COMPARISON OF DETECTION PROBABILITY ASSOCIATED WITH BURROWING OWL SURVEY METHODS

COURTNEY J. CONWAY,[1] U.S. Geological Survey, Arizona Cooperative Fish and Wildlife Research Unit, School of Renewable Natural Resources, 104 Biological Sciences East, University of Arizona, Tucson, AZ 85721, USA

JOHN C. SIMON, Arizona Cooperative Fish and Wildlife Research Unit, 104 Biological Sciences East, University of Arizona, Tucson, AZ 85721, USA

Abstract: Populations of western burrowing owls (*Athene cunicularia hypugaea*) appear to have declined in many portions of their range. A standardized survey and monitoring program is not available to quantify changes in abundance or distribution. Before a standardized survey method is selected for long-term, continent-wide burrowing owl monitoring, potential survey protocols should be rigorously tested. We evaluated 3 potential burrowing owl survey methods: line transect, roadside point-count, and driving surveys. We also examined the effectiveness of using call-broadcasts on point-count surveys to increase detection probability. We conducted 3 replicate burrowing owl surveys (either point-count or driving surveys) along 1,350 km of roads (114 survey routes) in eastern Wyoming, USA, between June and August 2000. Detection probability varied among observers for both point-count and driving surveys. Detection probability was higher on point-count surveys ($\bar{x}$ = 64.3%) compared to driving surveys ($\bar{x}$ = 37.5%), and point-count surveys sampled a larger effective area away from the road. Walking line-transect surveys proved ineffective and inefficient for monitoring burrowing owls at large (statewide) scales. Nest-site detection probability was 47% during driving detection trials and 79% during point-count detection trials. We detected over twice as many owls per unit distance on our point-count routes (0.038 owls/km) compared to our driving routes (0.016 owls/km), but detected more owls per unit time on our driving routes (0.339 owls/hr vs. 0.229 owls/hr on point-count routes). We detected 22% more owls using call-broadcast even though all of our detections on point-count surveys were visual rather than aural. Estimates of breeding density were fairly similar based on our driving and point-count surveys (0.110 and 0.074 nest sites/km^2, respectively). Standardized point-counts using call-broadcast along roadsides offer the best approach for monitoring population trends of burrowing owls at large (statewide) spatial scales. Based on our results, we developed a standardized survey protocol for monitoring burrowing owls at large spatial scales. Implementation of these monitoring protocols would provide more precise estimates of population trends of burrowing owls in North America.

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Populations of western burrowing owls appear to have declined in many portions of their range (James and Ethier 1989, James and Espie 1997, Sheffield 1997, Desmond et al. 2000). Burrowing owls are listed as endangered in Canada and a Species of Concern in the United States (Sheffield 1997). Burrowing owls also are listed or being considered for listing as state threatened or endangered in several western states (James and Espie 1997, Conway and Smith 2000). Despite the perceived population declines, a standardized survey and monitoring program is not available to quantify suspected changes in abundance or distribution. Burrowing owls are not sampled effectively by existing continental monitoring programs (e.g., by the Breeding Bird Survey; Holroyd and Wellicome 1997). Because of low densities and patchy distribution of continental burrowing owl populations, effective management and conservation of burrowing owls require development and implementation of specialized monitoring methods (Andelman and Stock 1994). Local efforts to study or monitor burrowing owls use a variety of survey methods, but a standardized survey method that can be implemented on a regional or continental scale needs to be developed to estimate long-term population trends and compare with local trends. Such comparisons will allow managers to identify populations or regions that are suffering the greatest declines and target those areas for conservation.

The goal of most survey and monitoring programs is a reliable index to estimate the rate of annual change in number of breeding animals within a region (i.e., population trend). Reliable estimates of population trends require a standardized, repeatable sampling protocol with high detection probability, low variation in detection probability, and low observer variability (Thompson et al. 1998, Yoccoz et al. 2001, Pollock et al. 2002). Several approaches for monitoring burrowing

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[1] E-mail: cconway@ag.arizona.edu

owl populations have been used in local or regional studies, including driving surveys, roadside point-counts, and walking line transects. Each method has associated benefits and drawbacks for use in a continental effort to estimate population trend.

Driving surveys (driving slowly along secondary roads and counting owls and nest sites observed; Millsap and Bear 2000, Arrowood et al. 2001, VerCauteren et al. 2001) allow observers to cover a large geographic area in a relatively short time. However, data from driving surveys may suffer from low (or highly variable) detection probability. Roadside point-count surveys (short-duration roadside point-count surveys established along secondary roads; Coulombe 1971, Haug and Didiuk 1993, Korfanta et al. 2001) may have higher (and less variable) detection probability and may increase detection of owls away from roads. However, distance surveyed per day by each observer is reduced because of the time required to conduct the point-counts, and vocal surveys typically are restricted to morning hours. Both driving and point-count surveys may provide biased estimates of population change because they oversample areas near roads. Walking line-transect surveys or systematic walking surveys (Rodríquez-Estrella and Ortega-Rubio 1993, Johnson 1997, Martell et al. 1997, Trulio 1997) can eliminate some of the potential biases associated with driving and point-count surveys, but are much more labor-intensive.

Observers using any survey method (but especially point-count or walking surveys) can broadcast burrowing owl calls in an effort to increase detection probability during surveys (Haug and Didiuk 1993). However, the extent to which call-broadcast increases detection probability may vary temporally (i.e., at different periods throughout the day or across stages of the breeding cycle) and regionally, and the effects of call-broadcast on variance in detection probability is not known. Use of broadcast equipment also introduces another set of nuisance variables that can vary spatially and temporally among replicate surveys. For example, spatial or temporal variation in equipment quality or broadcast volume can introduce bias into estimates of population change. Passive surveys may detect fewer owls per unit effort, but may avoid many of the biases associated with call-broadcast surveys.

The benefits and drawbacks of each potential survey method should be evaluated before a standardized method for a long-term, continent-wide burrowing owl monitoring program is selected. To address these issues, we designed a study to evaluate 3 potential burrowing owl survey methods: walking line transect, roadside point-count, and driving surveys. Our goal was to estimate detection probability and variance in detection probability associated with each potential survey method. We also examined the effectiveness of using call-broadcast to increase detection probability. Finally, we used our estimates of detection probability in combination with our count data to provide the first estimate of burrowing owl nest-site density across a large geographic area.

METHODS

We conducted our study in eastern Wyoming, USA (Crook, Campbell, Weston, Converse, Niobrara, Goshen, Platte, and Laramie counties). We chose eastern Wyoming for our method evaluation because we knew that burrowing owls bred throughout the region, yet we did not know the specific location of any nests prior to our study. We selected survey routes a priori by looking at topographic maps of eastern Wyoming and chose routes based on proximity to available field housing. We made our selections without prior knowledge of road conditions, vegetation type, land use, or location of burrowing owls or black-tailed prairie dog (*Cynomys ludovicianus*) colonies. We established routes on topographic maps using all presumed passable (i.e., no 4-wheel drive) roads radiating from our 2 field houses (1 in Yoder, Wyoming, and the other near Wright, Wyoming). We alternated adjacent pre-selected routes as driving and point-count routes. We focused our survey efforts during the nestling period (mid-Jun–early Aug) because we assumed that detection probability of nest sites would be highest during this stage. We refer only to adult owls unless noted otherwise.

Survey Methods

Driving Surveys.—We pre-selected 55 driving survey routes (each route was 16 km). Three observers drove the same routes in 3 separate vehicles with 20-min intervals between passes. We varied the chronological order of the 3 observers across routes. Although owls perched close to a road will sometimes flush when a vehicle passes, we assumed that 20 min was enough time for owls to resume normal behavior/activity. Observers drove 24 km/hr (15 mi/hr) and stopped the vehicle (but never exited the vehicle) to verify identification of any suspected owls or owl nests detected while driving.

Observers recorded the location (using a Global Positioning System [GPS] receiver), distance (km) from start of the driving route, azimuth (using a compass) from the observer to each owl and to the presumed nest site detected, and also estimated distance (m) to each owl detected. We also recorded whether the observer needed binoculars to confirm identification. Because binocular quality is likely to vary substantially on any large-scale monitoring effort, we were interested in the proportion of detected owls that required observers to use binoculars.

For each owl, the observer recorded the activity of the bird when initially detected: perched at a mound/burrow, perched on the ground but not at a mound/burrow, perched on a plant or structure off the ground, in flight foraging, or in flight due to being flushed. Each observer also estimated the number of nest sites (i.e., breeding pairs) detected along each route. At the end of each route, the 3 observers compared notes on number and location of both individual owls and presumed nest sites detected. We immediately returned to areas where owls and/or suspected nests were detected after all 3 observers completed the survey route to verify the number and actual location of nest burrows by using binoculars and spotting scopes and/or walking out to the locations where owls were detected. We also returned to each of these areas repeatedly during the summer to conduct detection trials. These repeated visits helped verify the number and location of nest sites sampled.

We defined a "nest site" as a defended nest burrow and its satellite burrows and assumed that a burrow at which an owl was seen standing during repeated visits was a nest site. Prior to nestling dispersal (which is when we conducted our surveys and trials), burrowing owls stand at or very near their nest burrow during daylight hours (Thomsen 1971) and forage mostly at night (Grant 1965, Thomsen 1971, Martin 1973). Unpaired males will sometimes defend a burrow throughout the nesting season, and these burrows are included in our definition of a nest site. Although the proportion of nest sites occupied by unpaired males influences local demographic parameters, having observers on broad-scale surveys determine whether each individual bird is paired is not logistically feasible. Moreover, the proportion of unpaired males is typically <10% in most burrowing owl populations.

We conducted driving surveys throughout the day (0600–2000 hr) between 17 June and 3 August because these surveys rely exclusively on visual detections. A broad range of possible survey times is 1 potential benefit of this method. A driving route required an average of 45 min to complete.

Point-count Surveys.—We pre-selected 59 point-count survey routes (8 km). Each route consisted of 10 survey stations at 0.8-km (0.5-mi) intervals. Adjacent survey points were sometimes >0.8 km apart if burrowing owl habitat was not present or visibility of the surrounding area was impaired. The 0.8-km spacing ensured that adjacent points were statistically independent of each other (i.e., individual owls and nest sites were not visible from >1 point). At each survey station, the observer pulled the vehicle off the road, parked on the road shoulder, exited the vehicle, and performed a 6-min point-count survey. We conducted both passive point-count surveys and call-broadcast point-count surveys. Passive surveys consisted of 6 min of listening for burrowing owl calls and scanning the surrounding landscape for owls using binoculars. Call-broadcast surveys consisted of a 3-min passive segment followed by a 3-min call-broadcast segment (6-min total survey time). Burrowing owl calls were broadcast at 90 dB (measured 1 m from the speaker) using a portable cassette player (Optimus Model SCP-88, Radio Shack, Fort Worth, Texas, USA) and a mini-amplified speaker (Radio Shack Catalog No. 32-2040, Radio Shack, Fort Worth, Texas, USA). The 3-min call-broadcast segment consisted of 30 sec of calls followed by 30 sec of silence, with this pattern repeated 3 times. The first 2 30-sec call periods consisted of the primary song of male burrowing owls (*coo-coo*; Haug et al. 1993), and the final 30-sec call period consisted of an alarm call (*quick-quick-quick*).

Observers scanned the landscape in a 360° arc around the survey station during the entire 6-min survey. For each owl detected, observers recorded all survey segments during which each bird was heard and/or seen: first, second, or third min of passive period, first 30-sec call period, first 30-sec silent period, second 30-sec call period, etc. Observers recorded whether each owl was detected visually, aurally, or both. Observers also recorded the azimuth and distance (m) to each owl detected, whether each bird was at a burrow, and the number of presumed nest sites detected.

We conducted point-count surveys in the mornings (0600–1115 hr) between 19 June and 8 August. Surveys were restricted to the morning because local and regional survey efforts that rely on vocal responses typically are restricted to morning, and burrowing owls vocalize less frequently as morning progresses. A point-count survey route required an average of 80 min. Three observers independently performed each point-count survey route in separate vehicles with a 20-min interval between passes. The first observer placed small flags at each survey station so that the subsequent observers conducted their point-count surveys at the exact location for each survey station. Once all 3 observers completed a route, they compared notes on number and location of owls and nest sites detected. The 3 observers returned to areas where owls were detected immediately after the route was completed to verify the number and location of nest burrows using binoculars and spotting scopes and/or walking to locations where owls were detected. Of the 3 replicate surveys conducted on each route, 1 (and occasionally 2) was passive (no calls were broadcast) so that we could evaluate the usefulness of call-broadcast. Of the 167 replicate surveys, 69 were passive surveys and 98 were call-broadcast surveys. On each route, we alternated which observer performed the passive survey and whether the passive observer was the first, second, or third observer (in chronological order). We examined routes where ≥1 observer detected ≥1 owl and used Repeated Measures Analysis of Variance to evaluate whether observer sequence influenced our results.

Line-transect Surveys.—Observers walked parallel transects (200 m apart) that were 1.6 km (1 mi) long while broadcasting calls of burrowing owls and used a handheld GPS receiver to ensure that the transect was straight. We conducted 6 line-transect surveys (6.5 hr of observer survey time), and we detected no owls or nest sites on these surveys. Walking line-transect surveys required substantial time prior to conducting surveys to obtain permission to access private lands. Based on our initial effort and the time required, we discontinued line-transect surveys due to the ineffectiveness of this method for locating and/or monitoring burrowing owls on a statewide scale.

Detection Probability

Double-observer Method.—We calculated detection probability (p) of burrowing owl nest sites associated with each unique pair of observers (e.g., observer 1 and 2) using the equations: $\{p_1 = [x_{11}x_{22} - x_{12}x_{21}]/[x_{11}x_{22} + x_{22}x_{21}]\}$ and $\{p_2 = [x_{11}x_{22} - x_{12}x_{21}]/[x_{11}x_{22} + x_{11}x_{12}]\}$, where x_{11} is the total number of nest sites detected by observer 1, x_{22} is the total number of nest sites detected by observer 2, x_{12} is the number of nest sites detected by observer 1 but not detected by observer 2, and x_{21} is the number of nest sites detected by observer 2 but not detected by observer 1 (Nichols et al. 2000). We calculated detection probability of nest sites rather than individual owls because nest sites are stationary, and determination of whether or not each observer detected or failed to detect each individual nest site was straightforward. This multi-observer approach provided 2 estimates of detection probability for each observer because we used 3 observers on each route.

We calculated variation in detection probability across observers for each survey method by taking the average of the 2 estimates of p for each observer and calculating the coefficient of variation based on the 3 observer-specific estimates of p (i.e., CV = [SD of p_1, p_2, p_3]/[mean of p_1, p_2, p_3]). We estimated the cumulative detection probability with x replicate surveys as $\{1 - [1 - p]^x\}$, where p is the average detection probability associated with a single survey.

Because we had lag time between successive observer surveys and almost all birds were detected visually, overall detection probability of active nest sites can be expressed as $\{p = [p_{vis}]\times[p_{obs}]\}$, where p_{vis} is the probability that ≥1 owl is visible at a nest site that is known to be active, and p_{obs} is the probability that a naive observer with no prior knowledge of the area detects that active nest. Breaking detection probability into 2 components is useful because observer bias affects p_{obs} but not p_{vis}. Therefore, we can determine whether low detection probability is caused by owl behavioral patterns or observer bias. This knowledge will help suggest ways to maximize detection probability on future surveys.

For calculating detection probability of active nest sites, we assumed that individual owls observed ≥0.8 km apart along a driving route (or at different survey stations along a point-count route) were associated with different nest burrows. This assumption is reasonable because breeding owls typically stay very close (<0.15 km) to their nest burrow during the day (Thomsen 1971; Green and Anthony 1989; C. J. Conway, personal observation). When >1 owl was observed in the same area (<0.8 km apart) during a survey, an observer used behavioral cues to estimate the number of nest sites. When >1 observer detected a nest site at the same location (within 0.15 km and on the same side of the road) and post-survey effort suggested that only 1 active nest burrow was present in that area, we assumed that the observers detected the same nest site. We also returned to areas where we detected nest sites repeatedly throughout the breeding season, which allowed us to verify the actual number of active nests in each area. Moreover, nest density was low in eastern Wyoming; we detected >1 nest site at only 2 survey points on our point-count surveys.

Detection Trials.—We conducted both driving detection trials and point-count detection trials. All detection trials were conducted between 0830 hr and sunset. To minimize bias and to ensure that all data used in calculation of detection probability were based on active nests, we only used trials that preceded the last trial to record activity at each nest.

We conducted driving detection trials to estimate p_{vis} during driving surveys. For these trials, observers drove by active burrowing owl nests at 24 km/hr and looked for owls. We conducted trials at active nests found during our driving surveys and at a randomly selected subset of nests that we found incidentally. Immediately after a driving detection trial, the observer conducted a more thorough check of each nest by returning to the point on the road closest to the nest and thoroughly scanning the area for owls using binoculars. Number of replicate driving detection trials varied among nests ($\bar{x}$ = 3.5, range = 1–9) depending on the date the nest was originally located and the physical location of the nest. We conducted driving detection trials between 2 June and 4 August.

We conducted point-count detection trials to estimate p_{vis} during point-count surveys. These trials involved observers returning to survey points at which we detected nest sites during our point-count surveys. Observers conducted a 6-min survey (3-min of passive survey followed by 3-min of call-broadcast) and recorded whether they detected owls at these known nest sites. We also conducted point-count detection trials at a randomly selected subset of nests that we found incidentally. We conducted these trials from a point on the road nearest the nest. Number of replicate point-count detection trials varied among nests ($\bar{x}$ = 10, range = 3–34) depending on the date the nest was originally located and the physical location of the nest. We conducted point-count detection trials between 19 July and 4 August.

Effects of Call-broadcast on Detection Probability.—We used a paired *t*-test to compare number of owls detected between observers conducting 6-min passive surveys and those conducting the paired call-broadcast surveys (3-min passive period followed by 3-min call-broadcast period) on the same survey routes. We also used a chi-square analysis to compare the proportion of point-count survey routes on which observers using call-broadcast detected more owls than those conducting passive surveys.

Because the number of initial detections should decline with time during the course of a survey, we also examined the distribution of initial detections during each min of our 6-min point-count detection trials. If call-broadcast did not increase detection probability, we expected to see a continuous decline in new detections during each successive min of our 6-min surveys and/or trials. In contrast, if call-broadcast increased detection probability, we expected to see an increase (or no decline) in the number of new owls detected during the fourth min of our survey. We used chi-square analysis to compare the proportion of owls initially detected during the last 3 min between passive and call-broadcast surveys.

We also assessed the usefulness of including an alarm call in the call-broadcast sequence. If including an alarm call further increased detection probability of burrowing owls, we expected to see an increase (or no decline) in the number of new owls detected during the sixth min of our survey. We used chi-square analysis to compare the proportion of owls initially detected during the final min between passive and call-broadcast surveys.

In each of the tests mentioned above, we used a 1-tailed analysis because we were testing a directional hypothesis. We also used a chi-square analysis to examine whether the owls detected during the call-broadcast portion of our point-count detection trials were more likely to be detected during the 3 30-sec passive periods or the 3 30-sec call-broadcast periods.

Nest-site Density

We estimated nest-site density of burrowing owls in eastern Wyoming for both driving and roadside survey methods as {[(average number of nest sites detected per survey route)/(detection probability)]/[effective area surveyed per route]}.

RESULTS

All routes included at least some potential burrowing owl habitat: native grassland, abandoned pastures, active grazing allotments, and/or roadside shoulders adjacent to active pastures. Prairie dog colonies made up a very small proportion of the total area surveyed; prairie dog colony covered ≥25% of the land area within 200 m at only 7 (0.1%) of the 590 point-count stations. However,

Table 1. Comparison of survey effort, owls and nest sites detected, and detection probability between driving surveys and point-count surveys for burrowing owls in eastern Wyoming, USA, Apr–Aug 2000.

	Driving surveys	Point-count surveys
No. of routes	55	59
No. of replicates	3	3
Length of route (km)	16	8
Effective area surveyed per route (km^2)	4.8	5.0
Average time required (min)	45	80
Total no. of individual owls detected (observer average)	29 (14)	32 (18)
Total no. of nest sites detected (observer average)	23 (11)	24 (14)
Percent of routes with zero owls	85	81
Average no. of owls detected/km	0.016	0.038
Average no. of nest sites detected/km	0.013	0.030
Average no. of owls detected/hr	0.339	0.229
Average no. of nest sites detected/hr	0.267	0.178
Average distance (m) to owls detected (range)	50 (7–150)	206 (75–500)
p (detection probability of nest sites ± CV)[a]	37.5 ± 22.1	64.3 ± 19.2
p_{vis} (probability that ≥1 owl visible at known nest)[b]	47.0	78.9
p_{obs} (probability that naive observer detects nest site with ≥1 visible owl; p/p_{vis})	79.8	81.5

[a] Average and coefficient of variation using multi-observer approach from replicate surveys of 3 naive observers.
[b] From detection trials of known active nests.

we detected burrowing owls at 6 of those 7 points. Eighty-six percent of the burrowing owl nests we located were in black-tailed prairie dog burrows, but we did locate nests outside prairie-dog colonies in badger (*Taxidea taxus*) and ground squirrel (*Spermophilus* spp.) burrows.

Survey Methods

Driving Surveys.—We conducted 165 driving surveys on 55 separate 16-km driving routes (total of 885 km of Wyoming roads; Table 1). We recorded 37 owls during driving surveys (29 individual owls, of which 8 were recorded by >1 observer). We located 23 probable nest sites on 8 routes. Each observer detected an average of 14 owls (0.016 owls/km), 11 nest sites (0.013 nest sites/km), and 0.339 owls/hr (0.267 nest sites/hr) during driving surveys (Table 1). Observers needed binoculars to confirm identification on only 4 of 37 owls detected. Sixteen owls were perched on a mound or beside a burrow, 4 were perched on the ground but not at an obvious mound/burrow, 9 were perched off the ground (i.e., on a fence), 2 were detected aurally, 3 were detected in the air foraging, and 3 were detected as they were flushed by the vehicle.

Point-count Surveys.—We conducted 1,670 6-min point-count surveys consisting of 590 survey points along 59 separate survey routes conducted by each of 3 observers (Table 1). In total, we conducted 3 replicate point-count surveys for burrowing owls along 472 km of Wyoming roads. Combined, the 3 observers recorded 53 owl detections (representing 32 individual owls) at 18 of the 590 survey points (on 11 of 59 routes). All 53 detections were visual, and most owls were detected during the first 2 min of the 6-min survey (Fig. 1). The 32 individual owls we detected were associated with 24 nest sites (Table 1). Each observer averaged 17.7 owls detected (0.038 owls/km), 14 nest sites detected (0.030 nest sites/km), and 0.229 owls/hr (0.178 nest sites/hr) of survey time (Table 1). Observer chronology did not affect the number of owls detected ($F = 2.41$; df = 1,10; $P = 0.152$). Observers detected owls at much greater distance on point-count surveys ($\bar{x} = 206$ m) compared to driving surveys ($\bar{x} = 50$ m; Table 1).

Detection Probability

Double-observer Method.—For driving surveys, detection probability averaged over 3 observers was 37.5% (Table 1). Detection probability averaged 46.7% when restricted to driving surveys conducted during morning hours. For point-count surveys, detection probability averaged over 3 observers was 64.3% (Table 1). The 3 observers detected owls at 7, 10, and 15 points of the 18 survey points (on 11 routes) at which burrowing owls were detected. Variation in detection probability across observers was slightly lower on point-count surveys (CV = 19%) compared to driving surveys (CV = 22%).

Detection Trials.—We observed owls at 118 of 251 driving detection trials ($p_{vis} = 47\%$) at 71 individual burrowing owl nests. Probability of detecting an owl at an active nest was highest (55.9%) during the morning (Fig. 2). Probability of detecting an

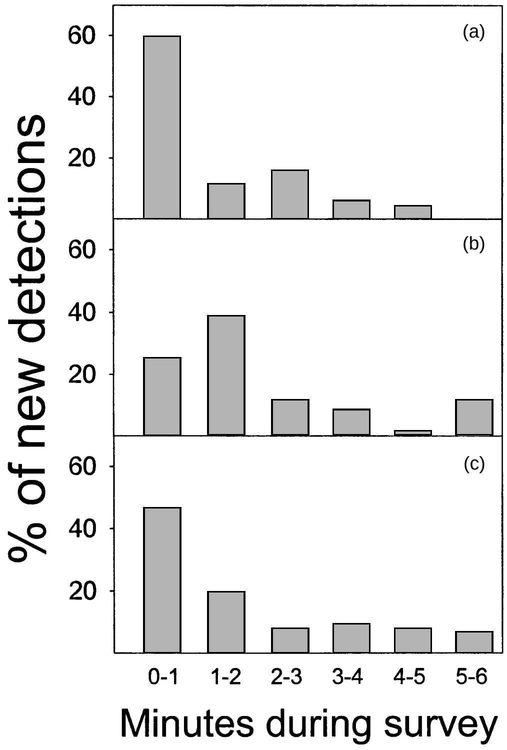

Fig. 1. Percent of burrowing owls initially detected during each of 6 1-min segments during (a) 69 passive (no call-broadcast; *n* = 18 owls detected), and (b) 98 call-broadcast, point-count surveys (*n* = 35 owls), Jun–Aug 2000; and (c) 255 call-broadcast, point-count detection trials at known active nests (*n* = 330 owls), Jul–Aug 2000, in eastern Wyoming, USA. The call-broadcast surveys and trials consisted of a 3-min passive period followed by 3 min of call-broadcast.

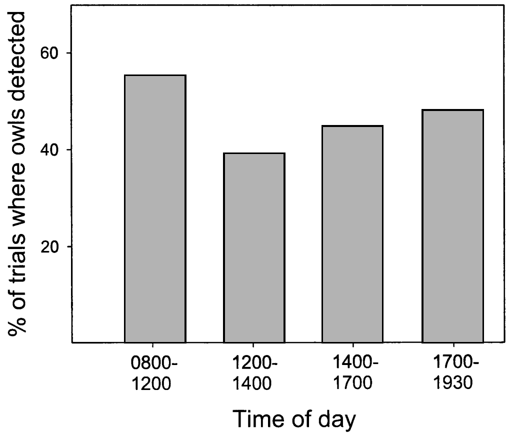

Fig. 2. Percent of 251 driving detection trials at which observers detected ≥ 1 burrowing owl during 4 daily time periods at 71 nests known to be active at the time of the trial in eastern Wyoming, USA, Jun–Aug 2000.

owl at an active nest did not vary during the duration of our study; 48.2% from June through mid-July, 43.8% from mid-July through early August.

We conducted 255 point-count detection trials at 43 nests. We detected only 2 owls aurally, and these birds also were detected visually. Detection of new owls declined rapidly during the course of a 6-min point-count survey (Fig. 1). To calculate p_{vis}, we only used nest sites at which we were confident of the number of active nests on the route and only trials that preceded the last trial that detected activity (to ensure nests were indeed active during trials). We detected owls on 45 of 57 trials (p_{vis} = 78.9%).

Effects of Call-broadcast on Detection Probability.—Although sample sizes were small, some evidence suggests that call-broadcast increased detection probability of burrowing owls even though all of our detections were visual rather than aural. Observers conducting call-broadcast surveys detected on average 22% more owls than did observers conducting passive surveys (t = 0.76, df = 10, P = 0.231). The number of owls detected on call-broadcast surveys was greater than the number detected on passive surveys on 8 of the 11 routes that had owls (χ^2 = 2.27, df = 1, P = 0.066). The effect sizes were not statistically significant, possibly due to our limited sample of points (18 of 590) and routes (11 of 59) with owls.

Eleven percent of the 18 owls recorded were initially detected during the final 3 min of our 6-min passive surveys, whereas 23% of the 35 owls recorded were initially detected during the final 3 min of our 6-min call-broadcast surveys (χ^2 = 1.07, df = 1, P = 0.150; Fig. 1). Inclusion of alarm calls appeared to be particularly effective. No new owls were detected during the sixth min of passive surveys, whereas 11.4% of the 35 owls detected were initially detected during the sixth min of call-broadcast surveys (χ^2 = 2.23, df = 1, P = 0.068; Fig. 1). Of the 81 owls initially detected during the 3-min call-broadcast segment of our point-count detection trials, 67% were initially detected during 1 of the 3 30-sec call-broadcast periods, whereas only 33% were initially detected during 1 of the 3 30-sec passive periods (χ^2 = 9.0, df = 1, P = 0.003).

Nest-site Density

Using results from our driving surveys, we estimated 0.53 nest sites/route and 0.111 nest sites/km^2 (an average observer detected 0.200 nest sites/route, nest-site detection probability was 37.5%, and all owls were within 150 m of the road so we effectively surveyed 4.8 km^2 per 16-km survey route). Using results from our point-count surveys, we estimated 0.37 nest sites/survey route and 0.074 nest sites/km^2 (an average observer detected 0.237 nest sites/route, nest-site detection probability was 64.3%, and the effective sampling area associated with a point-count survey route was 5 km^2).

DISCUSSION

Survey Methods

Walking line-transect surveys is not a viable method for monitoring burrowing owls on a statewide scale. Driving surveys and point-count surveys both showed promise as standardized survey methods. Observers averaged over twice as many owls detected per unit distance on our point-count routes (0.038 owls/km) compared to our driving routes (0.016 owls/km), but averaged more owls per unit time on our driving routes (0.339 owls/hr vs. 0.229 owls/hr on point-count routes). Therefore, driving surveys are more effective if the goal is to maximize the number of owls or nest sites detected per hr of survey time, whereas point-count surveys are more effective if the goal is to maximize the number of owls or nest sites located in a given area.

Detection Probability

Double-observer Method.—Detection probability was higher using point-count surveys (p can be increased slightly on driving surveys if observers restrict surveys to morning hours). We detected owls out to 500 m from the road on point-count surveys but only out to 150 m on driving surveys. Hence, potential biases associated with nests near roads will be reduced using point-count surveys.

Variation in detection probability across observers was only slightly lower on point-count surveys compared to driving surveys. Our estimate of 64% detection probability associated with point-count surveys (and 37% for driving surveys) represents overall detection probability (i.e., p_{vis} * p_{obs}). Our 2 estimates of detection probability for each observer were relatively similar for both observer 1 and observer 2, but differed for observer 3 depending on the observer with whom he was paired. Variation among observers in the distance at which they can detect birds is a possible cause of this discrepancy (Nichols et al. 2000). One potential way to determine whether distance limitations of 1 observer are the cause of partner-specific detection probabilities would be to examine distance versus detection functions for each observer. However, we were unable to detect noticeable differences in the distance functions among the 3 observers. Using 3, rather than 2, observers to calculate detection probability via the double-observer method is useful because observer variation in detection distances can be detected. In addition to varying among observers, detection probability may vary among different habitat types or land uses, and probably will vary among different portions of the owl's breeding range. Hence, our estimates of detection probability may not apply to other observers or other regions.

Detection Trials.—Probability of detecting an owl at a known nest site (p_{vis}) on a driving detection trial was only 47%, even though observers knew the location of each nest site prior to the trial. Detection probability (p_{vis}) during point-count detection trials (79%) was much higher. Observers were apparently failing to detect resident owls during the short time that they drove past the nest site during our driving detection trials. Failure by observers to detect visible owls at nest sites accounted for the lower detection probability associated with driving surveys. Our estimate of 47% for p_{vis} from driving detection trials and our estimate of 37% for p based on the double-observer method on driving surveys suggests that observer bias ($1 - p_{obs}$) on driving surveys was 20.2% (1 – [0.375/0.47]).

Point-count surveys allow observers to detect owls at active nest sites more easily than driving surveys. During our point-count detection trials, p_{vis} was higher (79%) than that on our driving detection trials (47%). Our estimate of 79% for p_{vis} from point-count detection trials and our estimate of 64% for p based on the double-observer method on point-count surveys suggests that observer bias ($1 - p_{obs}$) on point-count surveys was 18.5% (1 – [0.643/0.789]). Therefore, observer bias was also lower on point-count surveys.

Effects of Call-broadcast on Detection Probability.—We detected more owls on call-broadcast surveys compared to passive surveys even though owls did not respond vocally to our call-broadcast. Most owls detected during the 3-min call-broadcast portion of point-count trials were detected during the 3 30-sec periods of call-broadcast. Call-broadcast elicited behavioral changes in burrowing owls that increased visual detection. Owls in other regions respond vocally to call-broadcast

(Haug and Didiuk 1993; C. J. Conway, personal observation). For example, call-broadcast increased detection probability by 53% and the majority of owls (57%) responded aurally to call-broadcast surveys in Saskatchewan (Haug and Didiuk 1993). Inclusion of both the *coo-coo* call and an alarm call in the broadcast sequence may help maximize detection probability of burrowing owls. Call-broadcast probably is more effective at eliciting vocalizations from burrowing owls during earlier stages of the nesting cycle. Future studies should examine the effectiveness of call-broadcast during all stages of the nesting cycle.

We often recorded visual but not vocal responses because owls flushed from their nest burrow prior to many of our detection trials. Burrowing owls in other regions will not flush unless a vehicle or person approaches to within 50 m (C. J. Conway, personal observation). Owls in Wyoming may be less habituated to humans due to low human population density. The increased flush distance also may be a result of learned behavior to avoid prairie dog hunters. The effectiveness of call-broadcast may be greater in regions where burrowing owls are less affected by human presence. Although call-broadcast can increase detection probability on surveys, individual burrowing owls may habituate to the call-broadcast stimulus (or even to a vehicle) and cease responding. This habituation is a difficult problem to avoid when estimating detection probability associated with resampling individuals or nests, but probably is not a problem if survey routes are replicated only a few times annually.

Nest-site Density

Our estimate of nest-site density from driving surveys (0.111 nest sites/km^2) was similar to our estimate based on point-count surveys (0.074 nest sites/km^2). Our density estimate from driving surveys was slightly higher perhaps because detection probability of nests 200–400 m from the road was slightly lower than those 0–200 m on our point-count surveys. Density of burrowing owl nests also may be truly higher along roadsides, especially in agricultural areas where the area next to the road is not cultivated. Moreover, because agricultural areas often are alongside or bisected by roads, they may be oversampled compared to native grassland. Previous estimates of nest-site density of western burrowing owls (Ross 1974, Butts 1973, Desmond et al. 1995) are based on density within a particular prairie dog colony (excluding the interstitial landscape) and are not directly comparable. Our estimates of nest-site density were based on an extensive area (approx 16,835 km^2) within which we had no knowledge of owl densities prior to our surveys and included different types of land uses. Consequently, our density estimates represent the density of owls and nest sites that observers could expect to encounter during a standardized statewide burrowing owl monitoring program.

MANAGEMENT IMPLICATIONS

The status of western burrowing owl populations is in doubt because many local populations are declining or have been extirpated, yet Breeding Bird Survey data show no evidence of range-wide population declines. Burrowing owl population trends may differ among different land uses; owls may be increasing in urban and agricultural areas but declining in natural landscapes. A need exists for a standardized survey method throughout the North American range of the burrowing owl to better estimate population trends across different land uses and to resolve this discrepancy. We recommend point-count surveys to monitor population trends of burrowing owls. Roadside point-count surveys allow observers to cover substantial area during survey efforts but have potential biases because they only sample areas associated with roads. Consequently, land uses that tend to have high road density (e.g., agricultural and urban areas) may be oversampled relative to areas with other land uses. However, this aspect of the sampling design can be taken into account in the analysis of survey data by using a weighted analysis of areas stratified by land use. For these reasons, we developed standardized roadside point-count survey protocols (Appendix A) for use in a statewide, regional, or continental monitoring program designed to estimate the rate of annual change in number of adult burrowing owls (i.e., population trend).

Standardized call-broadcast surveys across broad geographic areas will help managers determine whether burrowing owl populations are declining across their range. This information will be important in determining whether populations deserve greater legal protection and whether habitat restoration efforts are needed. Implementing the survey program we recommended will substantially improve a manager's ability to estimate burrowing owl population trends compared to Breeding Bird Survey data for 3 reasons: (1) data from a greater number of survey routes will be available (i.e., greater statistical power to detect trend); (2) use of call-broadcast will increase detection probability during surveys; and (3) 3 replicate surveys will help reduce variation in trend estimates and will include surveys later in the breeding season (when detection probability is higher because juveniles and adults often are perched above ground during daylight hours).

Effectiveness of point-count surveys will vary across areas with different land uses. For example, agricultural areas have more roads bisecting the landscape, so these areas may be sampled more thoroughly compared to areas dominated by natural grassland and shrub-steppe. This issue must be taken into account in either the sampling frame (e.g., using stratified sampling of each type of land use in each state) or in the analysis and estimates of population trend (e.g., using a Geographic Information System to assign relative weights to each land-use type sampled in each state). A large-scale pilot project within 1 state that incorporates a variety of habitats and land uses would help determine how best to deal with this issue and also would help determine the number of routes needed to detect a population trend of a desired magnitude.

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Appendix A. Standardized roadside point-count survey protocol for burrowing owls in North America.

Roadside point-count survey routes should be selected within some structured sampling frame to ensure that observers do not preferentially place survey routes in areas with high breeding densities. For example, we recommend establishing 1 point-count survey route within each township/range that falls within the known breeding range of burrowing owls in each state. Each survey route will follow a secondary road, beginning within the center 4 sections of each township/range (sections 15, 16, 21, 22). Location of each route will be selected in advance of the survey based on perceived habitat for burrowing owls. The location of these point-count survey routes should in no way be influenced by previous knowledge of burrowing owl observations, historic records, or known nest sites. If no burrowing owl habitat is available within the center 4 sections, a route can be located in the surrounding 12 sections. We also recommend supplemental survey routes (in addition to the systematic survey routes outlined above) based on areas of known burrowing owl breeding locations. These routes should be treated separately from the systematic survey routes because they will be located in areas of known burrowing owl activity (current or historic).

We recommend that each survey route be ≥7.2 km (4.5 mi) in length and include 10 survey points separated by ≥0.8 km (0.5 mi). This interval will help ensure that observers do not recount individual owls at adjacent points but still provide adequate detection probability. The exact location of each survey point should be chosen to provide an optimal viewing radius of the surrounding area. Adjacent survey points may be located >0.8 km (0.5 mi) apart if no burrowing owl habitat is present or visibility of surrounding habitat is not optimal at the 0.8 km interval. The permanent location of each survey point should be marked or recorded using a GPS receiver so that the exact survey location can be re-surveyed in future years.

Because detection probability associated with a single point-count survey is only 64%, we recommend 3 replicate surveys of each route so that overall detection probability will be 95%. Surveys should be conducted after birds have returned from migration but prior to the date when young disperse (e.g., 15 Apr–7 Aug in Wyoming; 1 Apr–21 Jul in Washington, USA). One replicate survey should be conducted during each of 3 30-day survey windows with each survey window separated by 10 days (e.g., 20 Apr–19 May, 30 May–28 Jun, and 9 Jul–7 Aug in Wyoming). This approach will ensure survey effort during each of 3 nesting stages (pre-incubation, incubation/hatching, nestling) that probably differ in vocal and visual detection probability. Standardized burrowing owl surveys should include an initial 3-min passive segment followed by a 3-min call-broadcast segment. For the 3-min call-broadcast segment, we recommend a series of 30 sec call-broadcasts (*coo-coo* call and alarm call broadcast at 90 dB measured 1 m in front of the speaker) interspersed with 30 sec of silence.

Surveys should be restricted to the early morning (e.g., 0.5 hr before sunrise until 0900 hr) and evening hours (e.g., 1700 hr until 0.5 hr after sunset) because vocalization probability and above-ground activity often is higher during these times compared to midday (Grant 1965, Climpson 1977, Johnsgard 1988). However, more studies are needed to evaluate daily variation in detection probability during all stages of the nesting cycle. Surveys should not be conducted during rain or when wind speed is >20 km/hr. At each point, observers should record (1) the number of adult owls, (2) the number of juvenile owls, and (3) the number of presumed nest sites. Implementing this survey protocol over a large geographic area is feasible. For example, we estimate approximately 5 seasonal surveyors could conduct all of the surveys needed for the state of Washington (approx 450 routes) following this recommended survey protocol.