



## A novel approach to estimating density of American badgers (*Taxidea taxus*) using automatic cameras at water sources in the Chihuahuan Desert

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American badgers (*Taxidea taxus*) are large members of the weasel family Mustelidae. Badgers are important predators and creators of burrows in ecosystems in which they occur, but they are not well studied. Their range occurs over most of North America; however, most studies of badgers have occurred in California and the northern portions of their range, while few have occurred in southern habitats. Badger density has been estimated in Utah, Idaho, Wyoming, and British Columbia with no estimates from desert habitats. To measure badger density in a desert habitat, we placed automatic cameras at anthropogenic water sources (drinkers) in the Chihuahuan Desert, identified individual badgers by their dorsal head stripes, and estimated density using spatially explicit capture-recapture analysis. We modeled the detection process for individuals as a function of time, survey region, a learned and trap-specific behavioral response, and a finite mixture model. We then hypothesized that soil composition, soil depth, and land cover influence variation in badger density. From 1,282 camera-nights, we recorded 301 badger visits (23.5 visits per 100 camera-nights) and identified 30 individuals 170 times. The top model included a trap-specific behavioral effect for  $\lambda_0$ , a finite mixture model for the  $\sigma$  parameter, which controls the spatial scale over which the expected number of detections declines, and indicated that soil depth was an important covariate explaining variation in badger density. Estimated badger density was 0.10 badgers/km<sup>2</sup> (95% CI = 0.03–0.31), which is considerably less than the reported density estimates for nonendangered nondesert populations. Our method helps provide researchers with an ability to estimate density for American badgers in arid ecosystems. With modification, our method may be used across the geographic range of badgers, facilitating better understanding of an understudied species.

Key words: American badger, anthropogenic water source, camera trap, Chihuahuan Desert, density, dorsal head stripe, SECR, spatially explicit capture-recapture, *Taxidea taxus*

American badgers (*Taxidea taxus*) are large members of the weasel family Mustelidae. Badgers are charismatic (Justice 2015) and can be important members of ecosystems in which they occur due to their creation of burrows and soil mounds (Eldridge 2004). They are also significant predators of fossorial rodents and may consume birds, amphibians, insects, and plant material (Lindzey 2003). American badgers occur in the United States from the Pacific coast to Texas and Ohio, in Canada from British Columbia to Ontario, and in Mexico from the United States border to the central states of Jalisco and Guanajuato (Lindzey 2003), but they are not well studied. The lack of research is in part due to the low value of badger fur (Larivière 2014), low natural abundance, and the nocturnal and secretive

behavior of badgers. In particular, there are only a few outdated estimates of badger population density. Estimation of density is of interest for understanding basic ecology, but perhaps more importantly, it allows estimation of absolute population sizes in areas of similar habitat beyond the study area. These latter estimates may then be used by wildlife managers to regulate commercial fur trapping, which has the potential to over-exploit populations (Obbard et al. 1987). Indices of relative abundance, while often used by managers, do not provide as precise an understanding of the status of a species' population.

Most studies of badgers have occurred in California and the northern portions of their range (Lindzey 2003) while few have occurred in southern habitats or in deserts (Lindzey

1971; Lopez Soto 1980; Messick and Hornocker 1981; Minta and Mangel 1989; Goodrich and Buskirk 1998; Klafki 2014; Harrison 2016b). However, many desert areas have permanent anthropogenic water sources (drinkers) placed for the benefit of wildlife and livestock by game management agencies, ranchers, and others (Rosenstock et al. 2004). Badgers have been observed to visit drinkers throughout the year and may be readily photographed there (Harrison 2015).

Harrison (2016a) reported that individual American badgers may be identified by features of their dorsal pelage, opening the possibility that studies of population parameters and behavior may be conducted noninvasively with automatic, remotely triggered cameras placed at drinkers. Previous studies reporting American badger density used leg-hold live trapping with or without subsequent marking to identify individuals (Lindzey 1971; Messick and Hornocker 1981; Minta and Mangel 1989; Warner and Ver Steeg 1995; Goodrich and Buskirk 1998; Lindzey 2003). Trapping is, in general, inefficient and time-consuming compared to other methods of locating badgers (Harrison 2015) and presents a significant risk of injury to animals. The use of cameras offers the advantages over trapping of greater sample sizes, higher detection rates, no risk of injury, and multiple capture events during a survey occasion compared to a single live-capture trap. Higher detection rates also lead to better estimates of the point process for density, which may allow modeling density variation with covariates such as soil composition and land cover.

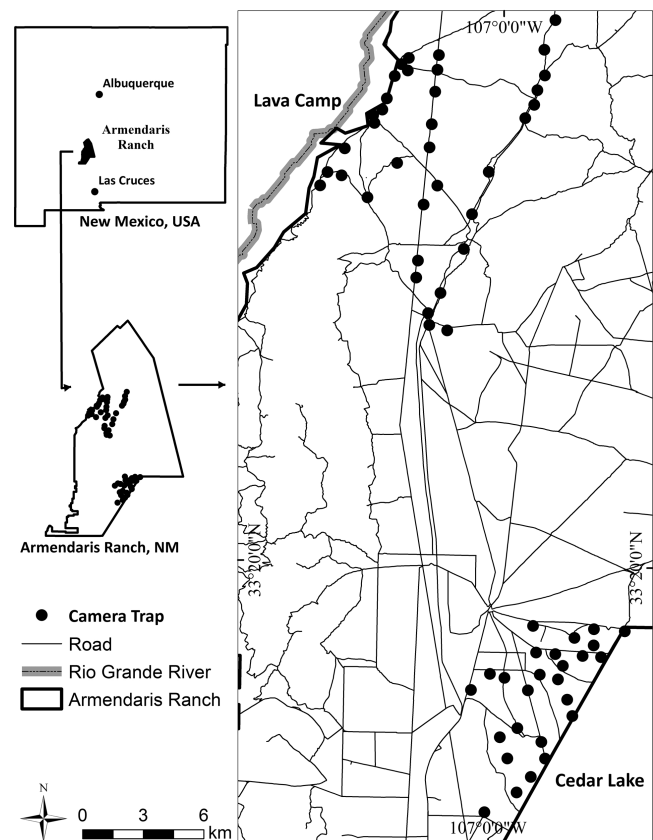
Most previous estimates of badger density were generated by simply dividing the captured or estimated population by the size of the overall study area, thus assuming the effective trapping area was the same as the overall study area. This is not an ideal procedure for geographically open populations in which individual home ranges may cross study area boundaries thus biasing abundance and density estimates (Foster and Harmsen 2012). Spatially explicit capture-recapture (SECR) models (Efford 2004; Borchers and Efford 2008), however, have provided researchers the ability to estimate density for geographically open populations. In short, SECR relates the distribution of latent activity patterns through a spatial point process model to an observation model that estimates the probability of detecting an animal given the distance between its activity center and a detector (Borchers and Efford 2008). Doing so allows density to be estimated directly without the need of estimating an effective trapping area and accounts for individual capture heterogeneity associated with the distribution of detectors relative to latent activity centers on the landscape (Efford and Mowat 2014).

To measure badger density in a desert habitat, we took advantage of an unusually high density of drinkers on a private ranch in the Chihuahuan Desert. We photographed badgers with automatic cameras placed at the drinkers, identified individual badgers by their dorsal pelage, and estimated badger density using a SECR analysis.

## MATERIALS AND METHODS

**Study area.**—We conducted our study in the Chihuahuan Desert on the 142,000-ha Armendaris Ranch, a private bison

(*Bison bison*) and hunting ranch in Sierra and Socorro counties in south-central New Mexico (Fig. 1). The study area was dominated by black grama grass (*Bouteloua eriopoda*) and shrubs, creosote bush (*Larrea tridentata*), honey mesquite (*Prosopis glandulosa*), longleaf jointfir (*Ephedra trifurca*), sand sagebrush (*Artemisia filifolia*), and little-leaf sumac (*Rhus microphyllum*). Topography was flat or low rolling hills and elevations were 1,300–1,500 m. Annual precipitation falls mostly in summer and fall and averaged 23.6 cm from 1951 to 2010 and 20.7 cm during field work (Western Regional Climate Center 2014). Average monthly minimum and maximum temperatures were 8.0°C and 23.7°C, respectively from 1951 to 2010 and 9.0°C and 24.2°C, respectively, during this study. Trapping was not allowed on the Armendaris Ranch other than for research. Drinkers for a quail (*Callipepla* spp.) hunting program were located throughout the Armendaris Ranch along roads at intervals of 1–2 km (Fig. 1; Rollins et al. 2006). Within the study area, the average minimum Euclidean distance between drinkers was 0.81 km ( $SD = 0.34$  km). Drinkers consisted of 2,000-liter reservoirs accessed by 150 × 20 cm openings and filled via sheet metal rainfall collectors ( $n = 59$ ) or concrete aprons ( $n = 3$ ). There were no natural water sources within the study area other than ephemeral pools created by precipitation events.



**Fig. 1.**—Location of American badger (*Taxidea taxus*) study sites in the Chihuahuan Desert on the Armendaris Ranch, New Mexico, United States, 2012. Dots indicate locations of cameras set at drinkers to estimate badger density. Cameras were set at all drinkers within the study areas.

There were no buildings within the study area and all roads were 2-track or 1-lane dirt. Vehicle traffic on roads was limited to ranch personnel and was low with at most only a few vehicles per day.

**Camera trap survey and individual identification.**—We set 62 total camera traps across the Lava Camp ( $n = 36$ ) and the Cedar Lake ( $n = 26$ ) survey regions from 28 May to 4 September 2012 in a temporally staggered fashion (Fig. 1). The 2 survey regions were 9,311 and 3,673 ha with 1 site/2.6 km<sup>2</sup> and 1 site/1.4 km<sup>2</sup> per region, respectively, based on a minimum convex polygon encompassing cameras in each region. The Euclidean distance between the 2 study areas was 15.0 km. We deployed 2 groups of 9 cameras in Lava Camp and 2 groups of 6 and 8 cameras in Cedar Lake. We relocated 3 of 4 camera groups to new drinkers in Lava Camp after 21 days and the fourth after 20 days. Set dates for each group were 28 May 2012, 12 June 2012, 18 June 2012, and 2 July 2012. In Cedar Lake, our deployment lengths were 21 days for 3 of 4 groups with the 4th group relocated after 28 days. Set dates for each group were 16 July 2012, 23 July 2012, 15 August 2012, and 16 August 2012. We sampled the Lava Camp region first, with 1 week of sampling overlap between the Lava Camp and Cedar Lake regions.

We used 1 automatic infrared-flash digital camera (Reconyx HC600 or PC900, Holmen, Wisconsin) at each drinker, placing the camera 1 m from the drinker opening. The detection zone encompassed the entire drinker opening and was approximately 2 × 5 m in surface area. We programmed our cameras to be active 24 h/day and to take photographs in bursts of 3 with a 1-s delay between bursts. Sensitivity was set to high. We identified individual badgers using the variability and unique patterns of badgers' white-dorsal head stripes (Fig. 2; Harrison 2016a). We compared facial scars, overall stripe shape, and unique nicks in

each dorsal head stripe. We ensured cameras were placed at a close enough distance to capture a clear picture and excluded all pictures that lacked clarity for unique identification or in which badgers were not facing cameras. Our field research protocols followed Sikes et al. (2016); we did not handle any badgers, requiring no animal care and handling permits.

**Density estimation.**—We estimated badger density using the “secr” package (version 3.0.1—Efford 2017) in the R software version 3.4.0 (R Core Team 2017) to construct likelihood-based SECR models. We collapsed daily camera trapping data from both regions together into 7, 14-day sampling occasions from which we created input files. These input files consisted of a capture history (i.e., individual ID, camera trap ID, occasion detected, and region detected) and camera trap (i.e., camera trap ID, Cartesian coordinates, occasion sampling history, region, and camera trap related landscape covariates) file. We allowed for varying effort in our modeling to accommodate the cameras being deployed in a temporally irregular fashion (Efford et al. 2013).

By maximizing the full-likelihood, we estimated model parameters for 2 submodels: the state submodel (i.e. density:  $D$ ) and the observation submodel ( $g_0$  and  $\sigma$ ). The state submodel describes the distribution of latent animal activity centers on the landscape during the sampling time period ( $D$ ) while the observation model relates detection probability ( $g_0$ ) at a detector to the spatial scale over which  $g_0$  declines as the distance between an animal's activity center and the detector ( $\sigma$ ) increases. We modeled  $D$  as an inhomogeneous Poisson spatial point process to explore how  $D$  varies with spatial covariates and to compare with constant density represented by a homogeneous Poisson spatial point process (Borchers and Efford 2008). Each point within the point process represented a putative home range of



**Fig. 2.**—Example of 3 individual American badgers (*Taxidea taxus*) photographed at drinkers in the Chihuahuan Desert, New Mexico, United States. Close-range photography is necessary for individual identification using the white dorsal head stripe. The same badger is pictured in the 2 left photographs.



an individual and density variation is examined by estimating the intensity of the point process in relation to covariate values. Because camera traps are proximity “count” detectors allowing  $> 1$  detection of an individual per sampling occasion at  $\geq 1$  camera trap, we substituted  $\lambda_0$  (the expected number of encounters per unit time of an individual) for  $g_0$  (the probability of detecting an individual at its activity center) into our observation submodel. We assumed that the mean  $\lambda_0$  for individual  $i$ , at camera trap  $k$ , on occasion  $s$  was a Poisson random variable (Borchers and Efford 2008). In addition, we assumed the shape of the detection function in the observation submodel was a hazard exponential, which is parameterized relative to the number of detections and is appropriate when using a “count” detector (Efford 2017).

Spatially explicit capture-recapture models require an area of integration, i.e., a habitat mask, from which density is estimated at specific points across a region where all individuals with a non-zero chance of detection occur (Ivan et al. 2013). Individuals may reside outside the habitat mask; however, these individuals should have a negligible detection probability (Borchers and Efford 2008). We defined our habitat mask by buffering camera traps by 3.1 km (using the suggest.buffer function) resulting in an area of integration that was 33,664 ha with mask spacing set at 400 m (Efford 2017). Within the mask, we treated open water (i.e., Cedar Lake) as nonhabitat and limited the western boundary of the mask by the Rio Grande River, which we viewed as a hard boundary to badger movement (Fig. 1, but see Weir et al. 2003).

We hypothesized that badger density may vary spatially by 3 landscape covariates: soil composition (comp), soil depth (depth, cm), and land cover type (cover). We hypothesized that soil composition and soil depth may be important if badgers distribute themselves based on soil characteristics that may influence den excavation. We also hypothesized that density may vary by the distribution of land cover types as badgers have shown preferential selection in land cover for den sites (Collins et al. 2012). Soil depth was a continuous covariate we extracted from the Soil Survey Geographic (Soil Survey Staff 2016) database using the Web Soil Survey. We categorized soil composition based on Levi and Bestelmeyer (2016) resulting in 6 categories: bottomland, clayey, loamy, loamy-skeletal, sandy, and shallow-not-sandy. We chose LANDFIRE’s 30 m Society of American Foresters & Society of Range Management cover type classification dataset (Rollins 2009) to represent the land cover for our study area. We used the bursage, grassland, lava, mesquite, and tarbush classifications and collapsed all other classifications into an “other” category. We speculate that soil composition and soil depth may also represent the distribution of fossorial and colonial rodents. We extracted all landscape covariates using ArcGIS 10.2.1 (Environmental Systems Research Institute, Inc. [ESRI], Redlands, California).

We also hypothesized that the parameters in our observation submodel ( $\lambda_0$  and  $\sigma$ ) are likely to vary over the course of our survey by 3 factors: time (t), survey region (reg), a learned (b) and trap-specific (bk) behavioral response, and a finite mixture model with 2 unknown mixture classes (h2). We chose these

factors to account for potential changes in detection over time due to the onset of seasonal rains or the breeding season since the Lava Camp survey occurred outside the breeding season while Cedar Lake survey occurred during. We assumed that the breeding season in New Mexico is similar to populations farther north, which is late July–August (Lindzey 2003). We included a behavioral response to investigate the effect of water as an attractant to badgers. We used a mixture model to represent biological differences between movement rates and home range sizes of males and females as we were unable to determine sex from the photographs. We note, however, that our mixture model may reflect individual heterogeneity present in the data that may not be equated to sex.

We used a multistep modeling process to determine the best model structure for the observation submodel parameters first and potential variation in density second. We selected this approach because in addition to estimating density, we were interested in determining which factors were important in detecting badgers (Doherty et al. 2012). First, we modeled  $\lambda_0$  and  $\sigma$  independently and concurrently as a function of time, survey region, or a finite mixture model (Borchers and Efford 2008). We then concurrently modeled  $\lambda_0$  and  $\sigma$  as a function of all additive combinations of the 3 factors. We modeled a learned or trap-specific behavioral effect only on  $\lambda_0$ . During this time, we modeled D as a function of land cover to account for variation in D that might influence the structure of the observation submodel (Table 1). We ranked and evaluated this model set using Akaike’s Information Criterion adjusted for small sample size ( $AIC_c$ —Hurvich and Tsai 1989; Burnham and Anderson 2002). We then took the top model’s parameter structure and used it to model variation in density as a function of soil composition, soil depth, land cover, or constant. We based our model rankings on the difference in  $AIC_c$  scores ( $\Delta AIC_c$ ) between the top-ranked model and the competing models and used the  $AIC_c$  weights ( $w_i$ ) to compare proportional support for each model (Burnham and Anderson 2002). We also estimated model deviance by multiplying the log-likelihood for each model by  $-2$ . We used model averaging if the top model did not receive  $\geq 0.90$  of the model weight.

## RESULTS

*Camera trap survey and individual identification.*—From a total of 1,282 camera-nights, we recorded 301 visits by badgers (23.5 visits per 100 camera-nights), of which 160 visits yielded photographs useful for identification (53.2% of visits or 12.5 individual identifications per 100 camera-nights). We identified  $n = 30$  total individuals ( $n = 18$  Lava;  $n = 12$  Cedar)  $n = 170$  total times ( $n = 117$  Lava;  $n = 53$  Cedar). The average maximum distance moved by individuals was 1.97 km. Twenty-five of 30 (83%) individuals were recaptured at multiple drinkers. We did not detect any individuals in both survey regions.

*Density estimation.*—Our most supported observation submodel included a finite mixture term for the spatial scale over which detection declines,  $\sigma$ , but only received half the model

**Table 1.**—Spatially explicit capture-recapture model selection results for estimating American badger (*Taxidea taxus*) density in the Chihuahuan Desert of New Mexico, United States in 2012. We used a multistep modeling process to determine the best model structure for the observation submodel first and variation in the state model (i.e., density) second. First, we modeled  $\lambda_0$  (the expected number of encounters per unit time of an individual) and  $\sigma$  (the distance over which detection declines) as a function of a learned (b) and trap-specific (bk) behavioral response, a finite mixture model (h2), no variation (1), region (reg; i.e., Cedar Lake or Lava Camp), and time (t). We held density (D) as a function of land cover type (cover) to account for variation in density that may be influencing the observation submodel. Second, we modeled the state model using the top model alone ( $\lambda_0[1]$ ,  $\sigma[h2]$ ), the 2nd-ranked model alone ( $\lambda_0[bk]$ ,  $\sigma[1]$ ), and the combined model structure from the top and 2nd-ranked models ( $\lambda_0[bk]$ ,  $\sigma[h2]$ ) from the observation submodel modeling process. We modeled D as a function of no variation, soil composition (comp), soil depth (depth), and land cover type. We only show models that received model weight.

Modeling process	Model	K <sup>a</sup>	$\Delta AIC_c^b$	$w_i^c$	Deviance
Observation submodel	D(cover) $\lambda_0(1)$ $\sigma(h2)$	10	0.00	0.50	701.83
	D(cover) $\lambda_0(bk)$ $\sigma(1)$	9	0.59	0.37	706.99
	D(cover) $\lambda_0(h2)$ $\sigma(h2)$	11	4.01	0.07	700.75
	D(1) $\lambda_0(1)$ $\sigma(1)$	3	5.23	0.04	731.72
	D(cover) $\lambda_0(b)$ $\sigma(1)$	9	5.51	0.03	711.91
State model	D(depth) $\lambda_0(bk)$ $\sigma(h2)$	7	0	0.54	678.84
	D(1) $\lambda_0(bk)$ $\sigma(h2)$	6	0.33	0.46	682.61

<sup>a</sup> Number model parameters.

<sup>b</sup> Relative difference between  $AIC_c$  of the  $i$ th ranked model and the top-ranked model.

<sup>c</sup> Model weight.

weight ( $w_i = 0.50$ ). The 2nd-ranked model included a trap-specific behavioral effect (bk) for  $\lambda_0$ , held  $\sigma$  constant, and received  $w_i = 0.37$  of the model weight. The 3 remaining models garnered the little remaining model weight ( $w_i = 0.14$ ) and included a finite mixture term for both  $\lambda_0$  and  $\sigma$ , held all parameters constant (i.e., the null model), and a behavioral effect on  $\lambda_0$  (Table 1). Variation in badger detection as a function of time or region did not receive any model support. Given the competitiveness between the top 2 models ( $\Delta AIC = 0.59$ ), we decided to incorporate the parameter structure from both models in the density modeling process. We did so by modeling density using the observation submodel from 3 scenarios: the top model alone, the 2nd-ranked model alone, and the combined model structure from both the top and 2nd-ranked models. The resulting top state model included the model structure from both the top and 2nd-ranked models in our observation submodel modeling process ( $\lambda_0[bk]$ ,  $\sigma[h2]$ ). The top state model supported badger density varying by soil depth with density increasing as depth increased (Table 1; Fig. 3) although the 95% confidence interval (CI) indicated no significant effect ( $\beta = 0.0072$ ; 95% CI =  $-0.0010$  to  $0.016$ ). Variation in badger density as a function of soil composition or land cover type did not receive any model support. There was considerable model selection uncertainty with the top model for density garnering 54% of the model weight and the 2nd-ranked model, which held density constant, receiving 46% (Table 1).

The estimated density for the top 2 models was 0.07 badgers/km<sup>2</sup> (95% CI = 0.04–0.21) and 0.15 badgers/km<sup>2</sup> (95% CI = 0.10–0.22), respectively. Model averaging the 2 models resulted in an estimated density of 0.10 badgers/km<sup>2</sup> (95% CI = 0.03–0.31). The mixture proportion was  $h_1 = 0.79$  (95% CI = 0.57–0.91) and  $h_2 = 0.21$  (95% CI = 0.09–0.43). The estimated baseline encounter rate was  $\lambda_0 = 0.80$  (95% CI = 0.53–1.23) with trap-specific behavioral response of  $\lambda_{0,bk} = 0.31$  (95% CI = 0.19–0.51). The  $\sigma$  parameter estimate for the 2

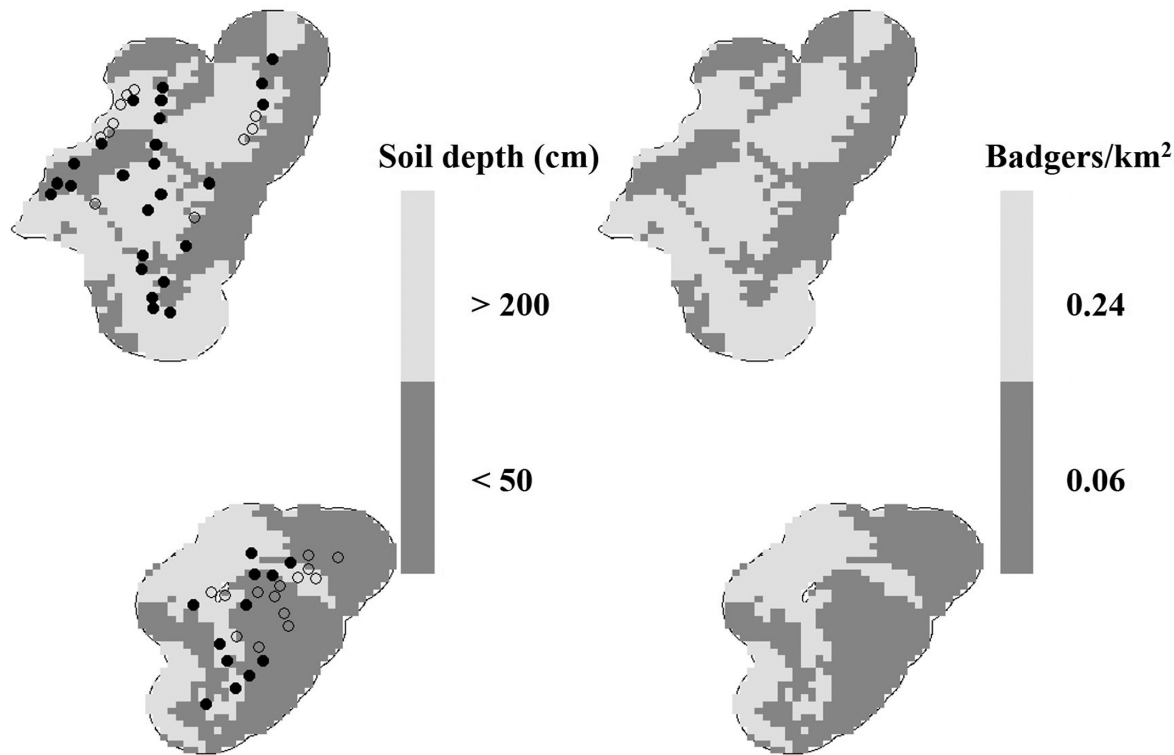
mixture groups was  $\sigma_{h1} = 360.89$  m (95% CI = 292.20–445.72) and  $\sigma_{h2} = 792.07$  m (95% CI = 627.43–999.92), respectively.

## DISCUSSION

The combination of automatic cameras placed at drinkers, individual identification using dorsal head stripes, and SECR analysis successfully led to an estimate of American badger density in a desert habitat. As predicted, our density estimate of 0.10 badgers/km<sup>2</sup> was lower than the estimates from previous studies from northern areas, with the exceptions of an endangered badger population in British Columbia (Klafki 2014) and an Illinois population in an agricultural landscape (Warner and Ver Steeg 1995) (Table 2). Previous authors often went to great lengths to capture all or at least a large proportion of the badgers in their study areas. If their density estimates were erroneous, the error would most probably have come from their estimation of effective trapping area size.

Our encounter rates of 23.5 badger visits per 100 camera-nights and 12.5 individual identifications per 100 camera-nights were far higher than the previously reported capture rates using leg-hold traps (Hein and Andelt 1995: 0.45 captures per 100 trap-nights; Collins et al. 2012: 0.35 captures per 100 trap-nights) or cage traps (Harrison 2015: 0.23 captures per 100 trap-nights). Our method was noninvasive, and no animals were injured. Camera trapping is also much less labor intensive than leg-hold or cage trapping, which require daily visits to trap sites (Harrison 2015).

The top model in our analysis indicated that soil depth was an important predictor of variation in latent activity centers (i.e., badger density; Table 1). Ecologically, the importance of this variable seems obvious given badgers have evolved a suite of morphological and behavioral adaptations necessary for a fossorial lifestyle. As we originally hypothesized, soil depth could be influencing the distribution of badger den



**Fig. 3.**—Habitat mask (33,664 ha) depicting soil depth, the location of drinkers that detected a badger (filled circle), and the location of drinkers that did not detect a badger (unfilled circle; left) and the predicted density (right) of American badgers (*Taxidea taxus*) in the Chihuahuan Desert, New Mexico, United States in 2012 using the top-ranked model based on  $AIC_c$  values from our spatially explicit capture-recapture analysis. Model-averaged estimated density across the Lava Camp and Cedar Lake study areas was 0.10 badgers/km<sup>2</sup>.  $AIC_c$  = Akaike's Information Criterion corrected for small sample size.

**Table 2.**—Location, habitat type, estimated density ( $\hat{D}$ ; badgers/km<sup>2</sup>), and 95% CIs reported by studies on American badgers (*Taxidea taxus*) in the United States and Canada. Density for this study was estimated by noninvasive photographic identification and enumeration combined with spatially explicit capture-recapture analysis. Previous studies utilized leg-hold trapping to mark and count individuals followed by division of population sizes by the overall size of study areas to obtain density. NA = no CI reported.

Location	Habitat	$\hat{D}$	95% CI	Authors
New Mexico	Hot desert	0.10	0.03–0.31	This study
Utah–Idaho	Sagebrush	> 0.40	NA	Lindzey (1971)
Idaho	Shrub-steppe	1.60–5.10	NA	Messick and Hornocker (1981)
Wyoming	Shrub-steppe	$\geq 2.00$	NA	Minta (1993)
Wyoming	Shrub-steppe	1.00–1.10	0.9–1.5	Goodrich and Buskirk (1998)
Illinois	Agricultural	0.14	NA	Warner and Ver Steeg (1995)
British Columbia	Forest–grassland	0.01	NA	Klafki (2014)

sites on the landscape and thus density. Reports of the depths of dens of American badgers are limited to 3 dens: 1.3 and 2.3 m in northwestern Utah and southeastern Idaho (Lindzey 1976) and 0.73 m in Nuevo León, Mexico (Lopez Soto 1980). The European badger (*Meles meles*) constructs setts between 0.6 m (Roper et al. 1991) and 1.5 m (Kaneko et al. 2010) in depth. Within our habitat mask, 52% of the area was characterized by a soil depth of  $\leq 0.5$  m, a consequence of the Armendaris lava flow from the Jornada del Muerto Volcano, while the remainder of the area contained a soil depth  $> 2.0$  m. Thus, it seems logical that badger density was highest in areas that had a soil depth  $> 2.0$  m (Fig. 3).

Conversely, variation in badger density could be dictated by the distribution of common fossorial prey species such as ground squirrels and kangaroo rats. Townsend's (*Urocitellus townsendii*) and Wyoming (*Urocitellus elegans*) ground squirrels, for example, excavate burrows that are on average 0.55 m ( $SD = 0.37$ ) and 0.65 m ( $SD = 0.36$ ) deep, respectively (Laundre and Reynolds 1993), with burrows up to 1.38 m being observed (Reynolds and Wakkinen 1987). Ord's kangaroo rats, meanwhile, excavate burrows that are on average 0.34 m ( $SD = 0.12$ ) to 0.41 m ( $SD = 0.20$ ) deep (Reynolds and Wakkinen 1987; Laundre and Reynolds 1993). Given the ability of fossorial rodents to inhabit burrows in soil depths  $< 0.5$  m, the

distribution of fossorial prey in our study area was not likely to be significantly affected by soil depth. Thus, we hypothesize that in our study area, variation in badger density was affected by soil depth through habitat requirements for badger dens.

Despite support in the top model for density variation by soil depth, there was also support that density was constant across the landscape in the 2nd-ranked model (Table 1). These contradictory results indicate that we did not have clear evidence of the significance of the effect of soil depth on density, perhaps because our sample size was insufficient or because drinker locations were not a representative sample of the variation of soil depth. If density does not vary with soil depth, then we hypothesize that denning habitat may not be limited at the landscape level because badgers within our study area are able to construct burrows in microhabitat sites such as the banks of dry streambeds, sand dunes created by road construction, or elevated areas surrounding vegetation. Paulson (2007) investigated factors that influenced den site selection of badgers at the landscape and microhabitat level and did not find soil depth to be an important predictor of den site location at either spatial scale. We note that our study was not specifically designed to test this hypothesis, and the influence of soil depth in our study may be a unique situation caused by the presence of a lava flow. Thus, we encourage future research to investigate the influence of soil depth and prey abundance on den site selection for the American badger.

Our analysis also suggested that there was a drastic difference in movement rates for 2 groups of individuals within the studied population. We hypothesized that the mixture model is probably representing movement patterns for male and female badgers. Home ranges of males are consistently larger than those of females on an annual basis, due primarily to large increases in movements of males during breeding seasons while similar home range sizes for the 2 sexes occur in nonbreeding seasons (Minta 1993; Lindzey 2003; Paulson 2007). Home range size of males is often  $\geq 2\times$  the size of home size of females, which seems to be reflected by the  $\sigma$  parameter estimates for the 2 mixture classes ( $\sigma_{h_1} = 360.89$  m versus  $\sigma_{h_2} = 792.07$  m). However, if the 2 classes do in fact represent male and female badgers, then the sex ratio is skewed towards females by almost a 4:1 ratio ( $h_1 = 0.79$ :  $h_2 = 0.21$ ), which is unlikely. Instead, we believe the skewed ratio is a consequence of surveying the Lava Camp and Cedar Lake regions before and during the breeding season, respectively. Much of the Lava Camp region was surveyed during the nonbreeding season (May–mid-July) while the entire Cedar Lake survey occurred during the breeding season (mid-July–August). Thus, we believe that home range size of males was smaller and more similar to home range size of females during the Lava Camp survey and nonbreeding season, which increased the proportion of the  $h_1$  mixture that was represented by a smaller estimated  $\sigma$  parameter. However, we note that our mixture model may not be representing sex but instead is modeling the inherent heterogeneity present in any mark-recapture dataset.

The most obvious limitation of our method is the number and distribution of detectors, which was driven by the availability

of drinkers in the study area. Other studies have recommended that trap spacing be  $\leq 2\sigma$  to ensure enough captures and spatial recaptures for accurate parameter estimates (Sollmann et al. 2012; Sun et al. 2014). The average minimum distance between drinkers in our study area was 810 m ( $SD = 340$  m) slightly exceeding the recommended  $2\sigma$  distance for the  $h_1$  mixture class ( $360.89$  m  $\times 2 = 721.78$  m) and a little more than half the distance of the  $h_2$  mixture class ( $792.07$  m  $\times 2 = 1,584.15$  m). Given the  $h_1$  mixture class represented 79% of the total mixture, it is probable that a higher density of traps would have helped increase the precision of our parameter estimates. Furthermore, one-half of the drinkers in a survey region were being monitored at any time due to a limited number of cameras available for deployment. Cameras also were deployed as 2 groups in a temporally staggered fashion, rather than simultaneously, which reduced the number of days that all cameras within an area were active and may have increased the average distance between actively monitored drinkers. Cumulatively, it is probable that this design resulted in fewer captures and recaptures than necessary for a more precise density estimate.

Our method requires specific sites on the landscape at which badgers may be predicted to visit at a useful detection rate and which are small enough that badgers will enter the field of view of a single camera and be photographed at close range. There were no obvious natural (i.e., nonanthropogenic) sites available on the Armendaris. Thus, an attractant, such as water, a scent lure, or food, is necessary to achieve a useful detection rate. Limitations above notwithstanding, drinkers of the design present on the Armendaris Ranch satisfy these criteria. Although water was probably an attractant at times, badgers drank during approximately one-half of visits (see below). They were often observed investigating apparent odors, suggesting that drinkers served as sites of social communication in addition to water. Our method does not require the presence of water per se. Bait stations may also be used (Harrison 2015).

It is unknown how the density of badgers in the study area may have been affected by the presence of drinkers. Individually identified badgers visited drinkers only 1–2 times per week during the survey period, and badgers never remained within the field of view of cameras for more than a few minutes (R. Harrison, pers. obs.). Also, on average, badgers drank during only 58% of visits (Harrison 2015b). Water needs of badgers have not been studied, but these rates of visiting and drinking do not appear to provide significant amounts of water to badgers, at least not during summer months which encompassed our survey period. Furthermore, prey species such as rodents were almost never observed in photographs and most home ranges of prey would not contain a drinker, thus prey densities were not likely significantly elevated by the presence of drinkers. Thus, given the low rate of visitation and drinking by badgers and the lack of evidence for elevated prey densities at drinkers, we believe any effect of the presence of drinkers upon badger density to be minimal. Gerber et al. (2011) found no effect of the presence of lures on density or movements of Malagasy civets (*Fossa fossana*), but increased recapture rates during surveys with lures improved population estimate precision. Similarly, du Preez et al. (2014) reported no effect of bait



upon ranging behavior of leopards (*Panthera pardus*). Estimated leopard densities were comparable between baited and unbaited surveys in one of their 2 study areas. In their 2nd study area, estimated leopard density was slightly higher in the baited survey, but this may have been due to the far greater recapture rate with bait.

In addition to providing a novel method to estimate density, our study has highlighted potential new avenues of research for the American badger including how the species responds to increased accessibility to water, how soil depth and prey availability influence variation in den sites and thus density, and general breeding season information for desert populations. Moreover, we suggest that other researchers employ similar methods to estimate density for American badgers across their range in an effort to monitor population trends for an understudied species.

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