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Assessing patterns of barn owl *Tyto alba* occupancy from call broadcast surveys

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Owing to habitat loss, changes in farming practices, urbanization, and high mortality through vehicle collisions, barn owls *Tyto alba* are a species of conservation concern in portions of their range. This species can be secretive and difficult to survey, particularly away from breeding sites, so factors related to barn owl occurrence often remain unknown. We conducted nighttime broadcast surveys for barn owls during the early- and post-breeding seasons and used an occupancy modeling framework to understand how factors related to landcover, landscape features, and human development related to occupancy in southern Idaho, USA. We also assessed the effectiveness of using broadcasts of conspecific vocalizations to improve owl detection. Barn owls were detected during 52 of 666 point counts and at 37 of 222 locations in the early-breeding season and 50 of 198 point counts and 31 of 66 locations in the post-breeding season. The probability of detecting barn owls was 0.32 ± 0.06 (SE) and 0.45 ± 0.07 (SE) during the early- and post-breeding seasons, respectively. Based on analysis within 1-km buffers surrounding point-count locations, occupancy in the early-breeding season increased with percentage of crop coverage and presence of trees and decreased with background noise. Post-breeding season occupancy increased with stream length and decreased with area of development and distance from the Snake River, a major geologic feature that likely provided roost sites in its canyon walls and riparian woodlands and a dispersal corridor for juveniles. Broadcast of barn owl vocalizations increased detection probability as much as nine times. Thus, incorporating call broadcast into future barn owl surveys should help investigators reduce false conclusions of absence. Ultimately, understanding factors influencing occupancy of barn owls will facilitate effective conservation, especially in light of population pressures related to factors such as roadway mortality and loss of nesting sites with increased urbanization.

Keywords: anthropogenic noise, broadcast calls, detection, Idaho, point counts

Barn owl *Tyto alba* populations have declined in numerous portions of their worldwide range. For instance, British populations declined over much of the last century (Ramsden 2003), and declines of 69% occurred within an 11-year period in portions of Spain (Martínez and Zuberogoitia 2003). In Canada, the breeding population is now restricted to two provinces, British Columbia and Ontario, in which the species is listed as threatened and endangered, respectively (COSEWIC 2010). In the United States, barn owls have declined in Midwestern states (Colvin 1985), and Connecticut, Vermont, Rhode Island, Illinois, Indiana, Iowa, Missouri and Ohio consider them as a species of greatest conservation need, threatened or endangered.

Anthropogenic factors, especially habitat conversion and urbanization, have presented threats to barn owls. Population declines have resulted from 1) loss of grasslands, reducing rodent populations and owl hunting opportunities (Colvin 1985, Taylor 1994, Hindmarch et al. 2014), 2) conversion of open barns and other old structures into closed, steel buildings, and the cutting of old trees for agricultural field expansion, which effectively remove roost and nest sites (Ramsden 1998, Taylor 1994), and 3) roads and the traffic increases along them which can increase rates of barn owl–vehicle collisions and decrease population persistence (Ramsden 2003, Charter et al. 2012, Grilo et al. 2012, Hindmarch et al. 2012, Borda-de-Água et al. 2014). Conversely, the use of nest boxes by humans has augmented habitat and populations in some areas (Marti et al. 2005, Martin et al. 2010, Wendt and Johnson 2017).

A comprehensive understanding of factors related to barn owl occupancy is important for owl conservation because it would help in identifying and preserving key habitats. With respect to development and road impacts, a greater understanding of these factors could also inform management of barn owl populations in light of increasing trends in urban development, including expansion of road networks that present serious threats to the conservation of many species (Laurance et al. 2014). Thus, our objective was to examine how local and landscape level factors influenced barn owl occupancy using data obtained from nighttime point count and call broadcast surveys.

We used an occupancy modeling framework (MacKenzie et al. 2006) to assess a suite of biotic and abiotic factors including land cover types such as development and agriculture, topography, and distance to rivers and roads that might correlate with barn owl occupancy. We also examined factors potentially influencing detection, including weather variables, noise, and the use of audio broadcasts of barn owl vocalizations. Occupancy models use data from repeat surveys to calculate detection probability under the possibility of imperfect detection and adjust parameter estimates of animal occupancy accordingly (MacKenzie et al. 2006). Occupancy estimates are considered more robust than naïve estimates, i.e. those from simple presence–absence data (Gu and Swihart 2004, Guillera-Arroita et al. 2014).

To help understand if and how patterns might differ, we assessed barn owl occupancy during the early-breeding season, when barn owls engage in territory establishment, pair bond formation, nest defense, and ultimately egg-laying/incubation, and during the post-breeding season when non-migratory adults typically remain near breeding sites but juveniles settle into potential breeding habitat. We also discuss factors that affected detection probability during the nighttime point-count surveys in each season, including the value of call broadcasts for enhancing detection. We believe results will be useful for designing future barn owl studies.

Material and methods

Study area

We studied correlates of barn owl occupancy in southern Idaho, USA (Fig. 1) between Boise (Ada County, 43°37′N, 116°12′W) and Burley (Cassia County, 42°32′N, 113°47′W), within the Snake River Plain ecoregion (McMahon et al. 2001). This area has a semiarid climate (Maupin 1995), with cold winters (average low and high temperature: –11.9–10°C) and hot summers (13.4–32.6°C, Western Regional Climate Center 2015). Elevation ranged from 820 m a.s.l. near Boise to 1330 m near Burley. Predominant land cover included shrub steppe/disturbed grasslands and irrigated agriculture, in addition to primarily rural municipalities. Shrub-steppe lands typically consisted of a mixture of native plants such as sagebrush *Artemisia tridentata*, bitterbrush *Purshia tridentata*, green rabbitbrush *Chrysothamnus viscidiflorus*, and bunch grasses, and to varying extents exotic invasive species such as cheat grass *Bromus tectorum*, tumble mustard *Sisymbrium altissimum* and Russian thistle *Salsola kali*. The main agricultural crops were sugar beets *Beta vulgaris*, potatoes *Solanum* spp., corn *Zea mays*, wheat *Triticum* spp., barley *Hordeum* spp., alfalfa *Medicago sativa* and soy beans *Glycine max*. Agricultural lands contained irrigation ditches, isolated groves of trees and human structures such as barns, grain silos, abandoned buildings and residences. There were also ~300 small to large dairy farms throughout the study area (Idaho Office of the Administrative Rules Coordinator 2014), which likely increased owl prey and nesting/roosting sites because of associated food production/storage for livestock and farm buildings. The study area also contained a >150-km long stretch of Interstate-84, a major road where barn owl–vehicle collisions are documented (Boves and Belthoff

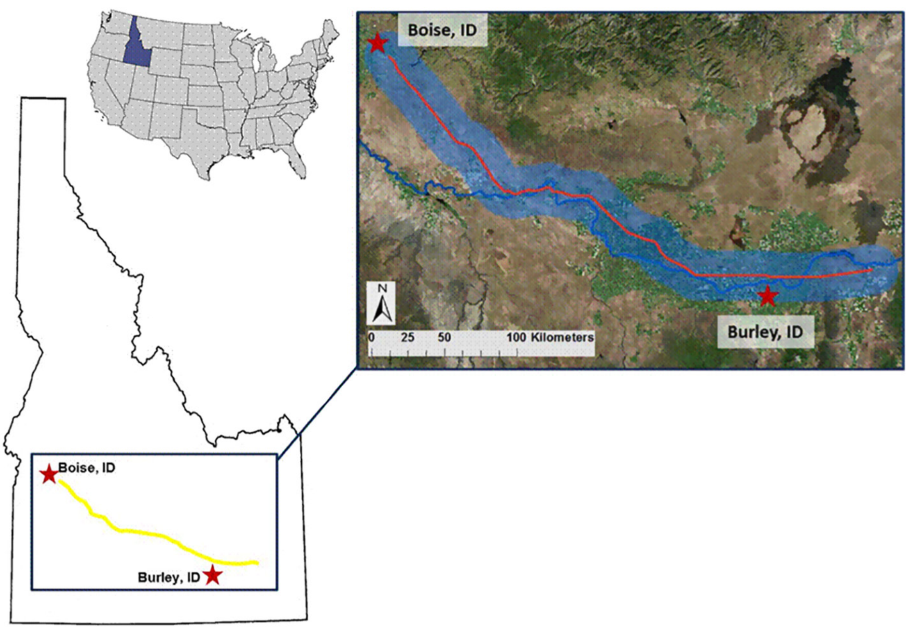

Figure 1. Location of 10 200-km² study area (blue) and Interstate-84 (red) in southern Idaho, USA, where we surveyed for barn owls during the early- and post-breeding seasons of 2014. Shrub lands and disturbed grasslands appear as brown, lava flows are black, and croplands, as well as forests in mountainous regions north of our study area, appear as green (ESRI 2013).

2012, Belthoff et al. 2015, Arnold et al. 2018). Portions of our research also occurred in the Morley Nelson Snake River Birds of Prey National Conservation Area, where the Snake River canyon was one of the main geologic features. This canyon is characterized by vertical walls of volcanic rock which provide nest and roost sites for many birds of prey, including barn owls.

Barn owl occupancy surveys

Using Arc GIS (ESRI 2013, ArcMap ver. 10.1), we generated random point-count locations to survey for barn owls within a 10 200 km^2 portion of southern Idaho (Fig. 1). Because portions of our study area were privately-owned lands with restricted access, we selected random points accessible from and located on the side of public roads, although we also excluded points that fell on interstate highways for safety reasons. Point-count locations surveyed during the early- and post-breeding season averaged 5.5 ± 0.1 (SE) km (n = 222) and 4.8 ± 0.3 km (n = 67) apart, respectively. As these distances are longer than typical barn owl foraging movements (Marti et al. 2005, Regan 2016), we considered survey points as independent.

Point count protocol

We conducted nighttime point counts for barn owls using a combination of 1) spotlighting (Condon et al. 2005), where two observers used handheld lights to scan for barn owls, and 2) broadcast of conspecific vocalizations. We recorded any individuals observed within ~250 m of point-count locations (visual detection) and when heard (aural detection) irrespective of distance (likely <500 m). We spent 16 min at each point-count location conducting three successive surveys. Survey 1 began with 5 min of silent listening and spotlighting. This was followed by survey 2 and 3, which each included 30 s of broadcast calling followed by 5 min of silent listening and spotlighting. By including broadcast only during survey 2 and 3, we were able to examine its effectiveness in improving detection relative to survey 1 which occurred without call broadcast. For broadcasting we used a FoxPro FX3 caller with pre-recorded barn owl vocalizations (typical screech calls from unknown sex barn owls, obtained from Stokes and Stokes 2010), broadcasted at 16 screeches min^{-1} at 105 dB(A) measured 1 m from the speaker (Fuller and Mosher 1987, Mosher and Fuller 1996). During each 30-s broadcast, we directed the speaker in the four cardinal directions for ~7.5 s each. We conducted point counts between 0.5 h after sunset and 0.5 h before sunrise and avoided surveying in persistent rain, dense fog (visibility ≤ 50 m), or when winds exceeded a score of 6 on the Beaufort scale (~40 – 50 km h^{-1}, Takats et al. 2001, Condon et al. 2005).

Number and timing of point counts

We conducted point counts at 222 locations (Fig. 2) from January–March 2014, which corresponded with the early-breeding season for barn owls; for instance, mean date of clutch initiation in nearby Utah is 13 March ± 5.9 (SD) days (Marti 1994). We revisited a sample of 66 of the 222 point-count locations in October–November 2014 to examine patterns of occupancy during the post-breeding period.

Detection and occupancy covariates

For each point count conducted, we recorded Julian date, time of sunset, and start and stop time of the 16 min spent

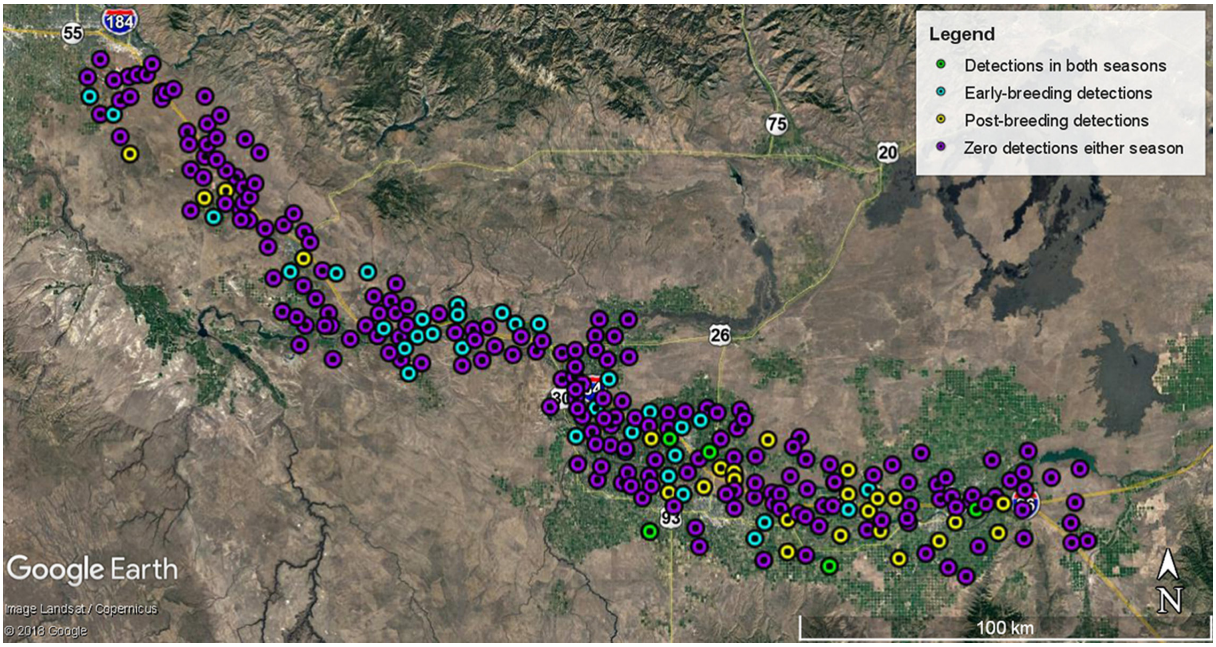

Figure 2. Point-count locations (n = 222) surveyed for barn owls in early- and post-breeding seasons (2014) in southern Idaho. Locations where barn owls were detected during one or both seasons or not detected are indicated. Shrub lands and disturbed grasslands appear as brown, lava flows are black, and croplands, as well as forests in mountainous regions north of our study area appear as green in the satellite image.

at each location, and we visually ranked fog into none, low (no effect on visibility) or moderate (visibility to ~300 m). We measured wind speed (km h^{-1}) and temperature (°C) using a handheld weather meter. Wind speed was measured three times during the 16-min survey period and averaged for the point count location, while temperature was measured a single time in the middle of the second survey. We used the mobile phone app 'Phases of the Moon' (Allaverdiev and Cain 2014) to estimate percent of potential moon illumination for a survey night. We also divided the sky into four quadrants, visually estimated the percent cloud cover in each quadrant, where 25% was maximum cloud cover per quadrant, and then summed quadrants to derive percent cloud cover. Using a handheld meter accurate to ± 1.5 dB, we measured background noise intensity in A-weighted decibels (dB[A]) twice per survey (total of six noise measurements at each point-count location) in the 31.5–8000 Hz range and used the average of the noise measurements at a point-count location in analyses. We categorized noise sources as road traffic, wind, or 'other.' And, because point-count locations often had multiple sources of noise, total occurrences sum to more than the number of point-count locations in results. Presence or absence of above-ground powerlines, fence posts, and trees at each point-count location was also recorded as these represented potential perching, roosting and, in the case of trees, nesting sites for barn owls, although we made no searches of the trees for cavities that might confirm their suitability as nest sites. We recorded time of barn owl detections, type of detection (aural, visual, or both), number of owls detected, and number and type of vocal responses.

Arc GIS and the 2011 National Land Cover Database (Homer et al. 2015) were used to estimate a suite of land cover, anthropogenic, and road variables (Table 1) within 1- and 5-km radius buffers centered on each point-count location to explore their potential relationship with barn owl occupancy. We deemed these distances relevant because 1 km corresponds to typical nightly foraging movements of barn owls, whereas 5 km more closely represents maximum estimated movements (Ramsden 2003, Marti et al. 2005, Regan 2016). We ultimately evaluated which of these spatial extents best explained occupancy and interpreted the corresponding 1- or 5-km models.

Data analysis – detection

Prior to formulating either detection or occupancy models, we screened variables for multicollinearity. We created a detection history from the three surveys per point-count location and explored the suite of detection variables (Table 1) using a forward stepwise variable selection procedure. The stepwise procedure retained covariates that lowered Akaike's information criterion (AIC, Akaike 1974) to create a final model of detection, which we then used in constructing models of occupancy. We generated detection models for the early- and post-breeding seasons and calculated probability of detection (p) for each. Occupancy (Ψ), the probability a species is present, was held constant during all detection analyses (MacKenzie et al. 2006).

Data analysis – occupancy

We used single-season models (MacKenzie et al. 2006) to estimate occupancy of barn owls separately for the early- and post-breeding seasons. There was one variable that prevented model convergence when analyzing early-breeding season occupancy, so it was removed (Table 1). Otherwise, final occupancy models were derived using stepwise forward variable selection with the land cover, road related, and other anthropogenic variables (Table 1) measured at the two spatial extents (1 and 5 km). We considered the model with the lowest AIC value to represent the better spatial extent for understanding occupancy.

Model performance

We evaluated performance of the early- and post-breeding season occupancy models using the area under the receiver operator characteristic curve (AUC, Zweig and Campbell 1993, Fielding and Bell 1997, Pearce and Ferrier 2000). Models with AUC between 0.5 and 0.7 are poor at distinguishing between an occupied and unoccupied site, models with values >0.7 are thought to be useful, those >0.8 are considered good, and models with AUC >0.9 are deemed excellent (Pearce and Ferrier 2000). As we used the same data to fit occupancy models and to calculate AUC, AUC values are best viewed as measures of model fit rather than measures of predictive ability.

Statistical analysis

We used the unmarked package (Fiske and Chandler 2011) for occupancy modeling in R ver. 3.0.1 (<www.r-project.org>) and the ROCR package for model performance evaluation and calculation of AUC (Sing et al. 2005). Odds ratios for detection and occupancy covariates, obtained by exponentiation of parameter estimates, are presented ± 95% CI. We calculated model-projected occupancy (± 95% CI) and display relationships across the range of observed covariate values for variables in final models.

Results

Early-breeding season

In the early-breeding season, barn owls were detected during 52 of 666 (7.9%) surveys and at 37 of 222 (16.7%) point-count locations. Most detections (48 of 52, 92.3%) occurred during the listening/observation period that followed call broadcast. Of the 52 barn owl detections, 67.3% were aural, 15.4% were visual, and 17.3% were a combination of visual and aural. Of the 17 visual detections, 57% occurred on nights when potential moon illumination was high (>91%). There were eight detections during survey 1 (1.2% of surveys and 3.6% of point-count locations), 22 in survey 2 (3.3% of surveys and 9.9% of point-count locations), and 22 during survey 3 (3.3% of surveys and 9.9% of point-count locations). The first detection to indicate barn owl occupancy at a survey point occurred eight times during survey 1 (15.3% of all detections), 18 times during survey 2 (35.0% of all detections), and 13 times during survey 3 (25% of all detections).

Table 1. Land cover, anthropogenic, road and detection variables evaluated in relation to barn owl detection and occupancy in southern Idaho, USA, 2014. Covariate values associated with naïve estimates of occupancy (i.e. barn owl detected or not detected at point-count location) calculated for 1-km radius buffers surrounding point-count locations in the early- (Jan–Mar, n = 222 point-count locations) and post-breeding seasons (Oct–Nov, n = 66 point-count locations) are shown.

			Early-breeding season		Post-breeding season	
Covariate	Description	Units	Occupied $\bar{x}$ ± SD min–max (n = 37)	Not-occupied $\bar{x}$ ± SD min–max (n = 185)	Occupied $\bar{x}$ ± SD min–max (n = 31)	Not-occupied $\bar{x}$ ± SD min–max (n = 35)
Land cover						
Percent water[1]	Percentage of water within buffer calculated from National Land Cover Database (NLCD2011)	%	2 ± 5 0–26	1 ± 3 0–22	0 ± 1 0–3	0 ± 1 0–3
Percent crops	Percentage of cultivated crops within buffer calculated from National Land Cover Database (NLCD2011)	%	52 ± 28 0–95	36 ± 33 0–96	54 ± 30 0–96	26 ± 33 0–92
Percent grassland	Percentage of grassland within buffer calculated from National Land Cover Database (NLCD2011)	%	15 ± 21 0–92	26 ± 29 0–98	14 ± 21 0–74	32 ± 31 0–96
Percent hay/pasture	Percentage of hay/pasture within buffer calculated from National Land Cover Database (NLCD2011)	%	17 ± 20 0–85	12 ± 17 0–82	14 ± 17 0–61	12 ± 21 0–85
Percent sage steppe	Percentage of sage steppe within buffer calculated from National Land Cover Database (NLCD2011)	%	9 ± 13 0–59	18 ± 21 0–90	11 ± 20 0–75	23 ± 26 0–90
Terrain roughness	Standard Deviation of the slope within buffer calculated from a digital elevation model (DEM) in GIS	%	6.46 ± 4.14 2.69–23.28	5.91 ± 4.10 2.80–37.80	5.65 ± 4.58 3.12–22.58	5.17 ± 1.64 3.28–10.46
Trees	Trees absent or present at a point-count location based on visual assessment	0/1	–	–	–	–
Distance from Snake River	Distance between point-count location and Snake River, measured in GIS	km	10.62 ± 8.58 0.35–30.24	16.93 ± 15.86 0.15–57.31	10.89 ± 9.50 0.60–38.82	27.86 ± 18.03 1.37–57.31
Stream length	Cumulative length of streams within buffer	km	2.13 ± 1.40 0.00–5.05	2.19 ± 1.71 0.00–7.53	2.46 ± 1.52 0.00–4.99	1.70 ± 1.48 0.00–5.10
Anthropogenic						
Background noise	Noise intensity at point-count location, mean of six readings	dB(A)	40.84 ± 4.41 34.38–52.40	43.01 ± 7.35 34.12–69.23	41.21 ± 4.77 35.80–54.30	43.98 ± 8.27 36.20 –70.92
Distance to nearest dairy	Distance between point-count location and nearest commercial diary, measured in GIS	km	10.93 ± 11.40 0.41–35.52	9.14 ± 7.66 0.58–34.59	5.97 ± 5.09 0.41–25.94	9.36 ± 6.86 1.15–27.79
Noise	Type of noise during survey (traffic, wind, and other)	noise category	–	–	–	–
Percent development	Percentage of development (combined low, medium, and high) within buffer calculated from National Land Cover Database (NLCD2011)	km^2	6 ± 2 3–11	7 ± 6 0–48	7 ± 2 3–13	8 ± 7 0–24
Fences	Fences absent or present at point-count location based on visual assessment	0/1	–	–	–	–
Powerlines	Above-ground distribution powerlines absent or present at a survey point based on visual assessment	0/1	–	–	–	–
Road						
Distance from Interstate 84	Distance between point-count location and Interstate 84, measured in GIS	km	7.39 ± 5.38 1.09–26.38	8.13 ± 6.27 0.05–22.62	8.05 ± 6.67 1.09–26.38	7.16 ± 5.65 0.06–22.62
Distance from major roads	Distance between point-count location and nearest State Highway, measured in GIS	km	4.97 ± 3.86 0.01–16.02	4.33 ± 3.87 0.00–21.08	4.06 ± 3.85 0.00–20.69	4.57 ± 3.87 0.03–14.06
Road length	Cumulative length of roads within buffer, measured in GIS	km	7.84 ± 3.90 1.99–17.23	7.77 ± 4.91 0–33.64	6.08 ± 3.02 1.40–15.28	7.92 ± 6.22 0.00–28.03

(Continued)

Table 1. Continued

Covariate	Description	Units	Early-breeding season: Occupied $\bar{x}$ ± SD min–max (n = 37)	Early-breeding season: Not-occupied $\bar{x}$ ± SD min–max (n = 185)	Post-breeding season: Occupied $\bar{x}$ ± SD min–max (n = 31)	Post-breeding season: Not-occupied $\bar{x}$ ± SD min–max (n = 35)
Detection						
Julian date	Julian date of point-count survey	Julian Day	40.61 ± 15.98 15–66	37.13 ± 17.97 13–66	306.19 ± 7.62 283–313	298.48 ± 11.06 283–313
Percent cloud cover	Calculated from visual assessment at each survey point at night	%	66.4 ± 36.2 0.00–100	51.2 ± 35.8 0.00–100	30.2 ± 33.6 0.00–95	31.4 ± 31.1 0.00–85
Sunset	Time of sunset	h: min	17:53 ± 00:25 17:25–18:35	17:39 ± 00:24 17:24–18:35	17:42 ± 00:37 17:19–19:09	18:16 ± 00:43 17:19–19:09
Percent potential moon illumination	Calculated from "Phases of the Moon" (Universe Today) cellular phone application	%	63.0 ± 38.7 2–99	58.6 ± 38.2 0–100	66.7 ± 42.4 1–99	60.6 ± 38.7 1–99
Broadcast call	Whether playback of barn owl vocalizations preceded the subsequent listening period	1 = yes, 0 = no	–	–	–	–
Fog	Calculated from visual assessment at each survey point at night	none/low/moderate	–	–	–	–
Wind speed (avg)	Measured twice per survey using handheld weather meter, average of six readings	km h^{-1}	1.5 ± 1.2 0.0–5.1	2.7 ± 2.2 0.0–19.7	2.5 ± 2.7 0.0–16.5	2.3 ± 1.7 0.0–7.2
Temperature	Measured once per survey using handheld weather meter, average of three readings	°C	4.9 ± 5.6 –4.6–14.3	1.6 ± 4.2 –6.6–13.6	7.7 ± 5.6 –0.5–18.7	10.4 ± 5.4 0.0–19.3
Background noise	Noise intensity at point-count location, mean of six readings	dB(A)	40.84 ± 4.41 34.38–52.40	43.01 ± 7.35 34.12–69.23	41.21 ± 4.77 35.80–54.30	43.98 ± 8.27 36.20 –70.92

[1]Removed from early-breeding season analysis because of lack of model convergence.

Barn owls uttered vocalizations during 44 detections (n = 110 individual vocalizations). Most (n = 106, 96.3%) were the screech call (1.9 ± 0.2 [SE] screeches per detection, range: 1–7). The other four vocal responses (3.6%) were high-pitched 'kewick' calls, which have chittering or twittering characteristics (Bunn et al. 1982). The kewick calls only occurred when >1 barn owl was detected at a point-count location, although there were other times when multiple owls were detected and no kewick calls were heard. We detected >1 barn owl at seven of 222 (3.2%) point-count locations (n = 6 two owls, n = 1 at least three owls).

Detection

Probability of barn owl detection during the early-breeding season was 0.32 ± 0.06 (SE). Detection increased with playback of barn owl calls and with increasing Julian date, percent potential moon illumination, and percent cloud cover (Table 2). Odds of detection were over four times higher with broadcast of barn owl vocalizations, and they increased by 1–3% for every one-unit increase in Julian date, percent potential moon illumination, and percent cloud cover, although the CI on the odds for potential moon illumination and cloud cover overlapped 1.0 (Table 2).

Sources of noise

Background noise intensity at point-count locations (n = 222) was 42.6 ± 0.3 (SE) dB(A), and there were no point-count locations devoid of noise [range: 34.12–69.23 dB(A)]. Road traffic was the most common source (192 of 222 point-count locations, 86.5%), followed by 'Other' (74 of 222 point-count locations, 33.3%), and wind (24 of 222 point-count locations, 10.8%). Although, background noise occurred at all point-count locations during the early-breeding season, noise was not among the variables in the final detection model (Table 2).

Occupancy

Occupancy models based on land cover, anthropogenic, and road-related variables measured at the 1-km spatial extent had a lower AIC than those measured at 5-km (Table 3). Thus, we selected the 1-km extent for examining correlates of barn owl occupancy in the early-breeding season.

Barn owl occupancy in the early-breeding season increased with percent of crops and presence of trees, and it decreased as background noise increased (Table 3, Fig. 3). Odds of occupancy increased by almost four times with the presence of trees and by 4% with each 1% increase in crop coverage (Table 3). Finally, odds of occupancy were only 0.9 of the previous level with each 1 dB(A) increase in background noise, although the CI for odds on this variable overlapped 1.0 (Table 3). Model performance was in the useful range with AUC = 0.7.

Post-breeding season

During the post-breeding season, barn owls were detected during 50 of 198 (25.3%) surveys and at 31of 66 (46.9%) point-count locations. Similar to the early-breeding season, most detections (86%, 43 of 50) occurred in the periods following broadcast calls. Of the 50 detections, 54% were aural, 22% were visual, and 24% were both visual and aural. Of the 23 visual observations, 84% were on nights when potential moon illumination was >91%. Six detections occurred in survey 1 (3.0% of surveys and 9.1% of point-count locations), 20 occurred in survey 2 (10% of surveys and 30.3% of point-count locations), and 24 occurred in survey 3 (11.9% of surveys and 36.4% of point-count locations). The first detection to indicate barn owl occupancy at a point-count location during the post-breeding season occurred six times during survey 1 (12%), 15 times during survey 2 (30%), and 10 times during survey 3 (20 %).

Barn owls vocalized during 39 detections (n = 70 vocalizations). Most vocal responses (n = 69, 98.5%) were the screech call (1.9 ± 0.3 [SE] screeches per response, range: 1–10). We heard the high pitched kewick call as a vocal response only once during the post-breeding period, but it occurred when multiple owls were detected. We detected multiple barn owls at 9 of 66 (13.6%) point-count locations (n = 6 instances of two individuals, n = 1 instances of three, and n = 2 instances of four).

Detection

Barn owl detection probability during the post-breeding season was 0.45 ± 0.07 (SE). Detection increased with playback of barn owl vocalizations, increasing Julian date, and lower background noise (Table 2). Odds of detection were over nine times higher with broadcast of barn owl vocalizations and increased by 11% with each 1-day increase in Julian date. With each 1-dB(A) increase in background noise, odds of detection were 0.9 of those at the previous level (Table 2).

Table 2. Covariates associated with barn owl detection in Idaho, USA in the early- (Jan–Mar) and post-breeding (Oct–Nov) seasons of 2014 derived using forward variable selection in an occupancy model framework. Odds ratios (OR) calculated from parameter estimates and their 95% CI (lower, upper limit) are shown.

Covariate	Estimate	SE	95% CI	OR	95% CI OR
Early-breeding season					
Intercept	–5.67	1.05	–7.72, –3.61	–	–
Broadcast call	1.45	0.45	0.57, 2.33	4.26	1.76, 10.30
Julian date	0.03	0.01	0.01, 0.05	1.03	1.01, 1.05
Percent potential moon illumination	0.02	0.01	0.00, 0.04	1.02	1.00, 1.04
Percent cloud cover	0.01	0.01	–0.01, 0.03	1.01	0.99, 1.03
Post-breeding season					
Intercept	–27.67	9.72	–46.72, –8.62	–	–
Broadcast call	2.22	0.55	1.14, 3.30	9.21	3.13, 27.06
Julian date	0.10	0.03	0.04, 0.16	1.11	1.04, 1.17
Background noise	–0.09	0.04	–0.17, –0.01	0.91	0.84, 0.99

Table 3. Final occupancy models for barn owls in Idaho, USA during the early- (Jan–Mar) and post-breeding (Oct–Nov) seasons of 2014 based on measurements at 1- and 5-km spatial extents around point-count locations. Parameter estimates (SE, 95% CI) and odds ratios (OR) with their 95% CI (lower, upper limit) are shown.

Covariates	Estimate	SE	95% CI	OR	95 % CI OR
Early-breeding season					
1-km model parameters					
Intercept	1.79	2.47	–3.05, 6.63	–	–
Percent crops	0.04	0.01	0.01, 0.06	1.04	1.01, 1.07
Trees	1.34	0.65	0.07, 2.61	3.82	1.07, 13.65
Background noise	–0.10	0.06	–0.22, 0.02	0.90	0.80, 1.02
5-km model parameters					
Intercept	2.15	2.21	–2.18, 6.48	–	–
Trees	1.17	0.66	–0.12, 2.46	3.22	0.88, 11.75
Distance from Snake River	–0.05	0.02	–0.09, –0.01	0.95	0.91, 0.99
Background noise	–0.09	0.05	–0.19, 0.01	0.91	0.83, 1.01
Stream length	0.21	0.02	0.17, 0.25	1.23	1.19, 1.28
Post-breeding season					
1-km model parameters					
Intercept	4.33	1.77	0.86, 7.80	–	–
Distance from Snake River	–0.15	0.04	–0.23, –0.07	0.86	0.80, 0.93
Percent development	–0.29	0.13	–0.54, –0.03	0.75	0.58, 0.97
Stream length	0.47	0.32	–0.16, 1.10	1.60	0.85, 3.00
5-km model parameters					
Intercept	6.97	3.62	–0.13, 14.07	–	–
Distance from Snake River	–0.12	0.04	–0.20, –0.04	0.89	0.82, 0.96
Percent water	–0.22	0.15	–0.51, 0.07	0.80	0.60, 1.07
Background noise	–0.10	0.08	–0.26, 0.06	0.90	0.77, 1.06

Early breeding 1-km model AIC = 292.86.
Early breeding 5-km model AIC = 300.55.
Post breeding 1-km model AIC = 169.20.
Post breeding 5-km model AIC = 173.11.

Sources of noise

Background noise during post-breeding season point-counts (n = 66) averaged 42.7 ± 0.5 (SE) dB(A) and ranged from 35.4 to 79.0 dB(A). Main sources were road traffic (57 of 66 locations, 86.4%), and 'Other' (17 of 66 locations, 25.8 %). Similar to during the early-breeding season, background noise was recorded at all point-count locations, but noise was among the variables in the final detection model for the post-breeding season (Table 2).

Occupancy

Similar to the early-breeding season, the final post-breeding season occupancy model had a lower AIC at the 1-km spatial extent (Table 3). This model suggested that barn owl occupancy increased with stream length and decreased with percentage of land cover in development and with distance from the Snake River (Table 3, Fig. 4). Odds of barn owl occupancy increased by 1.6 times with each 1-km increase in stream length and were just ~0.8 of those at the previous level with each 1% increase in development (Table 3). Odds of occupancy were 0.9 those of the previous value with each 1-km increase in distance from the Snake River (Table 3). Model performance was good with an AUC = 0.9.

Discussion

Our results provide information associating landscape and anthropogenic features to occupancy of a nocturnal avian species, and can potentially be useful for conservation and management where barn owls are declining within their worldwide range. Our study showed that when including call broadcasts in point-count surveys for barn owls, detection probability increased significantly during both seasons of study. Analysis of point-count data also revealed that that barn owl occupancy was influenced by the presence of trees, croplands and noise during the early-breeding season while distance from a major geologic feature, development, and streams were important during the post-breeding season.

The role of broadcast calls in facilitating detection of barred owls *Strix varia*, great horned owls *Bubo virginianus*, flammulated owls *Otus flammeolus*, screech-owls *Megascops* spp., northern saw-whet owls and other species is well documented (Takats et al. 2001, Barnes and Belthoff 2008, Kissling et al. 2010). Barn owls have been considered unresponsive, so broadcast surveys were not always recommended (Sara and Zanca 1989, Shawyer 2011). However, broadcast of barn owl vocalizations improved detection probability by nine times in our study, and detection was enhanced by broadcast during both early- and post-breeding seasons. On the island of La Gomera, Spain, where barn owls occur at very low densities, broadcasted vocalizations elicited barn owl vocal responses three times during 65 surveys, and Siverio et al. (1999) believed these owls would have gone undetected without broadcast calls. Wingert and Benson (2018) also found detectability of barn owls in Illinois, USA increased with call broadcasts when playing vocalizations near known nests. Thus, evidence that call broadcasts reduce false conclusions of absence during barn owl surveys has accumulated. However, even with aid of broadcasted vocalizations, the barn owl detection probabilities we observed were lower than for other owl species. For instance, detection

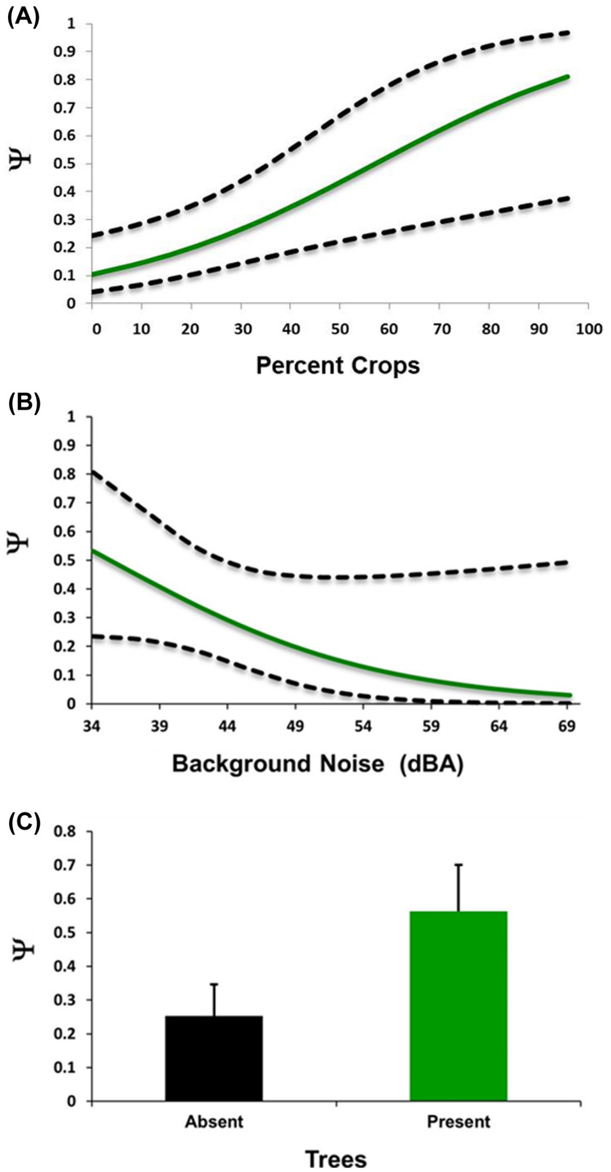

Figure 3. Model predicted relationships (± 95% CI) between barn owl occupancy (Ψ) and (A) percent crops, (B) background noise, and (C) presence/absence of trees during the early- breeding season in southern Idaho, USA.

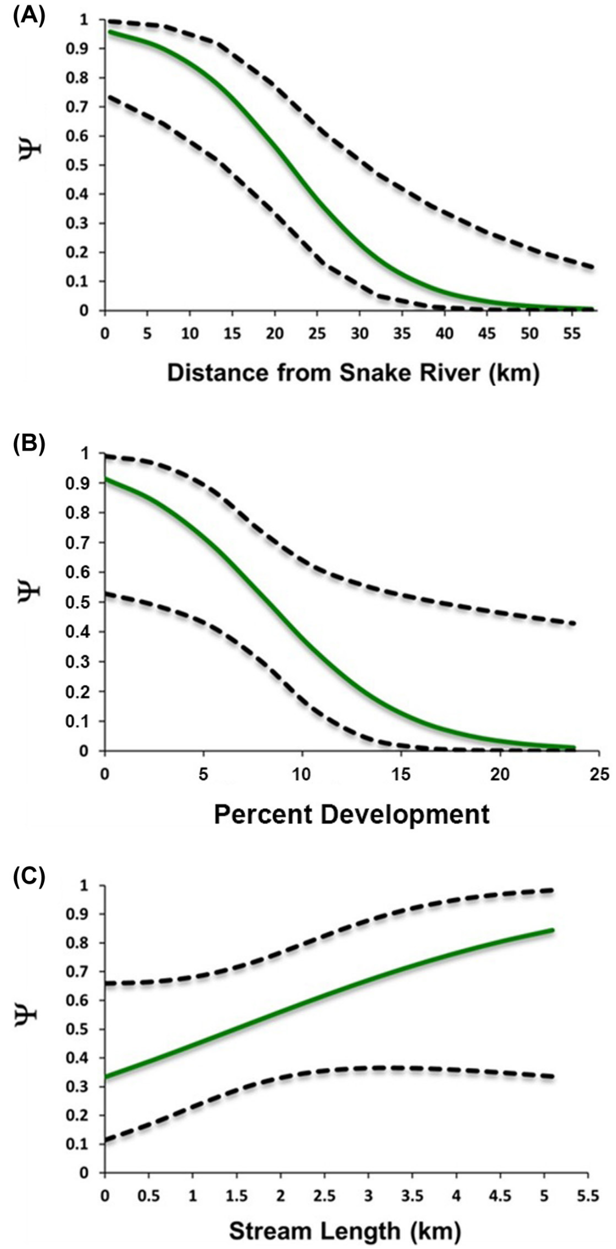

Figure 4. Model predicted relationships (± 95% CI) between barn owl occupancy (Ψ) and (A) distance from the Snake River, (B) percent development, and (C) stream length in southern Idaho, USA during the post-breeding season.

during call broadcast surveys for flammulated owls and northern saw-whet owls was close to 1.0 and 0.77 respectively, when estimated using occupancy modeling based on repeat surveys similar to our approach (Scholer et al. 2014) and with other methods (Barnes and Belthoff 2008).

The temporal effect of Julian date on barn owl detection during the early-breeding season could correspond to increasing breeding activities such as vocalizations, courtship and defense of nesting territories. We think that higher detection with increasing Julian date during the post-breeding season could have been influenced by increased interactions between territorial adults and juveniles across the landscape as the fledging/dispersal season progressed (Ritchison et al. 1988, Marti et al. 2005, Tomé and Valkama 2001). The trend toward increased detection with moon illumination may be related to the link between activity of owls and moonlight. For example, elf owl *Micrathene whitneyi* singing increases under brighter moon phases (Hardy and Morrison 2000), and eagle owls *Bubo bubo* call and display a white throat patch visible to others more frequently on moonlit nights (Penteriani et al. 2010). Thus, any tendency for barn owls to be more active during lunar phases with more illumination could help explain the trend in detection. Indeed, the majority of visual observations of barn owls in both the early- and post-breeding seasons occurred when potential moon illumination was at its highest (91–100%).

Background noise could have operated to reduce barn owl detection through several processes. Among these are 1) its potential to interfere with the ability of surveyors to detect vocalizations, and 2) the potential for noise to alter rates or characteristics of vocalizations and activity patterns (Goodwin and Shriver 2011, Oden et al. 2015). It is not clear why background noise would not have had similar effects on detection during both seasons, as average noise levels were similar between them. Nonetheless, detection of western screech-owls *Megascops kennicottii*, northern saw-whet owls, and flammulated owls is similarly lower under high noise conditions (Kissling et al. 2010, Scholer et al. 2014).

The timing of our post-breeding season surveys most likely overlapped a portion of the time period of dispersal, which would have included an influx of young barn owls into the population (Taylor 1994, Marti 1999, Marti et al. 2005). Compared to adults, juvenile owls are not well established on home ranges (Taylor 1994), and juvenile and adult owls may interact more frequently during this time (Ritchison et al. 1988). Therefore, the greater detection probability that we observed during the post-breeding season could have been associated with a population that included both adults and young of the year. In Portugal, Tomé and Valkama (2001) similarly detected fewer owls during the early-breeding season compared to the post-breeding season and documented an increase in abundance of barn owls from late summer to mid-autumn, concomitant with the period of juvenile dispersal.

We found that trees and crops had some of the strongest influences on occupancy during the early-breeding season, perhaps because of their potential importance for nesting and prey resources associated with successful reproduction. Both barn owls and their primary prey source, small mammals, can be plentiful in agricultural landscapes (Taylor 1994, Tomé and Valkama 2001, Marti et al. 2005, Martin et al. 2010). Agricultural lands were among the few areas with trees, which were often located near human structures and along irritation channels in the shrub-steppe dominated landscape in our study area. The positive association between barn owls and croplands and trees that we observed is consistent with other studies that link declines in occupancy and breeding success of barn owls to loss of nest and roost sites (Colvin 1985, Percival 1992, Taylor 1994, Hindmarch et al. 2012). For example, urbanization of farmlands and removal of open barns and trees led to habitat loss for barn owls in British Columbia, Canada (Hindmarch et al. 2012).

Although noise negatively affects detection rates of some owl species (Kissling et al. 2010, Scholer et al. 2014), it did not appear to affect occupancy for those species. In contrast, we noted a trend for occupancy of barn owls to decline with increasing noise. In fact, three of the four top models developed for both seasons (Table 3) included the variable background noise, and the parameter estimate for noise in each was of similar magnitude (–0.1– –0.09). We are currently learning more about how birds, including owls, respond to noisy environments (Francis et al. 2009, Francis and Barber 2013, McClure et al. 2013, Ware et al. 2015, Mason et al. 2016). For instance, northern saw-whet owls *Aegolius acadicus* are unwilling to hunt *Mus musculus* under high noise [61 dB(A)] treatments in controlled experiments (Mason et al. 2016). Coincidently, this sound intensity level of 61 dB(A) overlaps that level where barn owl occupancy dropped to zero in our study (Fig. 3). Noise disrupts breeding activities in other avian species (Halfwerk et al. 2011, Kight et al. 2012, Strasser and Heath 2013), and one reason why burrowing owls *Athene cunicularia* may avoid roads is that high traffic noise may impede vocal communication between mates and with offspring (Scobie et al. 2014). Barn owls can hunt almost exclusively by sound, and their hearing is some of the most sensitive ever tested (Knudsen 1981); thus, barn owls could be especially affected by noisy environments.

We believe the pattern for barn owl occupancy to increase near the Snake River canyon, in less developed areas, and in sites with longer stream segments during the post-breeding season was at least partially related to roost site and prey availability. Barn owls prefer less exposed roost sites, e.g., far back in crevices or in areas with low visibility/high cover (Rudolph 1978). The Snake River canyon provides this habitat to barn owls (Marti 1988, Boves and Belthoff 2012) because of numerous cavities and crevices in its rocky cliffs. Development can reduce habitat for small rodents and therefore hunting opportunities for barn owls (Hindmarch et al. 2012). The restricted distribution of trees, e.g. mainly near farmsteads and riparian corridors, probably contributed to the positive association between streams and barn owl occupancy. Small mammal abundance along stream buffers can be two-three times greater than surrounding crop fields regardless of the type of farming practice (Chapman and Ribic 2002), so riparian areas might be rich hunting habitat for owls. Meadow voles *Microtus pennsylvanicus*, important prey of barn owls (Marti et al. 2005, Marti 2010), are common within stream buffers (Chapman and Ribic 2002), and breeding success often increases with greater proportions of voles in barn owl diets (Gubanyi et al. 1992, Taylor 1994). Finally, river courses may also provide travel and dispersal corridors for barn owls (Shawyer 1998, Tomé and Valkama 2001).

Barn owls appear to be particularly susceptible to vehicle collisions along roads, and owl-vehicle collisions are geographically quite widespread (Moore and Mangel 1996, Massemin et al. 1998, Ramsden 2003, Grilo et al. 2012, 2014, Bishop and Brogan 2013, Loss et al. 2014, Belthoff et al. 2015). Mortality hotspots are often associated with agricultural landscapes and with high vehicle speeds and traffic volume (Illner 1992, Ramsden 2003, Boves and Belthoff 2012, Arnold et al. 2018). Even though we included analysis of distance from major roads and cumulative road lengths within buffers surrounding point-count locations, owl occupancy was not associated with these variables in either season.

Conclusions

Reduced occupancy in developed lands suggest that barn owl declines would most certainly occur if farmlands and riparian corridors were converted to more intensive development such as suburbs, shopping centers, or industrial complexes. Furthermore, because we found potential influences of anthropogenic sources of noise on barn owl occupancy and detection, the extent to which pervasive noise interferes with the acute hearing or other aspects of barn owl biology deserves further study. Finally, because detection probability in barn owl point-count surveys was substantially increased with call broadcasts during both seasons of study, future barn owl point-count surveys may benefit from call broadcasts.

We suggest that the silent listening period that we employed at the beginning of surveys be dropped, and that nighttime surveys simply begin with broadcast of barn owl vocalizations because of its effectiveness in improving detection.

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Permis – Boise State University's Institutional Animal Care and Use Committee reviewed and approved all field protocols (approval no. 006-AC13-016) prior to study, and research activities were authorized under appropriate agency permits.
Author contributions – All authors formulated the research questions and study design, and JRB and TR arranged funding for the study. TR collected data and conducted the research as part of the requirements for a graduate degree. All authors analyzed data and wrote the manuscript.

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