Natural burrow	Artificial burrow
Maintained area	0.12	0.21*	0.25*	0.34*	0.24*	–0.01	–0.06	–0.09	0.10
Cart path		0.12	–0.03	0.24*	0.40*	0.36*	–0.12	–0.02	0.02
Rough			0.76*	0.64*	0.33*	0.01	–0.11	–0.16	0.05
Fairway				0.50*	0.23*	–0.19*	–0.06	–0.04	–0.04
Sprinkler					0.24*	0.19*	0.04	–0.10	0.17
Green						0.10	–0.01	–0.01	–0.02
Tee box							0.01	0.01	0.20*
Tree								0.04	–0.08
Natural burrow									–0.08

* $P < 0.01$.

Fecundity

We failed to detect a difference in percent of nesting attempts that were successful among the different burrow types (χ^2=2.2, df=3, 158, P=0.530). We also failed to detect a difference in the number of young fledged per successful nest among the 4 different burrow types ($F_{3, 100}$=1.4, P=0.245; Table 2), or between artificial vs. natural burrows (linear contrasts: $F_{1, 100}$=0.1, P=0.746). However, nests on golf courses produced slightly fewer offspring compared to nests off golf courses (linear contrasts: $F_{1, 100}$=3.4, P=0.068; Table 2).

Golf course features that influenced occupancy

Correlation analysis. Distance to rough, fairway, sprinkler, and maintained area were all correlated. Distance to cart path and sprinkler also were correlated. However, none of the variables are correlated to distance to nearest natural burrow (Table 4).

Mann-Whitney U-tests. We examined the effects of golf course features on occupancy in 2 ways: 1) by comparing all 8 occupied artificial burrows to the 120 unoccupied artificial burrows and 2) by comparing the 4 artificial burrows used as nests to the 120 unoccupied artificial burrows on golf courses. Seven of the 8 artificial burrows occupied by owls were in nonmaintained areas. Artificial burrows farther from maintained areas were more likely to be occupied (either by unpaired males or as nests) compared to those close to maintained areas (Table 3). Occupied burrows (including nest burrows) were farther from a sprinkler head, farther from the rough, and were closer to a natural burrow compared to unoccupied burrows (Table 3). Overall, occupied burrows were not farther from fairways. However, burrows used as a nest only were farther from fairways than unoccupied burrows. We did not control for experiment-wise error in these univariate tests because we were more concerned about Type II errors (i.e., we did not want to conclude that owls did not avoid sprinklers, when in fact they did), so readers should consider that when interpreting our results. However, we also used a multivariate analysis (see below) that does not have this potential problem. Because nests occurred on only 2 courses, we also analyzed our data excluding the 6 golf courses that never had burrowing owls (i.e., we used only those burrows [n=60] at the 2 golf courses with owls). Our results are nearly identical when we conducted this restricted analysis.

Table 5. Binary logistic regression (*B*) using backward stepwise selection process examining 10 landscape features on golf courses that influenced use of artificial burrows by burrowing owls in south-central Washington 2001–2002.

Landscape feature	*B*	SE	Wald	df	*P*
Distance to maintained area	–0.067	0.057	6.2	1	0.013
Distance to cart path	0.141	0.035	3.7	1	0.056
Distance to fairway	–0.044	0.028	2.5	1	0.114
Distance to nearest natural burrow	–0.010	0.004	5.8	1	0.016

Logistic regression. Our logistic regression analysis suggested that distance to maintained area, cart path, fairway, and nearest natural nest burrow all affected the likelihood that an artificial burrow was occupied by owls (Table 5).

Annual site fidelity

We banded 19 adult owls in 2000, 80 in 2001, 85 in 2002, and 61 in 2003. Including both artificial and natural burrows, the proportion of owls banded on golf courses that returned to breed in a subsequent year (53%, n=30) was 47% higher (χ^2=3.24, df=1, P=0.075; data from all years pooled) than that for owls banded off golf courses (36%, n=215).

Discussion

Owls did not use artificial burrows on golf courses in overwhelming numbers; most burrows remained vacant 2 years after installation. Two of our participating golf courses (Horn Rapids and Sun Willows) had burrowing owls nesting in natural burrows on their property prior to the construction of artificial burrows. Owls used artificial burrows only on those 2 courses. The remaining artificial burrows on the 6 other courses were never used by owls. Hence, large-scale efforts to install artificial burrows on golf courses do not appear to be an efficient use of resources. Rather, installing artificial burrows on golf courses that have nesting owls nearby appears to be the only way that golf courses can help augment existing nesting opportunities.

Occupancy rate of artificial burrows on golf courses may have been low for several reasons. By design, many of our burrows were purposefully placed in highly disturbed areas (areas with severe habitat modification, regular mowing or watering, or high golfer activity). Artificial burrows placed in these areas were used only by 1 unpaired male, suggesting that most of these were unsuitable for owls. Next, occupancy of all artificial burrows (including those in nonmaintained areas and those off golf courses) was low compared to natural burrows. Nesting owls need more than just a hole in the ground. Artificial burrows placed in areas with low prey abundance or little foraging habitat may never be attractive to owls. Also, burrowing owls often nest in burrows that are close to ≥1 satellite burrows (Haug et al. 1993). Despite the fact that some owls did nest in isolated artificial burrows, burrows without satellite burrows nearby may be less attractive to nesting owls. Moreover, burrowing owls may need longer than 2 years to either increase in population size to fill the additional nest sites or to locate newly constructed artificial burrows. Studies of artificial burrows in Idaho showed much higher rates of occupancy than our study (Belthoff and Smith 2003). One possible reason for the difference was that in Idaho, artificial burrows were installed in clusters of 2 or 3 (i.e., there were satellite burrows) and were placed close to natural nests that were active in previous years. However, a confounding variable was that nearby natural burrows were blocked (Belthoff and Smith 2003). In our study natural burrows were left open, and owls could select either natural burrows or artificial burrows. Hence, occupancy of our artificial burrows, both off and on golf courses, may increase in the future if they are properly maintained (i.e., debris removed regularly to prevent plugging the entrance). Lastly, potential nest burrows may not limit burrowing owl populations in eastern Washington. Our study site was near the periphery of the species' range and the number of nesting burrowing owls in Washington has declined. Adding artificial burrows in areas nearer the center of the species range may prove more successful.

Our analysis of golf course features suggested that proximity to rough, fairway, sprinkler, and maintained area all influenced whether an owl will use an artificial burrow. These all are components of maintained areas, so any future installation of artificial burrows on golf courses should consider the distance to maintained area. However, distance to a sprinkler also is important: a burrow (even if was in a nonmaintained area) could be flooded by a sprinkler (either regularly or periodically as sprinklers sometimes do not point in the intended direction). Our logistic regression suggested that distance to fairway and cart path influenced occupancy, but distance to sprinkler did not. One possible reason for this was that distance to sprinkler was correlated both with distance to fairway and with distance to cart path. Distance to nearest natural nest burrow also influenced the probability that an artificial burrow would be used by owls. Perhaps this was because: 1) owls from these natural burrows were the only ones that located our artificial burrows, 2) nearby natural burrows improved attractiveness of artificial burrows because owls selected nest sites with many burrows, or 3) occupied natural burrows were in suitable locations, so artificial burrows close to them also were in suitable locations. For these reasons we focus on maintained areas, sprinklers, and nearby natural burrows in our recommendations in the Management implications section.

Providing new nest sites on golf courses did not result in a substantial increase in number of nests on golf courses (though 4 artificial burrows were used as nests). However, the number of adult burrowing owls using artificial burrows on courses increased 2 years after installation. This increase was due to unpaired, nonbreeding males occupying several artificial burrows. These individuals may be low-quality males or inexperienced first-year males that were unable to attract a mate. The conservation value of providing potential nest sites on golf courses for unpaired males is questionable.

The construction of artificial burrows on golf courses may be warranted in certain situations. While our sample size was small, and future studies should confirm this pattern, nesting attempts in artificial burrows on golf courses appeared to be more successful compared to other burrow types (all 4 nesting attempts in artificial burrows on golf courses were successful). One reason for their success may be that artificial burrows are more difficult for predators to enter. Indeed, nests in artificial burrows had a lower probability of depredation compared to nests in natural burrows in Alberta, Canada (Wellicome et al. 1997). We found no evidence to suggest that adult owls breeding on golf courses experienced reduced annual survival relative to owls breeding in adjacent urban and industrial areas. If adult survival was lower on golf courses, then we expected annual site fidelity to be lower compared to burrows off golf courses, but this was not the case. However, golf course burrows fledged fewer young than burrows off courses. Future studies should obtain a larger sample size to determine whether this pattern is real to ensure that installing artificial burrows on golf courses is not creating ecological traps for owls.

Management implications

Only certain golf courses should even consider installing artificial burrows for burrowing owls. In order to successfully attract burrowing owls, individual courses should meet a number of criteria. The most important factor affecting success of artificial burrow installation efforts is the preexistence of burrowing owls. For courses that have nesting owls within ~ 0.5 km of nonmaintained areas, burrows should be installed only in nonmaintained areas (≥10 m away from all maintained areas). No artificial burrow should be installed in the path of a sprinkler, and burrows should be installed >40 m away from any sprinkler to ensure that nests are not flooded. A recent study (Smith and Belthoff 2001*b*) showed that owls selected artificial burrows with larger chamber-volumes more often than the 22-liter chambers used for this study. Thus, golf courses should incorporate larger chambers into their design for artificial burrows and should include multiple satellite burrows. Following the installation of artificial burrows, golf course staff need to manage some potential problems. Changes in course layout or design should ensure that burrows (hence, owls inside the burrows) are not destroyed. In 2003 one of our participating golf courses changed their irrigation system during winter. When owls returned from migration, they found the course under construction. Subsequently, no owls occupied any burrows on that course. Thus, major maintenance activities should occur outside the owl's breeding season (February–August in WA). Secondly, artificial burrows require periodic upkeep. The substrate around an artificial burrow entrance can erode or blow away, and owls often will dig under the tunnel tubing. Once the tunnel entrance protrudes from the ground, young nestlings cannot retreat to the safety of the burrow. Lastly, artificial burrows can be installed any time of the year, but if they are installed during the breeding season, managers should not expect owls to occupy them during that breeding season. The efficacy of installing artificial burrows on golf courses is highly dependent on the characteristics of any given course. We recommend that courses be evaluated individually relative to the characteristics mentioned above to assess their potential for artificial nest installation.

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