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Use of spatial capture–recapture to estimate density of Andean bears in northern Ecuador

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Abstract: The Andean bear (*Tremarctos ornatus*) is the only extant species of bear in South America and is considered threatened across its range and endangered in Ecuador. Habitat loss and fragmentation is considered a critical threat to the species, and there is a lack of knowledge regarding its distribution and abundance. The species is thought to occur at low densities, making field studies designed to estimate abundance or density challenging. We conducted a pilot camera-trap study to estimate Andean bear density in a recently identified population of Andean bears northwest of Quito, Ecuador, during 2012. We compared 12 candidate spatial capture–recapture models including covariates on encounter probability and density and estimated a density of 7.45 bears/100 km^2 within the region. In addition, we estimated that approximately 40 bears used a recently named Andean bear corridor established by the Secretary of Environment, and we produced a density map for this area. Use of a rub-post with vanilla scent attractant allowed us to capture numerous photographs for each event, improving our ability to identify individual bears by unique facial markings. This study provides the first empirically derived density estimate for Andean bears in Ecuador and should provide direction for future landscape-scale studies interested in conservation initiatives requiring spatially explicit estimates of density.

Key words: abundance, Andean bear, camera-trap, density, Ecuador, population, spatial capture–recapture, *Tremarctos ornatus*

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The Andean bear (*Tremarctos ornatus*) is the only bear species in South America, is endangered in Ecuador, and is experiencing continued population declines across its range (Cuesta and Suárez 2001, IUCN 2008). Andean bears are predicted to decline by 30% within 30 years (Cardillo et al. 2004). Range-wide estimates of abundance vary from 5,000 to 30,000 bears (Peyton et al. 1998, Ruiz-Garcia 2003), with an estimate of >20,000 bears derived from extrapolating density estimates from American black bears (*Ursus americanus;* Peyton et al. 1998). Garshelis (2011) suggested that the few attempts at estimating Andean bear density were not adequate because of problems such as extrapolation of densities from American black bears, small sample sizes, sampling bias, and violation of statistical properties of models used. Thus, reliable range-wide estimates are lacking (IUCN 2008, Garshelis 2011) and deficiency regarding knowledge of the distribution and abundance of Andean bears is considered one of the principal threats to the species (Cuesta and Suárez 2001, IUCN 2008), hampering conservation and management efforts.

Empirically derived abundance estimates are lacking in Ecuador, as they are across the range of the Andean bear. Previous studies of Andean bears in Ecuador were not designed to estimate abundance or density and instead were focused on investigating habitat use based on sign surveys (Cuesta et al. 2003, Peralvo et al. 2005), food habits (Troya et al. 2004), or home range based on few radiocollared individuals (Castellanos 2011). There are few published papers on Andean bears in Ecuador, and we are unaware of any studies that have attempted to estimate abundance using any form of capture–recapture modeling.

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The Chocó–Andean region of Ecuador is located within 2 of the world's biodiversity hotspots: forests of the Chocó and Andes Tropicales (Sarmiento 1995, Myers et al. 2000, Rieckmann et al. 2011). The region is marked by high levels of biodiversity and endemism, but >50% of the region has been deforested as a result of colonization and unsustainable land use (Gentry 1986, Balslev 1988, Palacios and Neill 1993, Webster and Rhode 2001, Justicia 2007). In Ecuador, the Andean bear population is thought to inhabit approximately 58,000 km^2 including highlands, Andean foothill forests, and cloud forests. Of this area, only 19,000 km^2 are protected through the National System of Protected Areas (Peralvo et al. 2005), placing the Andean bear population at risk because of the potential for human-caused landscape change outside of protected areas.

In 2013, the Secretary of the Environment of the Metropolitan District of Quito designated (through municipal resolution) a corridor (650 km^2) to the northwest of Quito specifically for the conservation of Andean bears (Secretaría de Ambiente 2014). Although formally named the Andean bear corridor, the area was not specifically chosen for reasons typically associated with a corridor (e.g., movement, dispersal), and instead should be thought of as an area demarcated based on potential habitat (i.e., forest) for Andean bears. The corridor does not restrict activities of the human inhabitants, but rather aims to contribute to the conservation of the species through education and research. Despite the area's close proximity to the city of Quito, the local Andean bear population has only recently been identified, and the area has not yet been formally recognized to have an extant population (IUCN 2008). This area is centrally located between 2 protected national parks (Cotacahi–Cayapas and Los Illinizas; Fig. 1) and is critical to Andean bear population connectivity, yet is experiencing increasing threats from habitat loss and fragmentation due to an advancing agricultural frontier, mining concessions, highways, and a high incidence of human–bear conflicts within local communities (Sierra et al. 1999, Cuesta et al. 2003, Goldstein et al. 2006). As the human population increases and expands in Quito and surrounding areas, the newly identified population of Andean bears is increasingly threatened.

Our pilot camera-trapping study was initiated to estimate abundance of Andean bears within a portion of the designated corridor and to better understand land-cover types associated with density, both of which will be important to better understand and develop conservation measures for this population. Previously, there has been limited success with obtaining abundance estimates for Andean bears (Garshelis 2011) with camera-traps; however, density has been successfully estimated for 2 similar species—Asiatic black bears (*Ursus thibetanus*) and sun bears (*Helarctos malayanus*)—using spatial capture–recapture models (Ngoprasert et al. 2012). Here, we use our pilot data to demonstrate that camera-trapping can be used to estimate Andean bear density using spatial capture–recapture models and we describe our use of a scent attractant to facilitate individual identification at camera-trap stations.

Study area

The study area within the designated Andean bear corridor (Fig. 1) comprises 2 forest types: low montane evergreen forest between 1,300 and 1,800 m elevation, and montane cloud forest between 1,800 and 3,000 m (Sierra et al. 1999). Other cover types include agriculture, pasture lands, early successional forest, and agroforestry. Climate in the study area is influenced by winds coming from the coast toward the mountain range forming clouds and precipitation. Annual average precipitation in 2 nearby towns—Nanegalito and Nanegal—varies between 2.04 and 2.43 m, while the annual average temperature varies between 18°C at lower elevations and 12°C at higher elevations (INAHMI 2013). Although much of the eastern range of the northern Andes in Ecuador is protected by the National System of Protected Areas, the corridor represents an unprotected region in the western range between Cotacahi–Cayapas to the north and Los Ilinizas to the south (Fig. 1). Pululahua geobotanical reserve is the only protected area within the designated corridor.

Methods

We deployed 12 infrared remote cameras (Reconyx HC500 Hyperfire; Holmen, Wisconsin, USA) during 2012 within the designated Andean bear Corridor (Fig. 2). Andean bears move within a large home range throughout the year in response to changes in available food (Suarez 1988, Schoen 1990, Cuesta et al. 2003, Castellanos 2011); therefore, we limited our trapping effort to 4 months during the wet season (Sep–Dec) with relatively stable food resources, to maximize possible individual recaptures while adhering to geographic closure. We selected camera locations along game trails in areas with Andean bear signs to maximize detection of bears and checked cameras every 2 weeks to collect data and maintain cameras. Most camera locations were in primary forests with canopy coverage >70%; however, we attempted to stratify sites across elevation gradients and

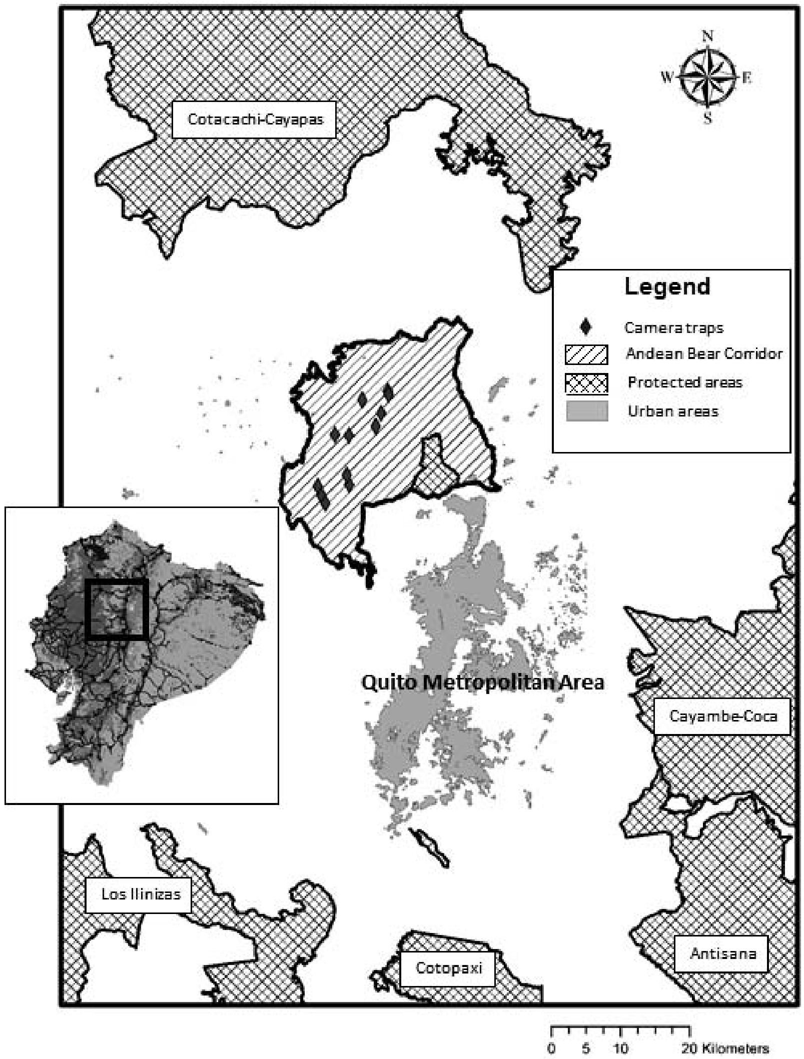

Fig. 1. Location of the Andean bear (*Tremarctos ornatus*) corridor (outlined in black) in the Metropolitan District of Quito in northern Ecuador, South America. Urban areas are solid gray and the corridor is located northwest of the city of Quito.

varying distance to disturbed areas. Average spacing of cameras was 8.74 km (min. = 0.53, max. = 18.64, SD = 5.00).

We affixed cameras to trees 1 m above ground level and positioned them 4 m from a rub-post baited with vanilla extract, which we applied to a rag and affixed to the post. Cameras used infra-red flash, and we set them to take 10 pictures/trigger event with rapid fire and no delay between trigger events. We set sensitivity to heat and motion at normal, and image resolution as 3 Megapixels. We identified individual bears based on unique facial markings using 2 independent observers (Ríos-Uzeda et al. 2007, Jones 2010, van Horn et al. 2014). We did not use photographs with only partial face patterns and those without observer congruence for density estimation.

We used logistic regression to test whether there was a relationship between number of photographs during a camera visit (event) and our ability to identify an individual. We fit a model with success of identification as a binary response variable and log-transformed total number of photographs for each event as a dependent variable and compared with a null intercept-only model

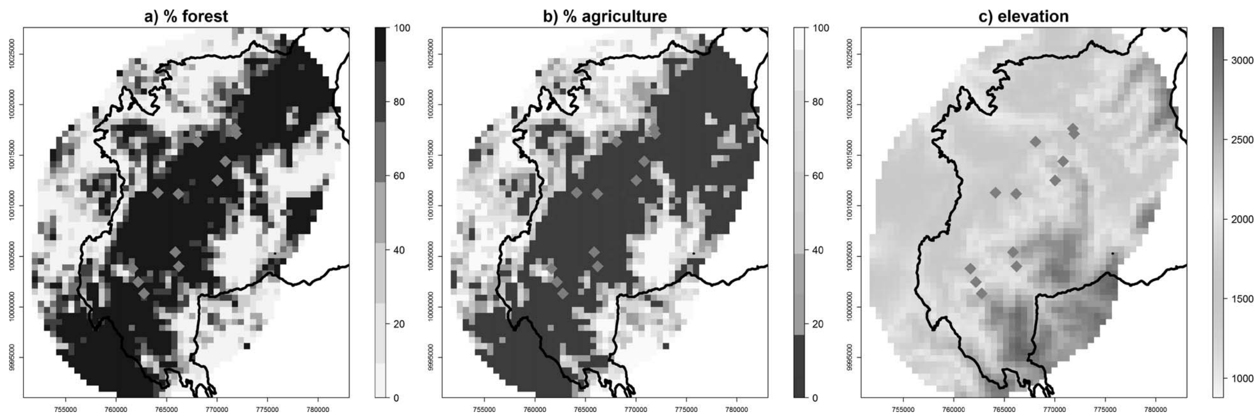

Fig. 2. State spaces for 3 landscape covariates (a) % forest, (b) % agriculture, and (c) elevation (scaled to [0,1]) in the Andean bear (*Tremarctos ornatus*) corridor within the Metropolitan District of Quito, northern Ecuador, South America. The 12 locations where we deployed camera stations during 2012 to record bears are identified by red diamonds.

using Akaike Information Criterion adjusted for small sample size (AIC_c). We assessed effect size using log odds.

We estimated Andean bear density using spatial capture–recapture (SCR) models fit using maximum likelihood within the package oSCR (Sutherland et al. 2016; Data S1 and Text S2). We compiled Bernoulli encounter histories for individuals detected at camera-trap locations ($J = 12$) over multiple ($K = 4$) 1-month sampling occasions. Spatial capture–recapture models assume that animals use space around a central point referred to as an individual activity center (s_i), and that these activity centers are distributed over a planar region referred to as the state space, denoted by S (Royle et al. 2014: chapter 5). The density of such activity centers may vary over the state space in relation to explicit covariates, the effects of which can be estimated (Borchers and Efford 2008). Further, SCR models assume a parametric model relating the probability of detection (p_{ij}) of an individual (i) at trap (j) as a function of distance from the individual activity center. We use the half-normal model, in which $p_{ij} = p_0 exp(d_{ij}^2/(2\sigma^2))$ where d_{ij} is the distance between the activity center of individual i and trap j, and p_0 and σ are parameters to be estimated (Borchers and Efford 2008, Royle et al. 2014: chapter 7, table 4). We created a candidate set of models including a null model, a model containing a trap-specific behavioral response to encounter (i.e., an individual's probability of detection at a trap changes subsequent to first encounter, also called a local behavioral response), a behavioral and effort-dependent detection model (i.e., no. of days a camera station was operational during a 1-month session), and models with land-cover density covariates. For density covariates, we transformed the land-cover layer (Ministerio de Agricultura, Ganadería, Acuacultura y Pesca) to a 30-m-resolution raster in ArcGIS (ESRI 2011; Environmental Systems Research Institute, Redlands, California, USA), imported to R (R Core Team 2015), and aggregated pixels to a 600-m $\times$ 600-m resolution to calculate percent cover for native forest and agriculture (including pastures, annual and permanent crops, and agricultural mosaic including crops and pasture lands). We used a 30-m resolution elevation layer (Jarvis et al. 2015), aggregated to the same 600-m $\times$ 600-m resolution (Fig. 2). We defined the final state space using a 10-km buffer surrounding trap locations (824.04 km^2) based on approximately the mean maximum distance moved to ensure a buffer of $\geq 2\sigma$ for unbiased density estimates (Royle et al. 2014). The state space is larger than the designated corridor area for Andean bears (Secretaría de Ambiente 2014), which should not affect density estimates but will bias estimates of N for the designated corridor. Thus, to estimate the total number of Andean bears in the study area during the 4-month survey period, we cropped the predicted realized density surface to the designated corridor and scaled the estimated density by the area of the designated corridor.

Results

Over the 4-month survey period (1,224 trap-nights), we collected 2,561 pictures of Andean bears, for which

Table 1. Numbers of camera-trap captures for each individual Andean bear (*Tremarctos ornatus*), number of traps an individual was captured in, and the maximum distance between all traps that an individual was captured in, for all 19 individuals captured in the Metropolitan District of Quito in northern Ecuador, South America, during 2012.

Individual	No. of captures	No. of traps with captures	Maxdist
1	3	2	2.93
2	4	3	3.89
3	1	1	0
4	1	1	0
5	2	2	2.05
6	2	1	0
7	1	1	0
8	5	2	2.05
9	3	2	9.72
10	3	1	0
11	3	2	1.44
12	1	1	0
13	3	3	7.38
14	1	1	0
15	1	1	0
16	1	1	0
17	1	1	0
18	1	1	0
19	2	2	5.75

we were able to identify 19 individual bears. Individual captures ranged from a single detection event (9 individuals) to an individual with 5 detections, with a mean of 2.05 captures/individual (Table 1). The logistic regression model indicated there was a positive relationship between number of photographs (coeff. = 0.77, SE = 0.22, 95% CI = 0.36–1.22) during a visit and successful identification of individuals (ΔAIC_c between null and alternative model = 12.81), with each additional photograph during an event increasing the log odds of successful identification by 0.77.

The top SCR models in the candidate set all included a positive effect of effort and a behavioral effect on detection (Table 2). The best model by AIC_c indicates an increasing probability of detecting an Andean bear if the camera is exactly at the activity center from 0.01 with 1 day of camera operation to 0.24 when the camera was operational for 30 days (Fig. 3). Positive beta coefficients for the behavioral response indicate that the probability of recapture was greater than the probability of initial capture (i.e., a "trap-happy" response; Table 3). The top model did not include landscape covariates on density. The second-best model ($\Delta AIC_c = 0.92$) provided evidence for a negative response of density to elevation; the third-best model ($\Delta AIC_c = 1.14$) suggested a negative response of density to agriculture, although the MLE for that model was numerically unstable because of the low variability of the percent agriculture covariate (most of the landscape in the vicinity of the traps had little or no agriculture); the fourth model ($\Delta AIC_c = 1.34$) indicated a positive response of density to forest cover, but again the MLE was numerically unstable (Table 2). The density estimate for the top model (density constant, behavioral response on detection probability; $AIC_c = 208.00$, $\Delta AIC_c = 0.00$; Table 2) was 7.45 bears/100 km^2 (95% CI = 2.71–12.19; Table 4). When applied to the restricted state space defining the corridor (having area 543.96 km^2), estimated abundance was 40.54 bears (95% CI = 14.76–66.31) within the corridor. We used the MLEs from the best model to produce the estimated posterior density within the corridor region of the state-space (Fig. 4). This is obtained by adding together the estimated posterior distribution of each individual's activity center including the estimated density of uncaptured individuals.

Discussion

We demonstrated that camera-trapping can be used as a viable method to identify individual bears for use in spatial capture–recapture models to estimate Andean bear density. Our density estimate of 7.45 bears/100 km^2 in northern Ecuador is similar to the one other estimate of Andean bear density derived from a small-scale camera-trap study in Bolivia with a density estimate of 4.4–6 bears/100 km^2 (Ríos-Uzeda et al. 2007). Initial estimates of range-wide Andean bear abundance (>20,000) were derived by assuming densities were similar to American black bear in North America (Peyton et al. 1998) including low densities (7 bears/100 km^2) and median densities (25 bears/100 km^2). The estimate from this study suggests the low density comparison is most appropriate, and both black bear estimates are greater than the existing estimate for Bolivia. Better range-wide estimates of Andean bear density are warranted to improve conservation planning and actions (IUCN 2008).

Previous studies recommended >1 camera-trap at a camera station to allow for better opportunities to identify individual Andean bears based on facial markings (Ríos-Uzeda et al. 2007), even when bait was used (Zug 2009). However, our use of vanilla scent attractant attached to the rub-post could possibly have resulted in increased detection and identifiability of Andean bears because there were greater odds of identification the longer an individual stayed at a camera station. Additional

Table 2. We compared 12 Andean bear (*Tremarctos ornatus*) density models in a candidate set using Akaike Information Criterion corrected for small sample size (AIC_c) and the difference between AIC_c of each model and the model with the lowest AIC_c (ΔAIC_c), and provide the weight of evidence for each model. Density covariates included elevation, % agriculture, and % forest cover; and detection covariates included a behavioral response to camera-traps baited with a scent lure, and number of days a camera station was operational during a 1-month occasion (effort), during a field study in the Metropolitan District of Quito in northern Ecuador, South America, during 2012. Models with 1 indicate a null model.

Density (*D*)	Detection (p_0)	Log-likelihood	No. of parameters	AIC_c	ΔAIC_c	w_i
1	behavior + effort	99.00	5	208.00	0.00	0.265
elevation	behavior + effort	98.46	6	208.93	0.92	0.167
agriculture	behavior + effort	98.57	6	209.04	1.14	0.150
forest	behavior + effort	98.67	6	209.34	1.34	0.136
1	behavior	101.50	4	210.99	2.99	0.600
elevation	behavior	100.79	5	211.59	3.58	0.044
1	1	102.95	3	211.90	3.90	0.038
agriculture	behavior	100.97	5	211.94	3.93	0.037
forest	behavior	101.13	5	212.25	4.25	0.032
agriculture	1	102.27	4	212.53	4.53	0.028
forest	1	102.38	4	212.77	4.76	0.024
elevation	1	102.57	4	213.14	5.13	0.020

studies could investigate this idea further by comparing detection and identifiability of Andean bears at sites with and without vanilla scent attractant. In addition, we also found a positive behavioral response to camera-trap stations, increasing recapture rates. The use of scent attractants will be increasingly important as camera-trap studies are designed to address landscape conservation questions requiring large-scale arrays with many camera stations.

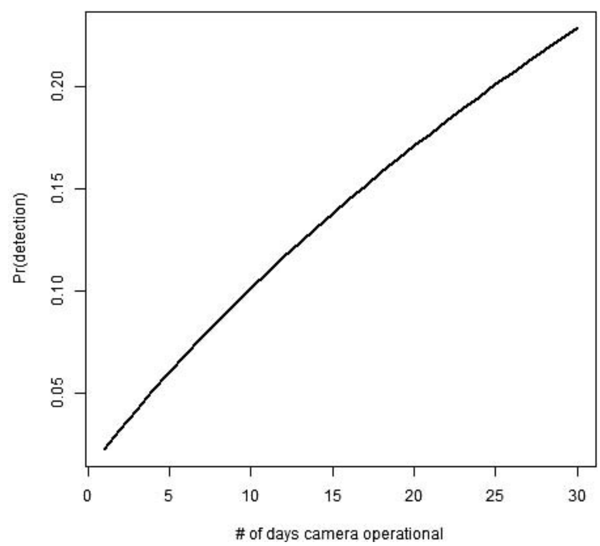

Fig. 3. Relationship between the number of days cameras are operational during 2012 at the study site in the Andean bear (*Tremarctos ornatus*) corridor, Metropolitan District of Quito, Ecuador, South America; and the probability of detecting an Andean bear if the camera is located exactly at the activity center.

Our methods provide relatively precise density estimates using only pilot data from a small number of camera-trap stations. However, a more comprehensive study is required to refine parameter estimates and allow for selection of models with landscape covariates. The design of the current study resulted in camera-trap stations located solely in native cloud forest habitat, and therefore the modeling approach was not able to distinguish between habitat covariates that likely affect density. Study design is an important consideration when undertaking any capture–recapture study; and, for spatial capture–recapture models, trap spacing and configuration of the trapping array are especially important to ensure spatial recaptures of individuals (Sollmann et al. 2012, Efford and Fewster 2013, Royle et al. 2014: chapter 10, Sun et al. 2014). Study design modifications including a camera-trap array stratified across landscape covariates of interest and an increased number of camera-traps would improve our ability to estimate the effects of habitat covariates on density as well as simultaneously reduce numerical instability. In addition, the habitat between camera stations was also consistently forested, so it was not possible to estimate resistance to movement using the SCR ecological distance model (Royle et al. 2013, Sutherland et al. 2015, Fuller et al. 2016). Local Andean

Table 3. Maximum-likelihood point estimates (SE) of covariate coefficients for all 12 candidate models for Andean bear (*Tremarctos ornatus*) density in the Metropolitan District of Quito in northern Ecuador, South America, during 2012. Density covariates included elevation, % agriculture, and % forest cover; and detection covariates included a behavioral response to camera-traps baited with a scent lure, and number of days a camera station was operational during a 1-month occasion (effort). Encounter models or density models with 1 indicate the null model. NA, not applicable.

Density model (*D*)	Encounter model (*p*)	Beta coeff. agriculture (*D*)	Beta coeff. elevation (*D*)	Beta coeff. forest (*D*)	Beta coeff. behavior (*p*)	Beta coeff. effort (*p*)
1	behavior + effort	NA	NA	NA	1.02 (0.69)	0.93 (0.53)
elevation	behavior + effort	NA	−0.51 (0.52)	NA	1.15 (0.69)	0.92 (0.53)
agriculture	behavior + effort	−2.7 (9.30)	NA	NA	0.94 (0.66)	0.88 (0.51)
forest	behavior + effort	NA	NA	3.00 (13.86)	0.91 (0.66)	0.89 (0.51)
1	behavior	NA	NA	NA	1.14 (0.67)	NA
elevation	behavior	NA	−0.55 (0.50)	NA	1.26 (0.67)	NA
agriculture	behavior	−2.6 (8.25)	NA	NA	1.05 (0.65)	NA
1	1	NA	NA	NA	NA	NA
agriculture	1	−4.00 (16.34)	NA	NA	NA	NA
forest	behavior	NA	NA	2.10 (6.73)	1.03 (0.65)	NA
forest	1	NA	NA	3.90 (17.11)	NA	NA
elevation	1	NA	−0.37 (0.43)	NA	NA	NA

bear home ranges exhibit strong asymmetry (Castellanos 2011), so estimates of home range size based on the SCR encounter-probability model used here could be biased because it is based on the Euclidean distance between the camera and an individual activity center and does not incorporate the influence of local landscape characteristics (Sutherland et al. 2015). Alternative distance metrics have been developed that relate to the landscape through which distance is being measured, thus allowing for asymmetry in space usage (Royle et al. 2013, Sutherland et al. 2015). Our initial results suggest that implementing a well-designed camera-trap study with a trapping array that samples across a gradient of land use and land-cover types and with trap spacing close enough that allows for estimation of resistance to movement could produce improved estimates of density and landscape connectivity (Sutherland et al. 2015, Fuller et al. 2016).

Table 4. Parameter descriptions, maximum-likelihood estimates, associated standard errors (SE), and transformations to the original scale for parameters from the D~1, p_0~behavior + effort spatial capture–recapture model fit in oSCR (Sutherland et al. 2016). Models were fit to data from an Andean bear (*Tremarctos ornatus*) camera-trapping study conducted in the Metropolitan District of Quito in northern Ecuador, South America, during 2012.

Parameter	Description	Estimate	SE	Transformation (95% CI)
p0.int	Baseline detection	−4.41	1.74	logit: 0.01 (0–0.05)
p.behavior	Capture probability of first capture is different from capture probability of recapture	1.02	0.69	none: 1.02 (−0.32–2.36)
sigma	Scaling parameter describing the distance (km) at which an animal can be detected from its activity center	1.03	0.19	log: 2.80 (1.76–3.83)
effort	Log-transformed no. of days a camera station was operational during an occasion (1 month)	0.93	0.53	identity: 0.93 (−0.10–1.96)
d0	Density parameter (per 0.36 km^2)	−3.62	0.32	log: 0.03 (0.01–0.04) or 7.45 bears/100 km^2 (2.71–12.19)

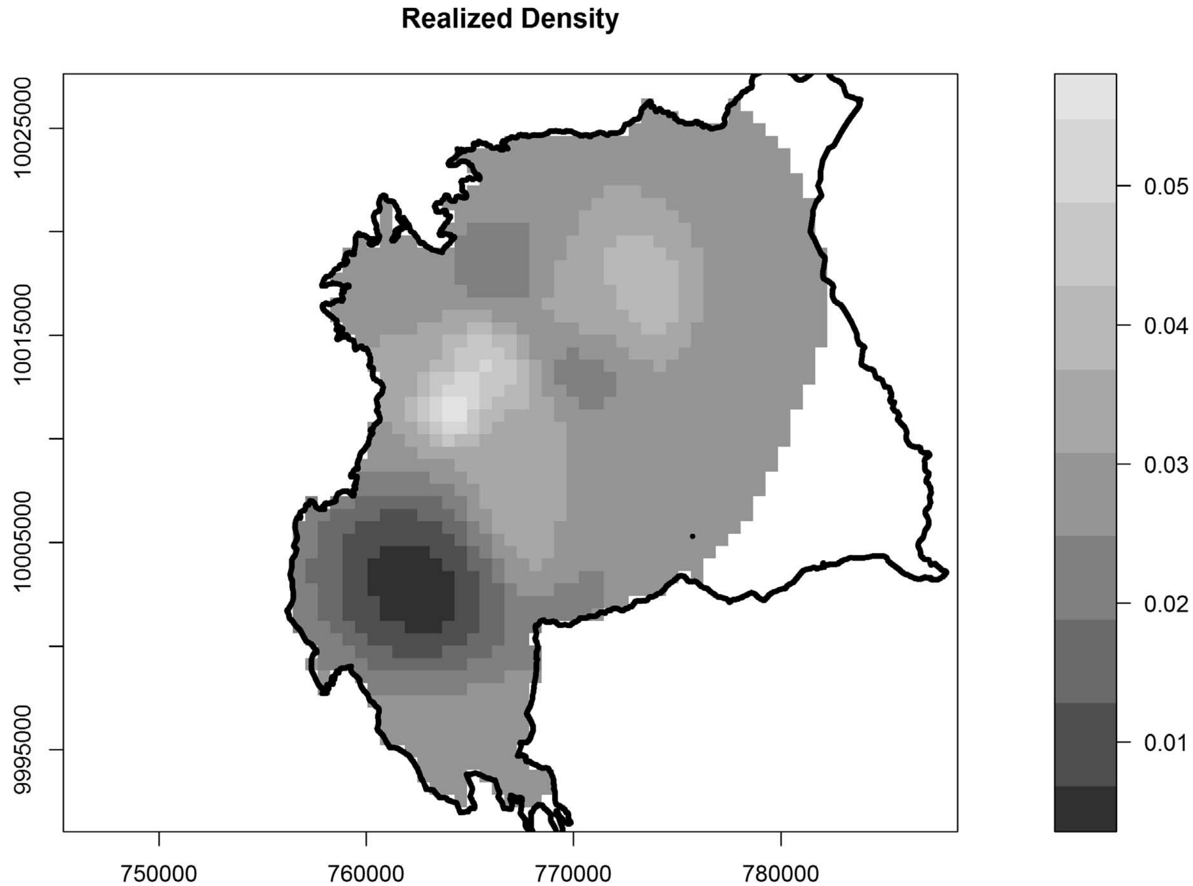

Fig. 4. Realized density surface for Andean bears (*Tremarctos ornatus*) in the Andean bear corridor, Metropolitan District of Quito, Ecuador, South America, based on estimates from spatial capture–recapture model $D\sim$ (null density model), $p_0\sim b$ (behavioral response detection model) fit in oSCR (Sutherland et al. 2016). Model derived from captures obtained from 12 camera stations set during 2012. Pixel resolution is 600 m × 600 m; thus, pixel density estimates are per 0.36 km^2.

Andean bears are often considered an umbrella species for the Andes Mountains region because they have large annual home ranges, require a variety of cover types, and provide ecosystem function by dispersing seeds (Peyton 1999, Peralvo et al. 2005, Zug 2009, Molina 2012). However, there is a lack of information on Andean bear distribution, making conservation for the species challenging (IUCN 2008). Although several studies have attempted to rank conservation areas important to Andean bears using models of habitat use (Cuesta et al. 2003, Peralvo et al. 2005), information on population abundance is necessary for conservation planning for the species. Further, maintaining habitat for Andean bears within protected areas alone will not be sufficient for maintaining the species because of the species' low density, high metabolic demands, and large home range sizes (Yerena 1998). Our pilot study offers a viable method to approach landscape-scale estimation of Andean bear density across the range using camera-trap arrays and spatial capture–recapture models. A large-scale study using the design considerations we highlight in this paper would allow for the use of spatial capture–recapture models as a landscape-scale objective to identify priority conservation areas or corridors, and would significantly advance conservation planning (Royle et al. 2013, Graves et al. 2014, Morin et al. 2017) for the species.

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Supplemental material

Data S1. Working space with data and covariates to run spatial capture–recapture analyses from script provided in S2—from Andean bear (*Tremarctos ornatus*) camera-trapping study conducted in northern Ecuador, during 2012.

Text S2. Script (for Data S1) to format Andean bear (*Tremarctos ornatus*) data and fit candidate model set in oSCR.