

It All Comes Out in the Wash:
Mammal Use of Riparian Corridors
in Semi-Arid Sonora, Mexico

by

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ABSTRACT

Land use change driven by human population expansion continues to influence the integrity and configuration of riparian corridors worldwide. Wildlife viability in semi-arid regions depend heavily on the connectivity of riparian corridors, since water is the primary limiting resource. The Madrean Archipelago in northern Mexico and southwestern United States (US) is a biodiversity hotspot that supports imperiled wildlife like jaguar (*Panthera onca*) and ocelot (*Leopardus pardalis*). Recent and ongoing infrastructure developments in the historically understudied US-México borderlands region, such as the border wall and expansion of Federal Highway 2, are altering wildlife movement and disconnecting essential habitat.

I used wildlife cameras to assess species occupancy, abundance, and related habitat variables affecting the use of washes as corridors for mammals in semi-arid Los Ojos (LO), a private ranch within a 530 km² priority conservation area in Sonora, México located south of the border and Federal Highway 2. From October 2018 to April 2019, I deployed 21 wildlife cameras in five different riparian corridors within LO. I used single-season occupancy models and Royal Nichols abundance models to explore the relationship between habitat variables and use of riparian corridors by mammal communities of conservation concern within this region.

Twenty-one mammal species were recorded in the study area, including American black bear (*Ursus americanus*), white-tailed deer (*Odocoileus virginianus*) and the first sighting of jaguar (*Panthera onca*) in this region in 25 years. For the 11 medium- and large-bodied mammals recorded, habitat variables related to perennial river characteristics (distance to river, weekly water, and site width) and remoteness (distance from highway, elevation, and NDVI) were important for occupancy, but the direction of the relationship varied by species. For commonly observed species such as

mountain lion (*Puma concolor*) and white-nosed coati (*Nasua narica*), topographic variety was highly informative for species abundance. These results highlight the importance of habitat diversity when identifying corridors for future protection to conserve wildlife communities in semi-arid regions. Additionally, this study provides robust evidence in support of mitigation measures (e.g. funnel fencing, over- or under-passes) along Federal Highway 2, and other barriers such as the border wall, to facilitate wildlife connectivity.

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INTRODUCTION

Wildlife movement worldwide continues to be impeded by human-disrupted landscape configuration and functioning. In dryland ecosystems such as the southwestern US and northwestern México, suitable habitat connectivity between riparian oases is increasingly essential for wildlife due to the compounding effects of multiple stressors in the context of an increasingly arid future (Fahrig 2003; Seavy et al. 2009; Ordeñana et al. 2010; Falk 2013; Brodie et al. 2015). Climate model projections show that southwestern North America is becoming more arid, specifically heightening the importance of riparian oases and their connecting washes for wildlife (Noss 1991; Seager et al. 2007; Matos et al. 2009; Capon et al. 2013). However, riparian ecosystems are often drained of surface and subsurface water, and further fragmented by human infrastructure like roads, which limits the ability for wildlife to effectively utilize these essential spaces (Forman & Alexander 1998; Ament et al. 2008). Despite the importance of riparian corridors for dryland organisms, few studies have investigated the suitability and use of semi-arid washes as habitat for mammals (Hilty & Merenlender 2004; Matos et al. 2009; Santos et al. 2011). Further, the literature is especially sparse within the ecologically important but politically contentious landscape of the United States-México borderlands (Koprowski et al. 2005; Avila-Villegas & Lamberton-Moreno 2013; Van Devender et al. 2013; Coronel-Arellano et al. 2018).

Human development is rapidly expanding in the semi-arid borderland region with water diversion, an increase in motor-vehicle travel, road expansion, and the construction of a physical border wall (Cohn 2007; Glista et al. 2009; Greenwald et al. 2017; Wilder 2018; Peters et al. 2018). This development creates challenges for wildlife movement across an already arduous landscape, particularly for imperiled, large-ranging species like jaguar (*Panthera onca*) or mountain lion (*Puma concolor*) which require

unimpeded habitat to thrive (Riley & Malecki 2001; Rabinowitz & Zeller 2010; Nicholson et al. 2014). The borderlands region includes the Madrean Sky Islands, a terrestrial archipelago of biologically diverse, isolated mountain peaks surrounded by desert landscapes across the states of Sonora and Chihuahua in México, and Arizona and New México in the United States (DeBano et al. 1995; Conservation International 2005; McCormack et al. 2009; Van Devender et al. 2013). Much of México's native plant populations and biodiversity of the North American southwest can be found within the Madrean Sky Islands, including the overlapping ranges of many Nearctic and Neotropical species (DeBano et al. 1995; Avila-Villegas & Lamberton-Moreno 2013; Van Devender et al. 2013; Coronel-Arellano et al. 2018). Wildlife with larger home ranges and greater geographical needs navigate the arid landscapes between sky islands for dispersal, mating, migration, and food (Koprowski et al. 2005; Avila-Villegas & Lamberton-Moreno 2013).

Roadway development fragments riparian corridors and habitat, creating difficult passage for wildlife and dramatic ecological outcomes such as edge effects, genetic isolation, wildlife mortality, and increased human accessibility to wildlife areas (Forman & Alexander 1998; Jackson & Griffin 2000; Epps et al. 2005). Mexican Federal Highway 2, near the United States-México border, has high levels of traffic, rarely allowing a reprieve for wildlife to cross and killing an estimated 2000+ vertebrates a year (Bravo 2017a). Beginning in 2017, the Mexican government began expanding and re-routing Mexican Federal Highway 2 to reduce fatal accidents and travel time and has worked with international NGOs such as the Wildlands Network and Sky Island Alliance to implement roadway mitigation such as under- and over-passes for wildlife (Bravo 2017b, 2017a, 2017c). Underpasses, fencing, and signage can help mitigate vehicle collisions,

but employing them is expensive and tedious due to the difficult terrain of the borderland region (Clevenger et al. 2001; Malo et al. 2004; Glista et al. 2009).

Dryland riparian corridors, often referred to as “washes” when seasonal, are essential movement and resource pathways for biodiversity (Gregory et al. 1991; Naiman et al. 1993; Virgós 2001), especially in arid and semi-arid regions where water is a limiting resource (Noy-Meir 1974). Local conservation actions aim to protect habitat and movement corridors for imperiled wildlife, but in many cases the habitat characteristics of suitable, or even preferred habitat, is unknown. For example, arid and semi-arid riparian areas differ considerably based on their geomorphic and vegetative characteristics such as width and slope, substrate (sand or rock), duration of surface water, and plant cover. Although the ecological importance of dryland riparian corridors for wildlife is generally well-investigated (Naiman et al. 1993; Virgós 2001; Merritt & Bateman 2012; Capon et al. 2013), little research has been done to quantify the characteristics of dryland riparian corridors that are most utilized by mammals and thus hold higher importance for protection or placement of mitigation efforts, especially in semi-arid regions (Ellison & van Riper III 1998; Brand et al. 2008; Matos et al. 2009; Paolino et al. 2018).

Often moving for specific goals like food and water, protection from predators, or finding mates, wildlife and their offspring constantly absorb and interpret information from their surroundings to effectively navigate landscapes (Jackson & Griffin 2000; Fryxell et al. 2008; Nathan et al. 2008). For example, jaguars must navigate through infrequent infrastructure gaps across numerous barriers between México and the US to defend territory and find mates. These infrastructure barriers complicate the movement of this endangered species and others. Thus, preserving passage within these corridors is important for maintaining the long-term viability of wildlife communities in the region.

Nested in the middle of the Madrean Archipelago, the 530 km² greater Cuenca Los Ojos conservation and priority corridor area rests along the US-México border ~100 km east of Agua Prieta, México. This understudied, semi-arid region has mountain tops of semidesert grassland divided by riparian habitats (Brown 1994; Hunt & Anderson 2002, 2004). Cuenca Los Ojos is essential habitat for wildlife connectivity in the greater Madrean Archipelago ecosystem, connecting the Peloncillo and Chiricahua mountains of the US with the Sierra Madre Occidental Mountain range of México, but it has the added difficulty of Mexican Federal Highway 2 bisecting the northern reach of its property. The Cuenca Los Ojos ranches and properties are one of three suitable habitat pinch-points for the northern extent of the jaguar home range (Culver 2016; Bravo & Davis 2017) and is predicted suitable habitat for the Mexican wolf (*Canis lupus baileyi*) both of which are endangered species in the United States and México (Bravo & Davis 2017). In 2007, the white-tailed deer (*Odocoileus virginianus*) was successfully reintroduced to the region after population reduction by hunting. Additionally, Cuenca Los Ojos is an important location for black bear (*Ursus americanus*) habitat connectivity and a successful reintroduction site for beaver (*Castor canadensis*) which are both endangered within México (NOM-059-SEMARNAT-2010). Several other regionally endangered and threatened species are hypothesized to take refuge in the riparian oases of Cuenca Los Ojos including Chiricahua leopard frogs (*Lithobates chiricauensis*) and several species of fish (Santos-Barrera et al. 2004; NOM-059-SEMARNAT-2010).

To inform mitigation placement for wildlife across Highway 2 and other infrastructure barriers in this region, I assessed the relationship between riparian corridor structure and mammal richness, occupancy, and abundance using wildlife cameras. Wildlife cameras are a non-invasive way to capture wildlife activity and habitat use, as well as record more elusive species (O'Connell et al. 2011). The cameras were

active from October 2018 to April 2019 across a range of diverse sites within two ranches in Cuenca Los Ojos. Despite the ecological importance of the dryland areas of the Madrean Archipelago, few studies have explored these mammal communities, especially near the international border. I hypothesized that first, there are differences in mammal resources and structure along the corridors. Second, mammal richness differs with distance from human disturbance and site difference from the predominant semi-desert grassland. Third, medium- and large-bodied mammal occupancy and abundance would vary by species depending on the presence of resources like shade, water, and vegetation, as well as structural characteristics of the corridors. Results from this study will help to inform wildlife policies and actions, including how and where to preserve riparian corridors during infrastructure build up in the borderlands region, like the reconstruction of Mexican Federal Highway 2.

METHODS

Study Site

I conducted this study within a 10 km by 10 km section of two private ranches El Diablo and Los Ojos Calientes (hereafter LO) within the greater Cuenca Los Ojos conservation area in Sonora, México located directly south of the United States - México border and on the Northwest section of the Sierra Madres (Figure 1). Nested within the Madrean Archipelago (Figure 1), the study site included a combination of semidesert grasslands with riparian canyons of oak woodland and is a part of the Sierra Madre Occidental pine-oak forest ecoregion (Brown 1994; Dinerstein et al. 2017). Elevation ranged from 1200 m to approximately 2000 m (JS pers. obs.), and precipitation is influenced largely by the stochasticity of the North American Monsoon season, ranging from 20 – 35 cm annually but mostly falling during the summer (Hunt & Anderson 2002; Loik et al. 2004; JS pers. comm.). Temperatures range from below freezing in the

winter to +37°C in the summer. The dominant vegetation in the riparian areas included cottonwood (*Populus fremontii*), sycamore (*Platanus wrightii*), and velvet ash (*Fraxinus velutina*) with ballmoss (*Tillandsia recurvata*) and woody shrubs like true mistletoe (*Phoradendron spp*) (Hunt & Anderson 2004). The drier sections of the riparian corridors included vegetation such as juniper (*Juniperus coahuilensis*), mesquite (*Prosopis spp.*), and various cacti species such as cholla (*Cylindropuntia spp*) and prickly pear (*Opuntia spp*) (Brown 1994; Hunt & Anderson 2002, 2004). Rio Cajon Bonito, the only perennial river within the region, is a part of the Rio Yaqui watershed on the western side of the Sierra Madre Occidental mountain range.

LO is owned and managed by Cuenca de los Ojos A.C., a Mexican nonprofit overseeing 53,000 ha of land dedicated to conservation and restoration efforts in the borderland region. LO is surrounded by other Cuenca de los Ojos A.C. owned ranch properties, the Janos Biosphere Reserve to the east, additional private ranches to the south, and communal owned lands (ejidos) to the west. Federal Highway 2, one of México's busiest highways, bisects the northern section of LO between Cajon Bonito and the US-México border (Figure 1). Because this highway is the only access between the states of Sonora and Chihuahua near the border, it is heavily used 24 hours a day to transport goods and people (Perez Cantu pers. comm.).

I assessed the mammalian community and habitat use across five different dryland riparian corridors within LO's jurisdiction (Figure 1). The corridors were selected via satellite imagery based on researcher knowledge of accessibility, drainage size, and probable habitat use of diverse sites. Three corridors (Diablo, Javelina, and Agua Fria) slope southwest towards the fourth study corridor (the perennial river, Cajon Bonito). When flowing, the fifth riparian corridor (Primavera) runs northwest towards Cajon Bonito.

Wildlife Cameras

I used 25 non-baited, remote wildlife cameras (Bushnell HD, Overland Park, Kansas; HCO Scoutguard, Norcross, Georgia) to detect mammal species located within corridors in LO from October 2018 to April 2019 (Appendix A). At each site, I placed cameras on trees facing the corridor within 150 m of the pre-selected location at ~0.7 m off the ground (knee-high). Sites were located 1 km apart from one another to reduce the probability of capturing the same individual on multiple cameras and to follow occupancy modeling assumptions of a closed site (MacKenzie & Royle 2005; Shannon et al. 2014; Mackenzie et al. 2017). I set cameras to capture images using a 2-photo burst, with a 1-minute photo interval, no video, and auto detection level to minimize blank images. Difference in species detection based on camera model (Bushnell HD and Scoutguard) was tested to ensure against bias. Four of the cameras malfunctioned during the study period, leaving 21 cameras that produced images for data analysis. Cameras were active for a total of 189 - 191 possible trap nights from October 2018 to April 2019 (Appendix A). I calculated trap nights as total number of days cameras were active from deployment until the collection, and I considered photographs of mammals to be independent at a site if taken >60 minutes apart (Bowkett et al. 2008; Rovero et al. 2014).

I sorted images following the CameraSweet method, also known as the Sanderson technique (Harris et al. 2010). This technique relies on a nested folder structure (e.g. Site X > Camera Y > Animal > # of animal) to quantify the images. When possible, I identified mammals to species. At least two observers reviewed each picture to ensure accurate identification. Rodent species smaller than ~1 kg were often difficult to distinguish and were grouped together as Rats & Mice (Thomas et al. 2020).

Habitat Characteristics of Riparian Corridors in LO

I measured seven habitat variables that I hypothesized to influence corridor use by mammals at each site, including site width(m), elevation (m), distance to highway (km), distance to river (km), presence of water (percent of weeks), NDVI, and topographic variability (m).

I calculated site width (m) by averaging the measured values at the location of the camera, 20 m upstream, 40 m upstream, 20 m downstream, and 40 m downstream (Hilty & Merenlender 2004; Renöfalt et al. 2005). Site width was defined as from one canyon wall to the opposite canyon wall. In the few sites with no canyon wall, sites were measured to the edge of the cottonwood trees. I recorded elevation using a hand-held GPS Garmin 66s device at the location of the camera.

Several habitat variables were measured using satellite imagery. I calculated distance to Federal Highway 2 (km) and distance to perennial river (km) from each camera location using ArcMap10.7.1 geographic information system (GIS) software base maps (ESRI, Redlands, California, USA). I used 30 m resolution Landsat 8 data to calculate the Normalized Difference Vegetation Index (NDVI) for each site as a proxy for productivity and vegetation coverage (Landsat-8 image courtesy of the U.S. Geological Survey). Twelve satellite pictures from October 2018 to April 2019 were used in ArcGIS 10.7.1 Image Analysis to measure the average NDVI within five 50 m radial buffers following the natural pathway of the corridor for each of the twelve images: the camera site, 100 m upstream and downstream from camera, and 200 m upstream and downstream from the camera. I used the average NDVI values close to 0 as an indication of dirt/non vegetated land, and 1 as dense forest canopy. For topographic variety, I calculated elevational differences within the same five 50 m radius buffers as drawn for NDVI using a digital elevation model from the NASA 2000 Shuttle Radar Topography

Mission (SRTM) at a 30 m resolution (SRTM 1 Arc-Second DOI: 10.5066/F7PR7TFT). The larger the value, the greater the elevational variation. The lower the value, the less elevational variation found at the site.

Surface water is a major limiting resource in the study system. I assessed the percentage of surface water at each site using the wildlife cameras images, recording surface water presence (1) or absence (0) for every week from camera deployment to camera pick up at each camera site. I then calculated the percentage of weeks (out of 14) water was present at each site during the study period.

Richness and Diversity

I estimated naïve richness at each camera site as the number of unique species recorded and corridor richness as the sum of all species across the camera sites within a corridor. Richness was standardized by camera effort to account for the four cameras that failed. Due to the coarser scale of naïve richness, all identifiable mammal species documented during the study period were included because they only needed one picture during the camera activity period (191 days from October 2018 to April 2019) to be considered present at the site. I also calculated naïve relative abundance index (RAI) based on the number of individual photos of each species divided by camera trap effort and multiplied by 100 for standardization (Coronel-Arellano et al. 2018). I computed Shannon's diversity index for each site using naïve richness to better understand the differences between camera sites. Additionally, to compare diversity and species richness in each corridor, I calculated the Renyi Index with RAI data from each camera site using the Vegan package (Oksanen et al. 2019) in R (Tóthmérész 1995; Kindt et al. 2006; R Core Development Team 2019). The Renyi index accounts for several diversity indices in one equation: species richness is approximated when the scale parameter (α) is zero; Shannon's diversity is approximated at $\alpha = 1$; the inverse Simpson's index is

approximated at $a = 2$; and the Berger Parker index is approximated as a approaches infinity.

Habitat Covariate Analysis

I conducted a principal components analysis (PCA) with an oblimin rotation on the correlation matrix of seven habitat variables (using the Psych package in R; Revelle 2019) including site width (m), elevation (m), distance to Federal Highway 2 (km), distance to perennial river (km), NDVI, topographic variety (m), and % weekly surface water (percent of total weeks). PCA captures the latent variables measured by our habitat covariates reducing our predictors in species-habitat models (Banville & Bateman 2012). All variables were transformed as necessary to meet recommendations of normality (Shapiro-Wilk test at $p < 0.05$). Three covariates (elevation, % weekly surface water, and distance to river) were still non-normal after transformation so the original data were retained in the PCA analysis. Components with an Eigenvalue >1 and factor loading >0.6 were considered to be significant. Rotated factor scores for the three PC composite variables (hereafter as ‘habitat covariates’) were used in all subsequent modeling analyses. I interpreted covariates with stronger component correlations to have higher importance in describing the component (Legendre & Legendre 1998).

Naïve Richness and Habitat Covariates

I used linear regression to analyze the relationship between naïve richness and the habitat covariates at each site. To test for habitat differences among the five riparian corridors, I transformed the PC composite habitat covariates as necessary for normality then performed an Analysis of Variance (ANOVA) and post-hoc Tukey test (or non-parametric Kruskal-Wallis and Wilcoxon rank sum tests) in R. All mammals recorded from October 2018 to April 2019 were used to model the naïve richness.

Occupancy Modeling

To assess the relationship between species occurrence and habitat covariates while accounting for imperfect detection, I used single-species, single-season occupancy modeling methods on medium- and large-bodied mammals in the study area using the ‘unmarked’ package in R (Leeuw 2009; Fiske & Chandler 2011). Occupancy modeling estimates the relative influence of covariates on species habitat use (MacKenzie & Royle 2005) as calculated from both presence and absence data. The detection probability (p) of a species informs the occupancy probability (Ψ) via a Bernoulli distribution. I divided the data into 14-day occasions across the entire study period (October 2018 to April 2019) resulting in 12 occasions. All sites were used for analyses. I use occupancy and abundance analyses only on medium- and large-bodied sized mammals (>1 kg in weight; Alvarenga et al. 2018) because larger bodied species are more likely to be detected on wildlife cameras (Thomas et al. 2020) and are thus more likely to be captured during the short 14 day occasions used in the occupancy analyses. Two species (coyote [*Canis latrans*] and jaguar) had only 4 independent detections which were not enough for modeling purposes, so only 11 of the 13 recorded medium- and large-bodied mammal species were modeled.

I first tested if camera effort and site width influenced detection probability for each of the 11 medium- and large-bodied species in the dataset. The ‘effort’ covariate is the proportion of days the camera was active for each occasion (Lewis et al. 2015). I applied effort and a standardized (Schielzeth 2010) site width covariate to the detection probability (p) using the global model structure (Lewis et al. 2015), which first tests the constant (no covariate) detection probability model ($p(.) \Psi(.)$) against the effort ($p(\text{effort}) \Psi(.)$) and site width ($p(\text{site width}) \Psi(.)$) detection models. I compared Akaike’s information criteria corrected for small sample size (AIC_c; Burnham & Anderson 2002)

with and without site effort and site width as covariates, and kept the variables if ΔAIC_c scores were lower than the global model (e.g. if camera effort had a lower ΔAIC_c value than the $p(\cdot)$ model, then effort was included as a covariate for detection probability in subsequent analyses for that species) (Lewis et al. 2015).

I then tested the relationship between the three PC composite habitat covariates and occupancy (Ψ) for each species using the appropriate covariates on detection (camera effort, site width and/or none) for each species, as determined by the global model testing. All possible combinations of the required detection covariates and the PCA covariates were tested for each species, totaling between 7 and 21 models. The top occupancy model for each species had the highest model weight and a ΔAIC_c separation greater than 1 from the next model. If two model were close in both model weight and AIC_c value, then they were both considered top models. Modeling results were averaged using the ‘MuMIn’ package in R (Barton 2019), and I reported the model-averaged beta estimate and variable importance value (VIV) for each covariate. Habitat covariates with a $VIV > 0.5$ were considered to be important for the occupancy estimate for that species (Burnham & Anderson 2002; Johnson & Omland 2004). Beta coefficient estimates were considered highly informative if the 95% confidence interval (CI) did not overlap zero, moderately informative if the 85% CI did not overlap zero, and uninformative if the 85% CI overlapped zero (Arnold 2010).

Abundance Modeling

In order to further understand relative habitat use of species with high occupancy in LO, I performed Royal-Nichols (R-N) abundance modeling using the ‘unmarked’ package in R for each medium- and large-bodied sized mammal that had an estimated occupancy value >0.8 (Fiske & Chandler 2011; Shannon et al. 2014). R-N abundance modeling uses a Poisson distribution to infer relative habitat use of each species. Model

interpretation and averaging followed the same methods as occupancy modeling and all camera sites were included in the modeling.

RESULTS

Habitat Characteristics of Riparian Corridors in LO

PCA reduced the seven measured habitat variables into three composite variables that explained 88% of the cumulative variance (Table 1). PC1 explained 39% of variance and was strongly related to characteristics of the perennial river, including distance to river, corridor width, and presence of surface water (hereafter as ‘river characteristics’). For example, a high PC1 score indicated a camera site close to the perennial river, large in width, and a constant source of surface water, while a low PC1 score indicated a camera site farther from the perennial river, on a corridor that is smaller in width, with no water present (ephemeral). Hereafter as ‘remoteness’, PC2 explained 31% of variance and was strongly related to distance from Federal Highway 2, NDVI, and elevation. A low score on PC2 indicated a camera site that was closer to the highway, lower in NDVI, and higher in elevation. Hereafter as ‘topographic variety’, PC3 explained 17% of the cumulative variance and was correlated only with topographic (elevation) variety (Table 1). A high score on PC3 indicated a camera site with steep cliff sides and/or hills which provided vertical habitat structure.

Averaged across camera sites, habitat variables related to river characteristics (PC1) and remoteness (PC2) varied significantly by riparian corridor (Figure 2, Appendix C). For example, the perennial river (Cajon Bonito) was relatively remote (and low elevation, high NDVI; PC2) while Javelina corridor lacked characteristics related to the perennial river (PC1; i.e. was narrower in width and had no water), and was less remote (PC2; higher elevation, lower NDVI; Figure 2, Appendix C). Corridors were not

significantly different in topographic variety (PC3) because elevation variation was relatively high within corridors.

Wildlife Species and Richness within Riparian Corridors of LO

Twenty-one out of 25 motion-activated cameras were fully functional during the study period (October 2018 to April 2019) including at least two cameras on each of the five corridors in the study area (Figure 1). Cameras were active from 187-191 days for a total of 3,778 trap nights, generating 1,519 independent pictures of mammals. Four cameras failed early; 117 days was the shortest activity period for a camera along the Diablo corridor (Appendix A).

Cameras captured images of 21 species of mammals during the 7-month study period (Appendix B), including 13 medium- and large-bodied mammals that were used in occupancy and abundance analyses (Table 2). Naïve species richness ranged between 3 and 16 species per camera site (Appendix A). The cameras also captured other non-mammal species in LO, including Gila monsters (*Heloderma suspectum*), bird species such as black hawk (*Buteogallus anthracinus*), grey heron (*Ardea cinerea*), northern cardinal (*Cardinalis cardinalis*), a variety of owls, and some species too blurry to be identified. Sixteen out of the 21 sites had either rancheros, dogs, livestock, or a combination of these categories documented during our study period. A camera site along Primavera corridor had the highest Shannon's diversity value of all 21 sites ($H = 2.38$), whereas the lowest Shannon's diversity score ($H = 0.53$) was along Cajon Bonito (Appendix A, Appendix E). Diablo corridor supported the highest richness of all camera sites (16) and the highest richness among corridors (19 out of 21 species). Javelina corridor supported the lowest camera site richness (3) and the lowest corridor richness (7 out of 21 species; Appendix C).

I recorded 86% of mammal species before day 40. Coyote (*Canis latrans*), cliff chipmunk (*Neotamius dorsalis*), and jaguar (*Panthera onca*; Figure 3a) were observed at days 54, 72, and 135, respectively (Appendix D). Seventeen of the 21 species occurred in both the perennial river corridor as well as in the non-perennial corridors (Appendix B). Hog-nosed skunk (*Conepatus leuconotus*) had the highest number of independent records (284 independent photos) and was recorded at 16 out of 21 sites (Table 2, Figure 3b). White-tailed deer was the second most abundant species with 250 independent photos at 17 out of 21 sites after being reintroduced in 2007 (Table 2, Appendix B). The most abundant predator was mountain lion (*Puma concolor*, Figure 3c) with 88 independent pictures at 17 out of 21 sites (Table 2). Three of the species captured in this study were elusive, with only 1-4 independent detections.

For the first time in over 25 years, jaguar was recorded in LO (Figure 3a). I documented the jaguar on four different cameras from 17 February 2019 to 27 March 2019 (Ragan et al. in review). This individual was documented traveling through Diablo corridor, with the highest topographic diversity (Figure 2), heading south from Federal Highway 2 and in the direction of Cajon Bonito. Historically, ocelot (*Leopardus pardalis*) were spotted within LO (Rorabaugh et al. 2020), however, no detections occurred during the study period. I recorded American black bear (*Ursus americanus*) at 7 different sites and with 11 independent photos. Black bears are endangered in México (Table 2, Figure 3d) (DOF 2010). Cuenca de Los Ojos A.C. reintroduced the white-tailed deer (*Odocoileus virginianus*) in 2007. Independent detections of white-tailed deer were the second highest (250 independent photos) and they were present at 17 out of 21 camera sites during the study period.

Species richness and diversity varied across the five corridors (Appendix A, Appendix C, Appendix E, Appendix F, Appendix G). Contrary to expectations, naïve

richness was not significantly related to any of the PCA composite habitat covariates or the individual habitat variables alone (Appendix F, Appendix G). The Cajon Bonito sites clustered around habitat variables related to perennial characteristics and had less variety in habitat characteristics than other corridors (Appendix F). Thus, I also tested the relationship between species richness, individual habitat variables (Appendix H), and composite habitat variables (Appendix I) in the non-perennial corridors after excluding Cajon Bonito sites. Naïve richness was significantly and negatively related to elevation ($p = 0.02$, $R = -0.69$) and significantly and positively related to NDVI ($p = 0.01$, $R = 0.73$; Appendix H). Both NDVI and elevation are included in the remoteness (PC2) component which was significantly and positively related to richness for non-perennial sites ($p = 0.03$, $R = 0.65$, Appendix I).

Occupancy Modeling

Occupancy modeling revealed independent relationships by some species among habitat covariates (Table 3; Appendix K). Overall, habitat covariates related to river characteristics (PC1) and remoteness (PC2) were more important variables for predicting medium- and large-bodied mammal species occupancy than topographic variety (PC3).

River characteristics (PC1) was particularly important for collared peccary (*Pecari tajacu*), grey fox (*Urocyon cinereoargenteus*), mountain lion, and Virginia opossum (*Didelphis virginiana*), but the models did not converge properly for all species and the direction and extent of the relationship varied by species (Table 3). Considering just the beta coefficients, which tell us the direction of the relationship a species has with modeled covariates and the certainty of that relationship, river characteristics (PC1) were highly informative for predicting occupancy of collared peccary (positive relationship) but were only moderately informative for both grey fox and Virginia opossum and uninformative for predicting the occupancy of mountain lion (Table 3). The beta

estimate confidence intervals of the other species were uninformative because they all were overlapping zero. However, the American black bear, bobcat (*Lynx rufus*), mountain lion, and white-nosed coati (*Nasua narica*) had river characteristics (PC1) included in their top model indicating river characteristics (PC1) influence occupancy for these species (Table 3, Appendix K).

While medium- and large-bodied mammal species had variable relationships with perennial river characteristics (PC1), species seemed to occupy more remote, lower elevation, and higher NDVI (PC2) sites, however lack of model convergence made it difficult to distinguish these relationships. Remoteness (PC2) was important and beta estimates were positive for American black bear, grey fox, hog-nosed skunk, Virginia opossum, and white-nosed coati. However, the relationship between remoteness and occupancy probability was only moderately informative for grey fox and Virginia opossum (Table 3).

In contrast, topographic variety (PC3) was not considered to be an important predictor for occupancy of species and was only moderately informative for white-tailed deer where the relationship was negative (deer occupied flatter terrain; Table 3). The beta coefficients for topographic variety for other species were close to zero, suggesting that for most species, topographic variety did not influence occupancy (Table 3).

Abundance Modeling

For common species such as hog-nosed skunk, mountain lion, Virginia opossum, white-nosed coati, and white-tailed deer (occupancy >0.8; Appendix J), the relationship between abundance and habitat covariates continued to be species dependent, but topographic variability (PC3) was both important and highly informative for four of the five species (Table 4). Abundance of mountain lion, Virginia opossum, and white-nosed coati was positively related to topographic variety (PC3), meaning these species were

most likely to use sites with greater vertical habitat (Table 4). Oppositely, and similar to occupancy results, white-tailed deer had a negative relationship with topographic variety and were more likely to use sites with flatter habitat (Table 4). Topographic variety was included in the top model for all species except hog-nosed skunk indicating it's strong influence on modeling abundance (Appendix L).

River characteristics (PC1) were important and moderately informative for abundance of both mountain lion (positive relationship, preferring drier, narrow width sites farther from the river) and white-tailed deer (negative relationship, preferring sites near the perennial river), but only moderately informative for hog-nosed skunk (Table 4). Remoteness (PC2) was also important and highly informative (and positive) for hog-nosed skunk and moderately informative (and positive) for Virginia opossum, whereas it was only moderately informative (and negative) for abundance of white-tailed deer (Table 4).

DISCUSSION

This study is the first to characterize occupancy and riparian corridor habitat preferences of a community of mammals on the Mexican side of the ecologically important US-México borderland region. Together, the findings provide evidence that mammal species occupy a range of habitat characteristics in semi-arid Los Ojos, including both the perennial river corridor with year-round access to surface water as well as structurally diverse, different elevation corridors where water is intermittent or ephemeral. Furthermore, Los Ojos is an incredibly diverse region with 11 different medium- and large-bodied mammals well represented in the region and 21 mammals identified in total. While individual species preferentially occupied, or were more abundant, in certain habitats over others, these findings demonstrate the importance of protecting a range of vegetative and geomorphic habitat characteristics to best facilitate

the movement and viability of semi-arid mammal communities within the Madrean Archipelago (Tews et al. 2004; Fischer & Lindenmayer 2007; Stein et al. 2014).

Habitat characteristics associated with the perennial river characteristics (PC1), and variables associated with site elevation, NDVI, and remoteness (PC2) were more important predictors of species presence than topographic variety (PC3). Instead, topographic variety was more strongly associated with modeling abundance for common species. For example, high-occupancy carnivores such as mountain lion, white-nosed coati, and Virginia opossum use sites with high canyon walls, while less common species like American black bear, collared peccary, and grey fox are more strongly associated with other habitat features. These findings suggest that structural diversity is less important when determining if a species is present. Characteristics dealing more with river characteristics (PC1) and remoteness (PC2) are driving the initial presence of the species, possibly due to the limiting resources in the region. Topographic variety is an important habitat characteristic for small mammals species (Hanser et al. 2011) and bird species (Lambertucci & Ruggiero 2016) but might not greatly impact a medium- and large-bodied mammal actively moving through the area. In contrast, when I modeled habitat use (abundance) it became clear that topographic variety (PC3) was highly informative for determining how often the site is utilized. It is important to consider the distinction between presence/absence (occupancy) and relative habitat use (abundance) when making management decisions for a landscape.

Surprisingly, species richness of riparian corridors was not influenced by diverse habitat covariates. In other words, contrary to other studies (Naiman et al. 1993), richness of the mammal community was not significantly higher near Cajon Bonito than the nearby non-perennial corridors. This finding might be due to the other sites having riparian characteristics and resources that make them more suitable than the

surrounding desert (Brand et al. 2008; Matos et al. 2009). Additionally, desert washes with intermittent water are known to be incredibly important for native biodiversity in arid landscapes but are often understudied (Bogan et al. 2014, 2019), especially within the context of mammal usage and monsoon behaviors. All non-perennial washes in this study were connected to the perennial water source, which may confound this finding. Occupancy modeling indicated that medium- and large-bodied mammals did not have consensus on their relationships with the habitat covariates. The community-level indecision could explain why no pattern is seen at the coarse scale of naïve richness. It also could suggest that sites facilitate different species needs along a corridor. Analyzing the naïve richness data sans Cajon Bonito revealed that more species were found at remote, lower elevation, higher NDVI sites (PC2). This pattern was not seen with the perennial river data included possibly due to the fluctuation in richness seen at the Cajon Bonito sites (Appendix A). This richness variation at Cajon Bonito sites is likely due to a lack of species funneling paired with an abundance of water and resources compared to the more arid sites.

The importance of habitat complexity is emphasized by the different habitat needs of each species and the diversity of small carnivores in this system. For example, all four species of skunk (*Conepatus leuconotus*, *Spilogale gracilis*, *Mephitis mephitis*, and *Mephitis macroura*) occupy sites in LO, signifying adequate habitat for the species to operate in the system together. Habitat specialization is more common in smaller carnivores (Kalle et al. 2013) and we recorded grey fox, bobcat, Virginia opossum, white-nosed coati, and larger carnivore species at high numbers within LO (Table 2; Appendix J). Coyotes were one of the least recorded species in our system despite being ubiquitous in North America. We expect this observation to be due to coyote preference for more topographically flat regions to avoid predators like mountain lions and hunt smaller

mammals (Linhart & Knowlton 1975; Arjo & Pletscher 2004). LO has high topographic variety and an abundance of mountain lion, thus not preferential habitat for coyotes. This high species presence indicates the importance of the diverse habitats within LO to facilitate a variety of needs. Grey foxes occupy a meso-carnivore role in the trophic hierarchy (Roemer et al. 2009) and prefer to be closer to the perennial river, whereas collared peccary are important herbivorous seed dispersers (Reider et al. 2013) and prefer more arid sites. However, both need diverse corridors to expand to new habitat, forage for resources, locate water, and to survive the summer heat, and both are found at overlapping sites in LO. Furthermore, habitat preferences of white-tailed deer differed strikingly from mountain lion (Table 3, 4) yet we know of their important predator-prey relationship (Cunningham et al. 1999; Ewanyk 2020). If species habitat preferences are only considered individually, protected areas will not maximize connectivity and could instead ignore critical habitat for prey species leading to unintended negative consequences (Bennett 2003; Beier et al. 2006, 2008; Abrahms et al. 2017).

Protection of habitat complexity across a variety of corridors will also mitigate species losses due to climate change (Naiman et al. 1993; Capon et al. 2013; Fremier et al. 2015), particularly for the Madrean Archipelago biodiversity hotspot, home to the greatest diversity in the southwestern United States (López-Hoffman & Quijada-Mascareñas 2012). Escaping from the warmer temperatures and less predictable but drier climates, species' ranges have expanded throughout the world, pushing towards cooler regions (Ragan et al. in review; Chen et al. 2011). Species require connected habitat to navigate these challenges. Without safe passage, only species who can rapidly adapt will survive. For example, in this study, a neotropical species, the jaguar, was spotted for the first time in LO in over 25 years, and ocelot have been captured on wildlife cameras in this area within the last 5 years (KR pers. comm.). Both of these

species are endangered and almost extirpated from the United States due to hostile landscapes facilitated by infrastructure barriers and management. For species viability, these neotropical organisms need to expand their home range and depend on the corridors in LO to do so. Protection of intact riparian corridors within the Madrean Archipelago will be imperative because many of the natural corridors along the rapidly developing US-Mexico borderlands that facilitate range expansions are now dry or encroached on by humans.

Although novel to the ecologically important conservation lands near the US-Mexico border, this study was conducted on only 5 riparian corridors on private land over one 7-month period. Future research should assess habitat occupancy and species richness in the landscapes outside of the corridors to provide additional context to wildlife habitat in the borderlands. Ridgelines and grasslands can also be important movement corridors for large-sized mammals, especially big cats (Beier et al. 1995; Rabinowitz & Zeller 2010; Nicholson et al. 2014). In particular, as newer technologies address camera sensitivity (false positives), it may be possible to better monitor grassland ecosystems for mammal communities in the near future. Additionally, expanding this study to the larger region and incorporating other conservation properties within Cuenca Los Ojos and properties under different management goals (e.g. Janos Biosphere reserve and ejidos, in addition to other private ranches) should be prioritized in the future to gain a greater context about wildlife connectivity in the region.

LO is one of only three projected pathways along the US-México border for jaguar to cross into the US, and is predicted habitat for Mexican wolves (Bravo & Davis 2017). This research further highlights the importance of LO's diverse riparian corridors for habitat connectivity and species movement. As the region develops with highway

expansion (Bravo 2017a), groundwater pumping (JS pers. comm.), river damming, and the completion of border walls (Peters et al. 2018), it is imperative that mitigation such as funnel and road fencing and over- or under-passes, are placed across barriers to reduce negative effects on wildlife species. When considering placement of mitigation measures, this research suggests prioritizing mitigation for corridors that contain the greatest diversity and complexity of habitat characteristics. A structurally diverse and complex set of riparian corridors is most likely to meet the needs of most species in this biodiverse ecosystem.

Table 1. Results from principal components analysis on seven habitat variables in the LO study area. Three components best described the measured variation in habitat covariates within LO. Factor loadings greater than 0.6 (grey shadowing) are considered significant.

	Oblimin rotation factor loadings		
	PC1	PC2	PC3
Distance to river (km)	-0.957	0.132	<0.1
Site width (m)	0.906	0.163	-0.207
Weekly water	0.795	<0.1	0.371
Distance to highway (km)	-0.283	0.981	-0.105
NDVI	0.393	0.763	<0.1
Elevation (m)	-0.386	-0.759	-0.128
Topographic variety (m)	<0.1	<0.1	0.996
Eigenvalue	2.76	2.17	1.20
Sum of squares loading	2.76	2.17	1.2
% explained variance	39%	31%	17%
% cumulative variance	39%	70%	88%

Table 2. Medium- and large-bodied mammal species recorded in Los Ojos, Sonora, México from October 2018 to April 2019. Twenty-one wildlife cameras along 5 riparian corridors recorded 13 medium- and large-bodied mammals during the 7-month study period. Occupancy and abundance modeling were performed on all species except coyote and jaguar due to low number (<5) of independent photos.

Scientific name	Common name	Sites where species was observed (out of 21)		Site		Independent photos (1519)	
		#	%	Perennial	Non-Perennial	#	%
<i>Bassariscus astutus</i>	Ringtail	9	42.9	x	x	58	3.8
<i>Canis latrans</i>	Coyote	4	19.0		x	4	0.3
<i>Conepatus leuconotus</i>	Hog-nosed skunk	16	76.2	x	x	284	18.7
<i>Didelphis virginiana</i>	Virginia opossum	11	52.4	x	x	95	6.3
<i>Lynx rufus</i>	Bobcat	15	71.4	x	x	85	5.6
<i>Nasua narica</i>	White-nosed coati	17	81.0	x	x	60	3.9
<i>Odocoileus virginianus</i>	White-tailed deer	17	81.0	x	x	250	16.5
<i>Panthera onca</i>	Jaguar	4	19.0	x	x	4	0.3
<i>Pecari tajacu</i>	Collared peccary	12	57.1	x	x	83	5.5
<i>Procyon lotor</i>	Raccoon	9	42.9	x	x	27	1.8
<i>Puma concolor</i>	Mountain lion	17	81.0	x	x	88	5.8
<i>Ursus americanus</i>	American black bear	7	33.3	x	x	11	0.7
<i>Urocyon cinereoargenteus</i>	Grey fox	8	38.1	x	x	19	1.3

Table 3. Relationship between habitat covariates and species occupancy of medium- and large-bodied mammals. For each species, variables with importance values greater than 0.5 are denoted with grey shading. ** indicates the variable is highly informative (95% confidence interval does not overlap zero); * indicates the variable is moderately informative (85% confidence interval does not overlap zero). The top occupancy models had the highest model weight and had a $\Delta AICc$ separation greater than 1 from the next top model. If two models were close in both model weight and AICc value, then they were both included (Appendix K). p = detection probability, Ψ = occupancy probability, and (.) = no covariate applied.

Common name	Beta estimates (SE)			Top occupancy model
	River Character - istics - PC1	Remoteness - PC2	Topographi c variety - PC3	
American black bear	-2.16 (8.64)	2.71 (7.85)	0.73 (2.21)	p(.) Ψ (PC2); p(.) Ψ (PC1+PC2)
Bobcat	-0.50 (0.74)	0.00 (0.32)	0.04 (0.26)	p(site width) Ψ (.); p(site width) Ψ (PC1)
Collared peccary	1.58 (0.85)**	-0.07 (0.36)	0.06 (0.27)	p(site width) Ψ (PC1)
Grey fox	-3.74 (3.14)*	3.26 (3.02)*	-0.02 (0.30)	p(.) Ψ (PC1+PC2)
Hog-nosed skunk	-0.96 (1.92)	2.29 (2.15)	0.06 (0.32)	p(.) Ψ (PC2); p(effort) Ψ (PC2)
Mountain lion	-3.22 (2.96)	0.65 (1.75)	0.29 (0.80)	p(.) Ψ (PC1)
Raccoon	0.13 (0.36)	0.21 (0.46)	0.17 (0.40)	p(.) Ψ (.)
Ringtail	0.07 (0.30)	0.26 (0.59)	0.23 (0.50)	p(.) Ψ (.)
Virginia opossum	-3.18 (2.69)*	3.29 (2.60)*	0.16 (0.45)	p(site width) Ψ (PC1+PC2)
White-nosed coati	1.23 (63.06)	22.62 (48.50)	0.20 (6.25)	p(.) Ψ (PC1); p(site width) Ψ (PC2)
White-tailed deer	0.05 (0.38)	0.37 (0.67)	-0.47 (0.68)*	p(effort) Ψ (.); p(effort) Ψ (PC3)

Table 4. Relationship between habitat covariates and species abundance of medium- and large-bodied mammals. High-occupancy species ($\Psi > 0.8$) were included in abundance analysis. A variable importance value greater than 0.5 is denoted with grey shading. ** indicates the variable is highly informative (95% confidence interval does not overlap zero); * indicates the variable is moderately informative (85% confidence interval does not overlap zero). The top occupancy models had the highest model weight and had a $\Delta AICc$ separation greater than 1 from the next top model. If two models were close in both model weight and AICc value, then they were both included (Appendix L). p = detection probability, λ = Royle-Nichols abundance, and (.) = no covariate applied.

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Common name	Beta estimates (SE)			Top abundance model
	River Character - istics - PC1	Remoteness - PC2	Topographic variety - PC3	
Hog-nosed skunk	0.15 (0.21)*	0.46 (0.30)**	0.02 (0.11)	p(.) λ (PC2); p(.) λ (PC1+PC2)
Mountain lion	-0.23 (0.27)*	-0.02 (0.10)	0.40 (0.25)**	p(.) λ (PC1+PC3); p(.) λ (PC3)
Virginia opossum	-0.17 (0.35)	0.35 (0.42)*	0.50 (0.44)**	p(site width) λ (PC2+PC3)
White-nosed coati	0.18 (0.26)	0.05 (0.14)	0.28 (0.27)**	p(site width) λ (PC3)
White-tailed deer	0.19 (0.23)*	-0.10 (0.18)*	-0.73 (0.26)**	p(effort) λ (PC3); p(effort) λ (PC1+PC3)

Figure 1. Wildlife camera site locations in Los Ojos, Sonora, México. Location of wildlife cameras to monitor habitat use of medium- and large-bodied mammals from October 2018 to April 2019. Sites were along five riparian corridors within the greater Cuenca Los Ojos study region south of the United States – México border and Mexican Federal Highway 2.

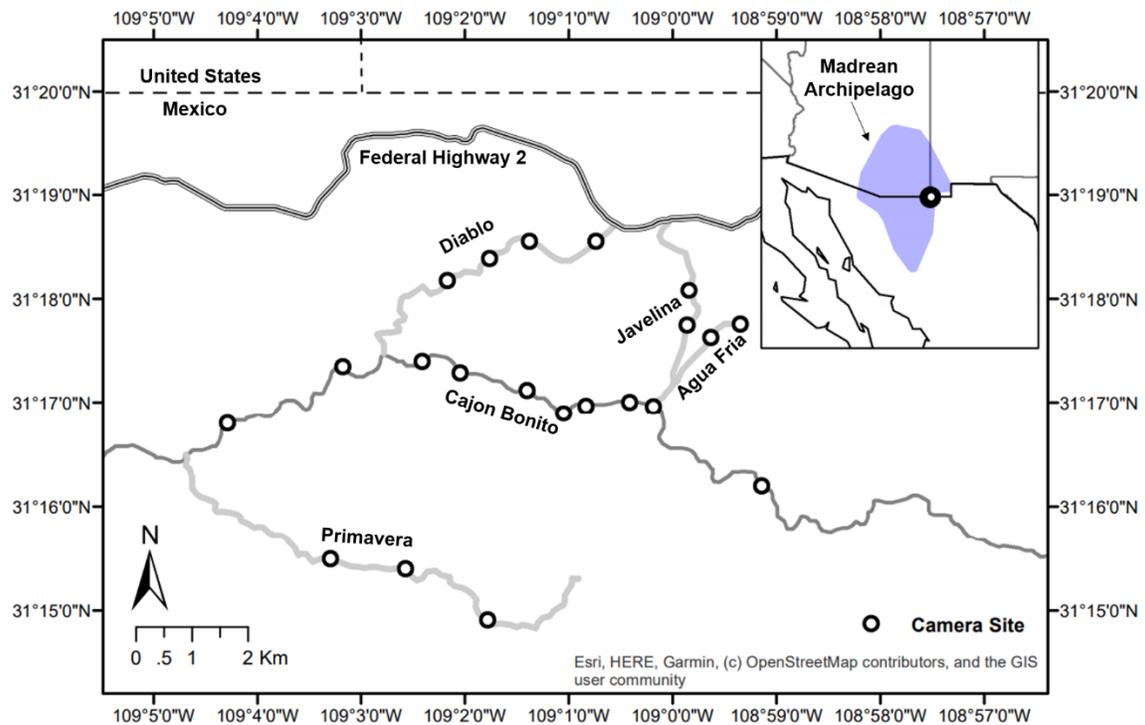


Figure 2. Habitat variability between five different riparian corridors in Los Ojos, Sonora, México. Corridor variability is shown in photos and boxplots of composite habitat covariates from a principal component analysis. Cajon Bonito (photo 1) is the perennial river. Lowercase letters indicate significant differences among the corridors (ANOVA and post-hoc analyses, $p < 0.05$).

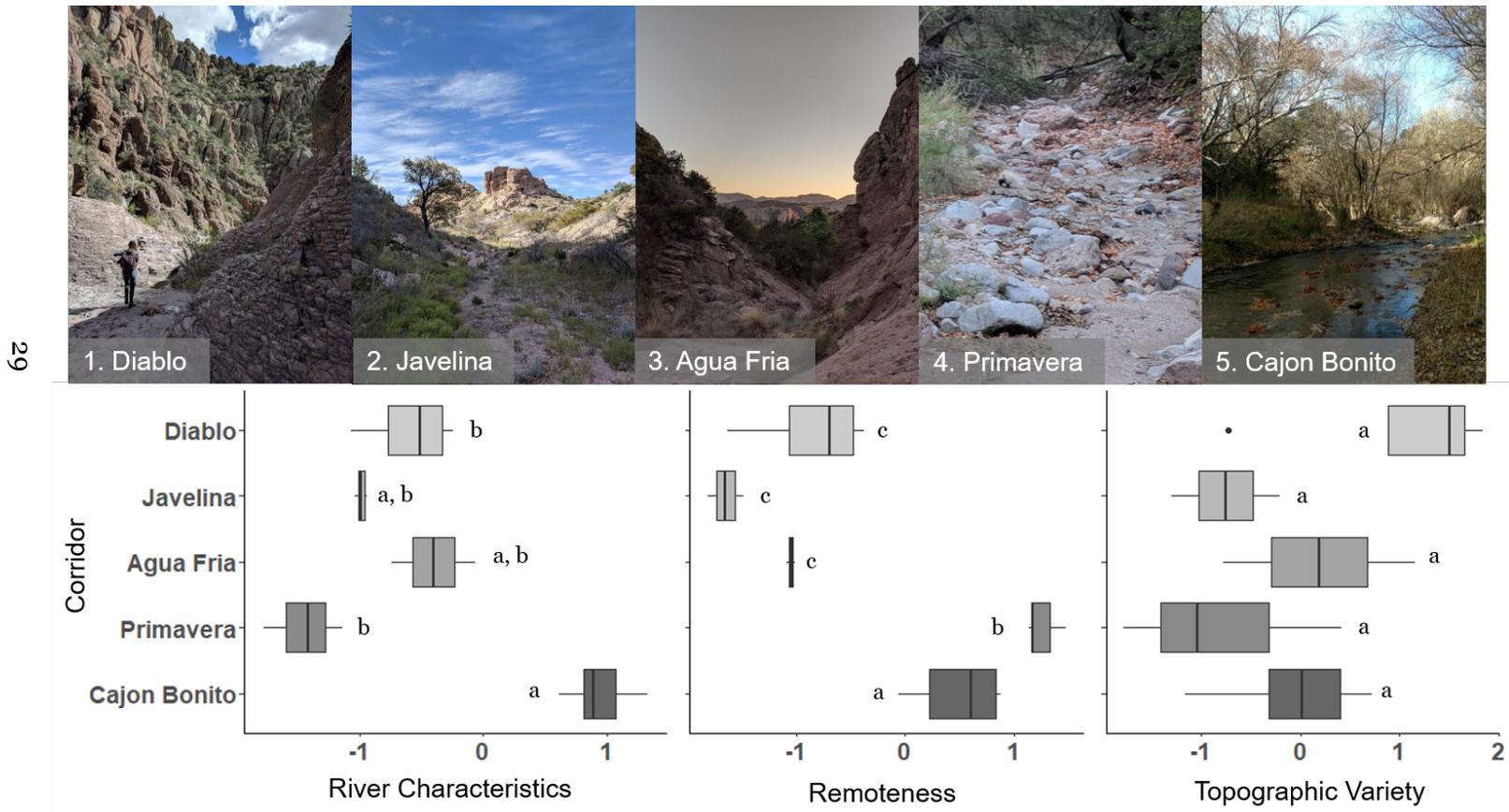
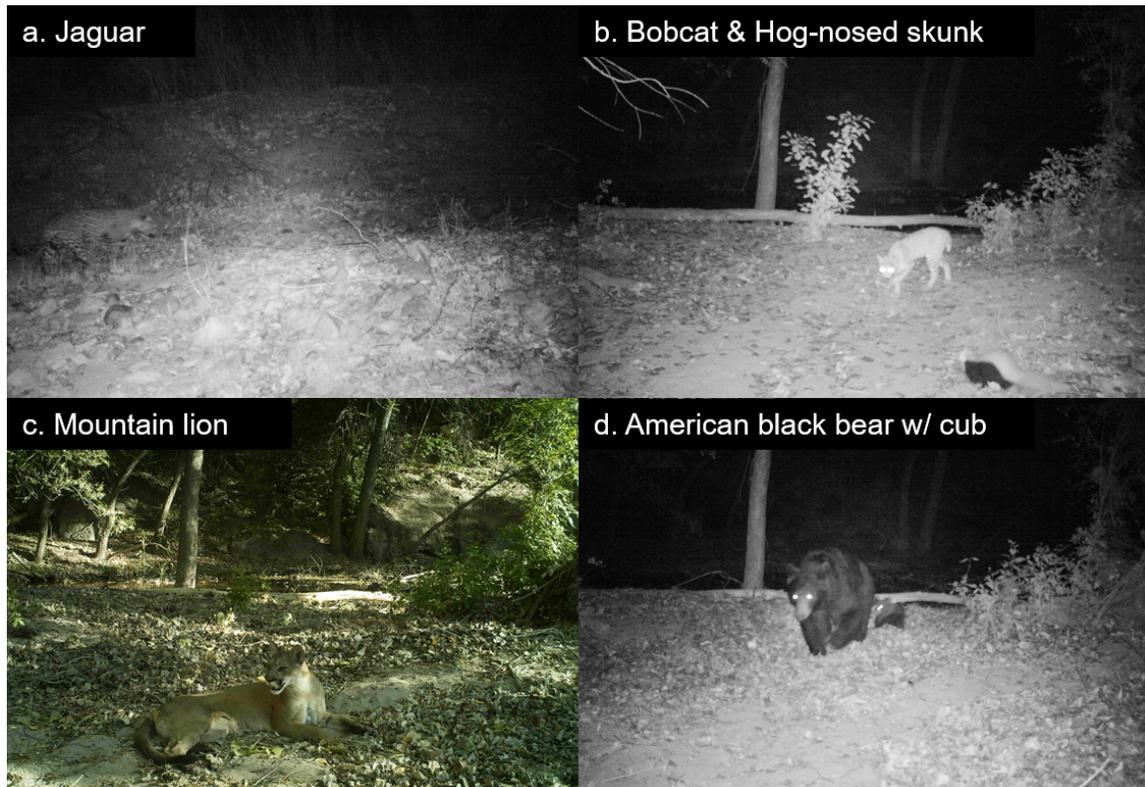


Figure 3. Images of five species captured on wildlife cameras in Los Ojos, Sonora, México from October 2018 to April 2019. Species include (a) jaguar (*Panthera onca*), (b) bobcat (*Lynx rufus*) and hog-nosed skunk (*Conepatus leuconotus*), (c) mountain lion (*Puma concolor*), and (d) American black bear (*Ursus americanus*) with cub.



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APPENDIX A
SITE AND CAMERA INFORMATION

Appendix A. Camera location and naïve mammal species diversity metrics for study sites within LO. All cameras were deployed and removed within 3 days of each other in October 2018 and April 2019, respectively. Cameras that failed early are indicated by bolding of the stop date.

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Site	Corridor	UTM Easting	UTM Northing	Trap nights	Camera stop date	Naïve species richness	Shannon's diversity index
LO03		691700	3461200	191	15-Apr-19	6	1.30
LO05		690000	3462600	189	13-Apr-19	6	1.38
LO06		689700	3462700	191	15-Apr-19	4	0.53
LO07		689000	3462600	189	13-Apr-19	4	1.31
LO08	Cajon	688700	3462500	189	13-Apr-19	9	1.75
LO09	Bonito	688100	3462900	189	13-Apr-19	11	2.14
LO10		687100	3463200	188	13-Apr-19	6	0.73
LO11		686500	3463400	117	1-Feb-19	10	1.85
LO13		685300	3463200	189	15-Apr-19	15	1.77
LO65		683500	3462200	189	14-Apr-19	14	1.76
LO18	Agua Fria	691300	3464100	189	13-Apr-19	12	2.23
LO20		690900	3463900	172	27-Mar-19	13	1.79
LO33		687600	3458800	187	14-Apr-19	12	1.01
LO35	Primavera	686300	3459600	187	14-Apr-19	15	1.87
LO37		685200	3459800	187	14-Apr-19	4	2.38
LO54		689100	3465500	127	11-Feb-19	10	2.22
LO55	Diablo	688100	3465500	188	13-Apr-19	16	0.89
LO56		687500	3465200	188	13-Apr-19	12	1.16

LO57		686900	3464800	188	13-Apr-19	11	2.11
LO75	Javelina	690500	464100	188	15-Apr-19	3	2.16
LO76		690500	3464700	156	14-Mar-19	6	2.24

APPENDIX B
MAMMALS IN LOS OJOS

Appendix B. List of mammals captured on 21 wildlife cameras along 5 riparian corridors in Los Ojos, Sonora, México from October 2018 to April 2019. Hog-nosed skunk (*Conepatus leuconotus*) was captured most frequently, while spotted skunk (*Spilogale gracilis*) was captured the least. Site type (perennial or non-perennial corridor) where species were observed are indicated with an 'x'.

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Scientific name	Common name	Sites where species was observed (out of 21)		Site		Independent photos (1519)	
		#	%	Perennial	Non-Perennial	#	%
<i>Bassariscus astutus</i>	Ringtail	9	42.9	x	x	58	3.8
<i>Canis latrans</i>	Coyote	4	19.0		x	4	0.3
<i>Conepatus leuconotus</i>	Hog-nosed skunk	16	76.2	x	x	284	18.7
<i>Didelphis virginiana</i>	Virginia opossum	11	52.4	x	x	95	6.3
<i>Lynx rufus</i>	Bobcat	15	71.4	x	x	85	5.6
<i>Mephitis mephitis</i>	Striped skunk	11	52.4	x	x	12	0.8
<i>Mephitis macroura</i>	Hooded skunk	7	33.3	x	x	44	2.9
<i>Nasua narica</i>	White-nosed coati	17	81.0	x	x	60	3.9
<i>Neotamius dorsalis</i>	Cliff chipmunk	2	9.5		x	3	0.2
<i>Odocoileus virginianus</i>	White-tailed deer	17	81.0	x	x	250	16.5
<i>Otospermophilus variegatus</i>	Rock squirrel	10	47.6	x	x	47	3.1
<i>Panthera onca</i>	Jaguar	4	19.0	x	x	4	0.3
<i>Pecari tajacu</i>	Collared peccary	12	57.1	x	x	83	5.5

<i>Procyon lotor</i>	Raccoon	9	42.9	x	x	27	1.8
<i>Puma concolor</i>	Mountain lion	17	81.0	x	x	88	5.8
	Rats & mice, unknown	6	28.6	x	x	84	5.5
<i>Sciurus nayaritensis</i>	Mexican fox squirrel	7	33.3	x		68	4.5
<i>Spilogale gracilis</i>	Spotted skunk	1	4.8		x	1	0.1
<i>Sylvilagus spp.</i>	Rabbit	9	42.9	x	x	192	12.6
<i>Ursus americanus</i>	American black bear	7	33.3	x	x	11	0.7
<i>Urocyon cinereoargenteus</i>	Grey fox	8	38.1	x	x	19	1.3

APPENDIX C
CORRIDOR HABITAT VARIABLES

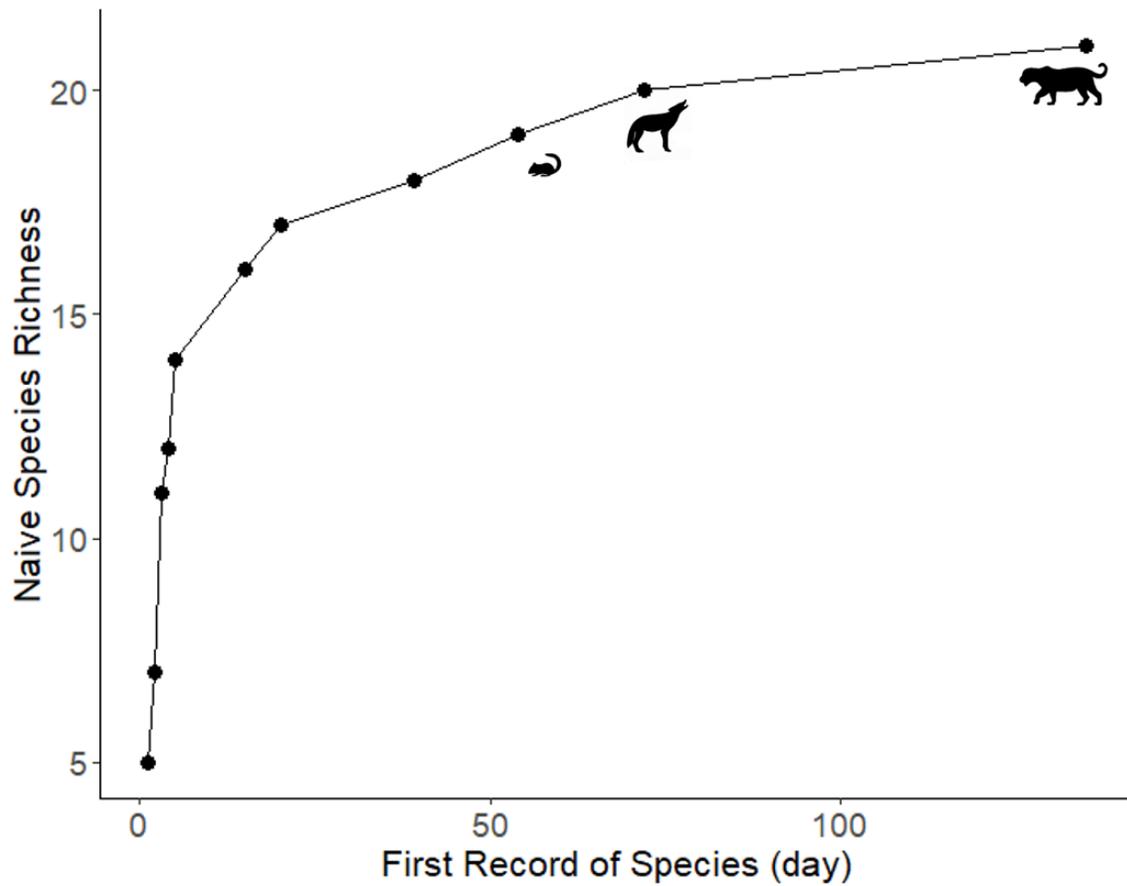
Appendix C. Summary statistics (mean[SE]) for habitat variables for each corridor within Los Ojos, Sonora, México.

		Corridor:	Cajon Bonito	Agua Fria	Diablo	Javelina	Primavera
Habitat Variables	River characteristics:						
	Distance to river (km)		0 (0)	1.89 (0.39)	3.84 (1.35)	2.09 (0.49)	5.13 (1.55)
	Site width (m)		45.85 (16.66)	10.70 (4.10)	9.49 (2.85)	3.71 (0.44)	7.37 (0.03)
	Weekly water (%)		100 (0)	50 (70.71)	63.89 (44.59)	0 (0)	0 (0)
	Remoteness:						
	Distance to highway (km)		6.85 (1.95)	3.13 (0.39)	2.21 (1.36)	2.13 (0.49)	15.87 (1.55)
	NDVI		0.42 (0.03)	0.31 (0.01)	0.31 (0.04)	0.26 (0.01)	0.40 (0.04)
Elevation (m)		1262 (16.45)	1417 (36.06)	1355 (63.16)	1458 (24.04)	1297 (29.82)	
Corridor metrics	Topographic variety:						
	Topographic variety (m)		13.08 (2.62)	14.80 (5.09)	17.50 (4.17)	11.20 (2.60)	10.73 (5.19)
	Naïve species richness		18	16	19	7	17
	% of total richness (n = 21)		85.71	76.19	90.48	33.33	80.95
	Shannon's diversity		1.32 (0.51)	2.01 (0.32)	1.87 (0.61)	1.02 (0.14)	2.17 (0.07)

APPENDIX D
SPECIES ACCUMULATION CURVE

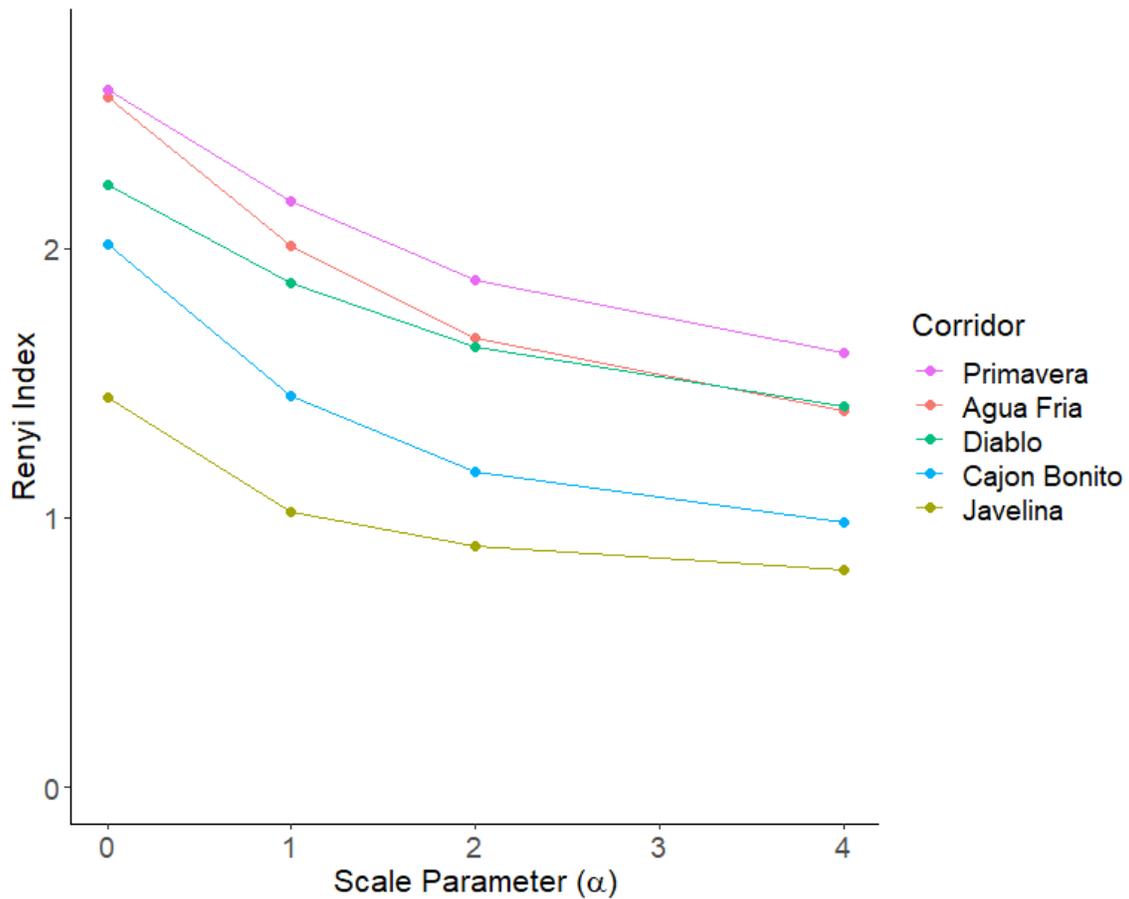
Appendix D. Species accumulation curve for mammals in Los Ojos, Sonora, México.

Cameras were deployed for 191 days. 75% of species were recorded by day 16, and 86% were recorded by day 40. Coyote (*Canis latrans*), cliff chipmunk (*Neotamius dorsalis*), and jaguar (*Panthera onca*) were captured at days 54, 72, 135, respectively.



APPENDIX E
RENYI INDEX

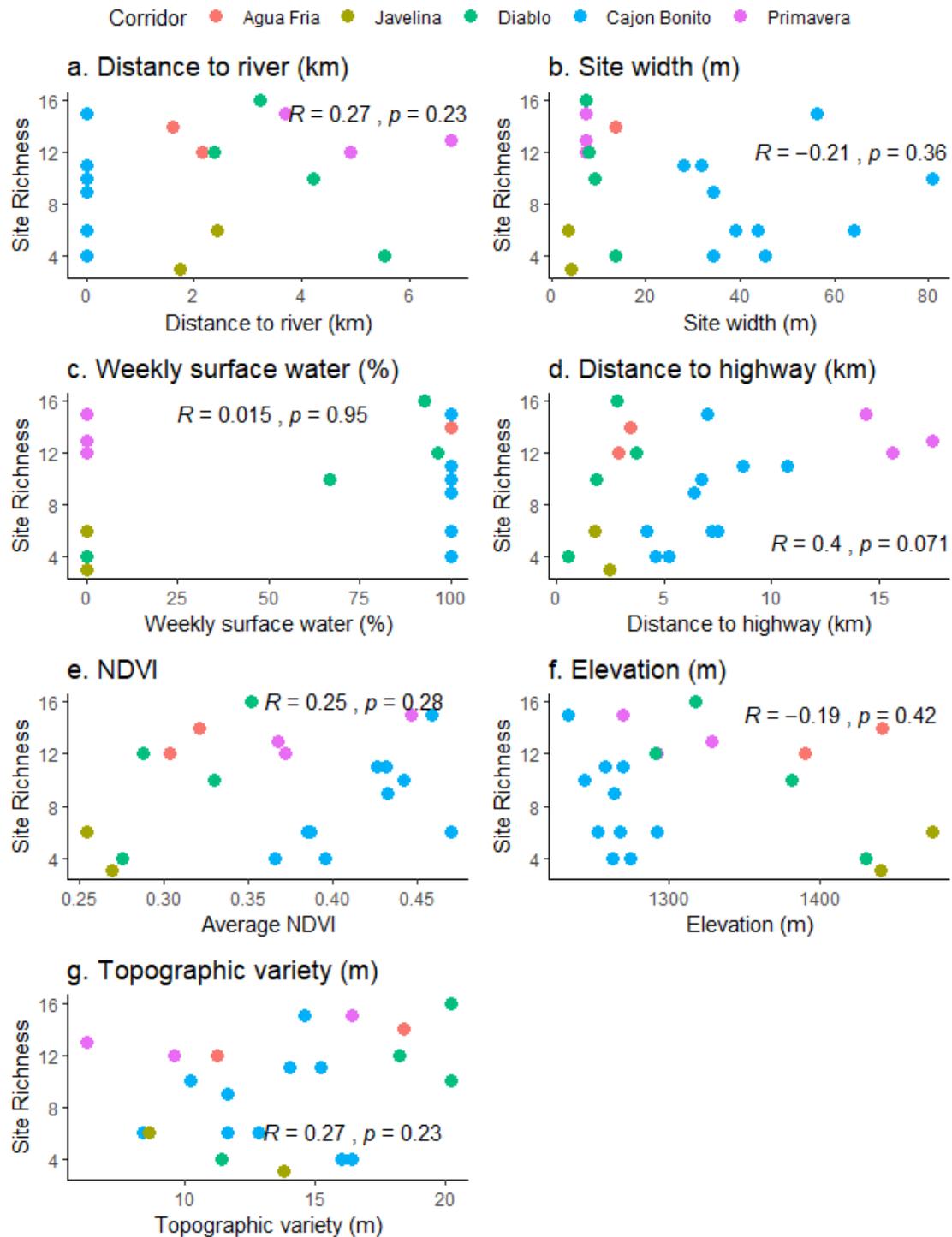
Appendix E. Renyi diversity index for each corridor in Los Ojos, Sonora, México. Species richness is approximated at scale parameter (α) = 0; Shannon's diversity $\alpha = 1$; the inverse Simpson's index is $\alpha = 2$; and the Berger Parker index is α as it approaches infinity. Only lines that do not overlap can be interpreted as different from one another. If lines cross, the diversity values are inconsistent across the indices and cannot be considered different from one another.



APPENDIX F

MAMMAL RICHNESS AND HABITAT COVARIATES FOR ALL SITES

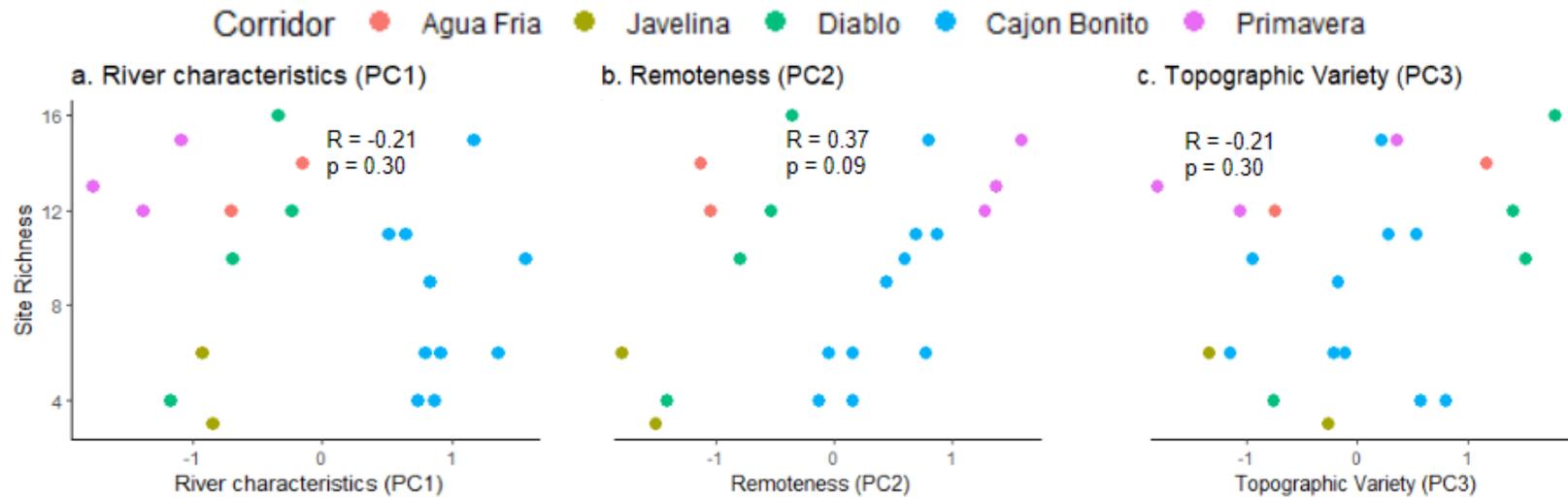
Appendix F. Relationships between naïve mammal richness at all sites and the seven measured habitat variables.



APPENDIX G

MAMMAL RICHNESS AND COMPOSITE HABITAT COVARIATES FOR ALL SITES

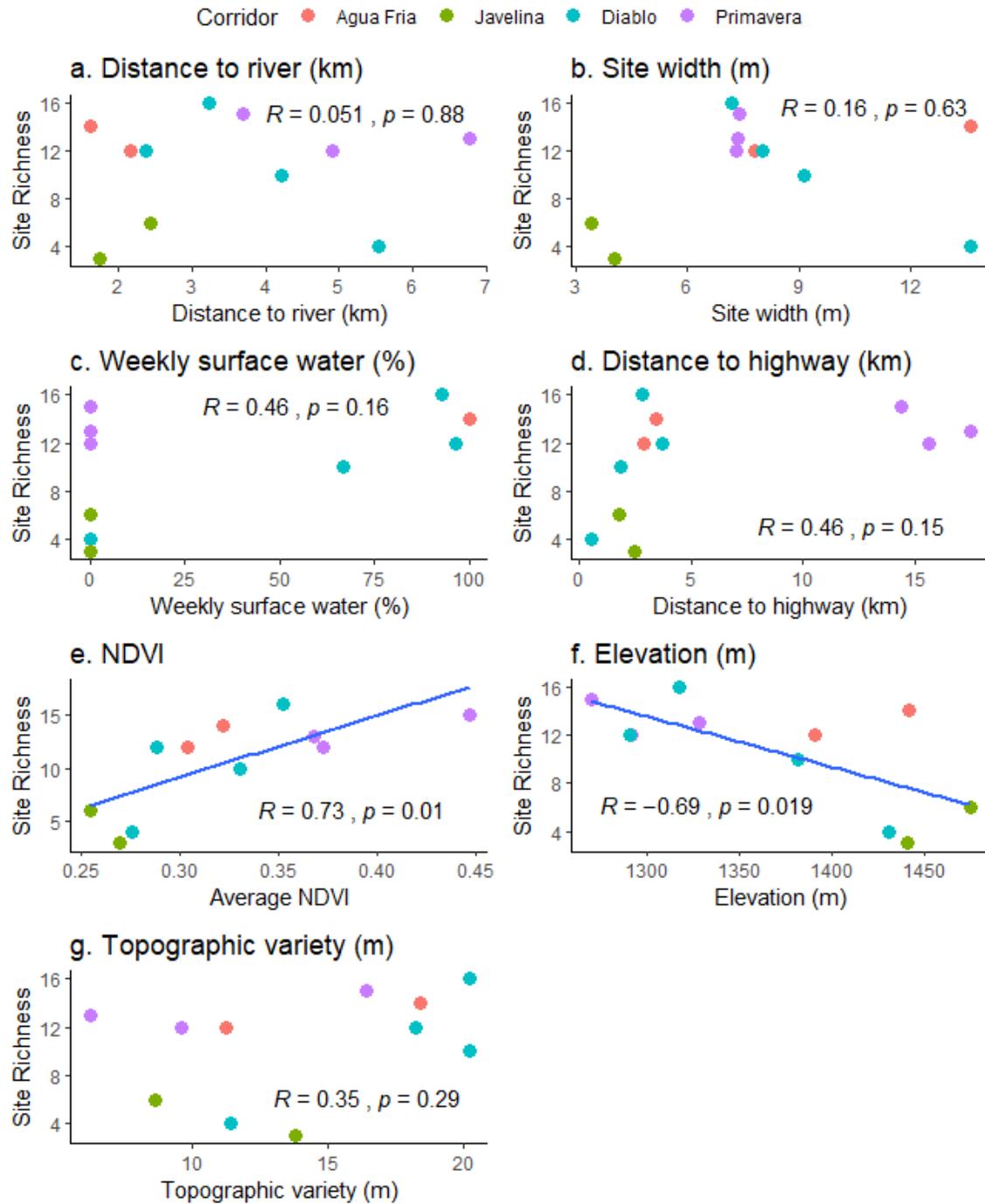
Appendix G. Relationships between naïve mammal richness at all sites and the three composite habitat variables.



APPENDIX H

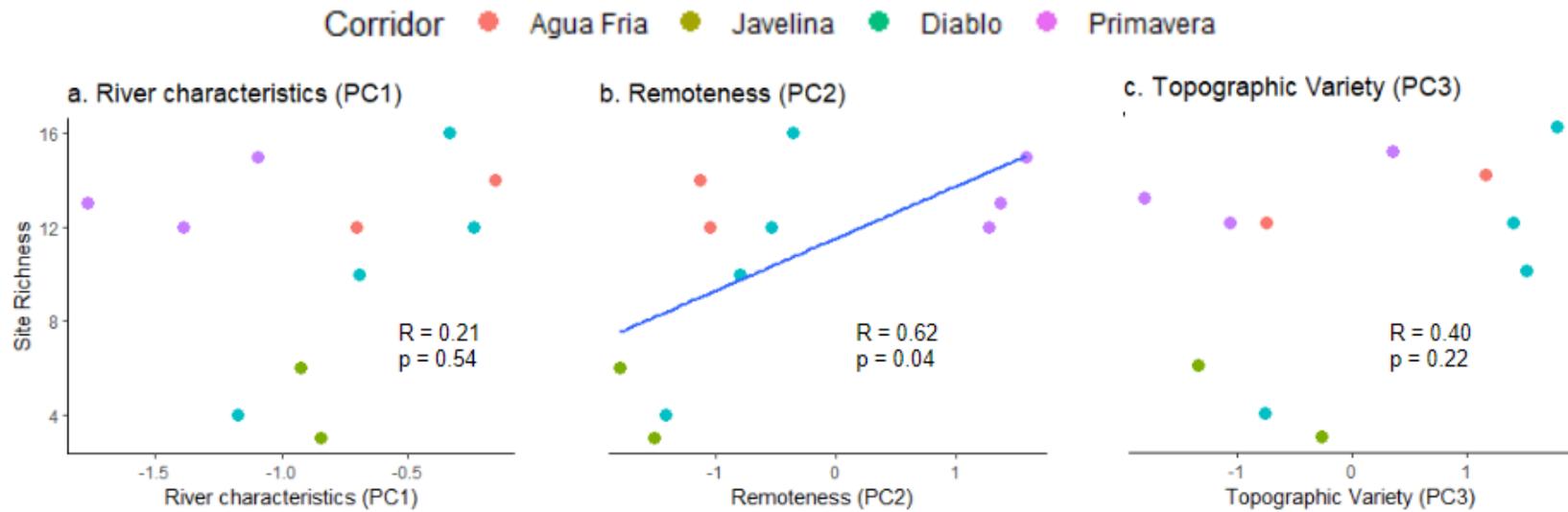
MAMMAL RICHNESS AND HABITAT COVARIATES EXCLUDING CAJON BONITO

Appendix H. Relationships between naïve mammal richness at non-perennial sites and the seven habitat variables.



APPENDIX I
MAMMAL RICHNESS AND COMPOSITE HABITAT COVARIATES EXCLUDING
CAJON BONITO

Appendix I. Relationships between naïve mammal richness at non-perennial sites and the three composite variables.



APPENDIX J
OCCUPANCY AND ABUNDANCE ESTIMATES

Appendix J. Estimated probabilities of occupancy (Ψ), abundance (λ), and detection (p) and associated standard errors (SE) of medium- and large-bodied mammals in Los Ojos, Sonora, México from October 2018 – April 2019. Species with occupancy > 0.8 were selected for abundance modeling.

	Occupancy		Abundance	
	Ψ (SE)	p (SE)	λ (SE)	p (SE)
American black bear	0.39 (0.19)	0.09 (0.03)	-	-
Bobcat	0.74 (0.10)	0.31 (0.03)	-	-
Collared peccary	0.63 (0.15)	0.31 (0.04)	-	-
Grey fox	0.73 (0.23)	0.12 (0.03)	-	-
Hog-nosed skunk	0.85 (0.1)	0.48 (0.03)	1.59 (0.43)	0.27 (0.05)
Mountain lion	0.97 (0.07)	0.29 (0.03)	1.9 (0.69)	0.13 (0.04)
Raccoon	0.48 (0.12)	0.16 (0.04)	-	-
Ringtail	0.49 (0.13)	0.15 (0.04)	-	-
Virginia opossum	0.84 (0.15)	0.40 (0.05)	0.79 (0.25)	0.24 (0.05)
White-nosed coati	1 (0)	0.20 (0.03)	6.78 (3.37)	0.02 (0.01)
White-tailed deer	0.81 (0.09)	0.54 (0.03)	2.08 (0.50)	0.28 (0.05)

APPENDIX K
OCCUPANCY MODEL RESULTS

Appendix K. Top 5 occupancy models with dot “(.)” model for medium- and large-bodied mammals in Los Ojos, Sonora, México from October 2018 to April 2019. Species are listed in alphabetical order.

Species	Occupancy Model	df	logLik	AICc	ΔAICc	weight
American black bear	p(.) Ψ (PC2)	3	-43.21	93.80	0.00	0.28
	p(.) Ψ (PC1+PC2)	4	-41.93	94.40	0.53	0.21
	p(.) Ψ (PC2+PC3)	4	-42.50	95.50	1.67	0.12
	p(.) Ψ (.)	2	-45.50	95.70	1.85	0.11
	p(.) Ψ (PC3)	3	-44.14	95.70	1.86	0.11
Bobcat	p(site width) Ψ (.)	3	-135.66	278.70	0.00	0.29
	p(site width) Ψ (PC1)	4	-134.27	279.00	0.30	0.25
	p(.) Ψ (PC1)	3	-136.95	281.30	2.57	0.08
	p(site width) Ψ (PC2)	4	-135.61	281.70	2.98	0.07
	p(site width) Ψ (PC3)	4	-135.63	281.80	3.02	0.06
	p(.) Ψ (.)	2	-138.59	281.80	3.10	0.06
Collared Peccary	p(site width) Ψ (PC1)	4	-102.44	215.40	0.00	0.60
	p(site width) Ψ (PC1+PC2)	5	-102.25	218.50	3.12	0.13
	p(site width) Ψ (PC1+PC3)	5	-102.27	218.50	3.17	0.12
	p(.) Ψ (PC1)	3	-106.70	220.80	5.44	0.04
	p(site width) Ψ (.)	3	-106.77	221.00	5.57	0.04
	p(.) Ψ (.)	2	-110.83	226.30	10.96	0.00
Grey fox	p(.) Ψ (PC1+PC2)	4	-48.54	107.60	0.00	0.61
	p(.) Ψ (PC1)	3	-51.76	110.90	3.34	0.12
	p(.) Ψ (PC1+PC2+PC3)	5	-48.52	111.00	3.45	0.11
	p(.) Ψ (.)	2	-53.67	112.00	4.42	0.07
	p(.) Ψ (PC2)	3	-52.77	113.00	5.37	0.04
Hog-nosed skunk	p(.) Ψ (PC2)	3	-158.97	325.40	0.00	0.19

	p(effort) Ψ (PC2)	4	-157.69	325.90	0.52	0.15
	p(.) Ψ (PC1+PC2)	4	-157.84	326.20	0.83	0.13
	p(site width) Ψ (PC2)	4	-157.89	326.30	0.92	0.12
	p(effort) Ψ (PC1+PC2)	5	-156.56	327.10	1.76	0.08
	p(.) Ψ (.)	2	-162.29	329.30	3.89	0.03
Mountain lion	p(.) Ψ (PC1)	3	-146.48	300.40	0.00	0.30
	p(effort) Ψ (PC1)	4	-145.43	301.40	0.98	0.18
	p(.) Ψ (PC1+PC2)	4	-145.82	302.10	1.75	0.12
	p(.) Ψ (PC1+PC3)	4	-145.97	302.40	2.06	0.11
	p(effort) Ψ (PC1+PC2)	5	-144.76	303.50	3.15	0.06
	p(.) Ψ (.)	2	-149.93	304.50	4.15	0.04
Raccoon	p(.) Ψ (.)	2	-69.16	143	0	0.337
	p(.) Ψ (PC2)	3	-68.47	144.4	1.36	0.171
	p(.) Ψ (PC1)	3	-68.59	144.6	1.6	0.151
	p(.) Ψ (PC3)	3	-68.65	144.7	1.71	0.143
	p(.) Ψ (PC2+PC3)	4	-67.65	145.8	2.8	0.083
Ringtail	p(.) Ψ (.)	2	-67.59	139.80	0.00	0.35
	p(.) Ψ (PC2)	3	-66.97	141.30	1.50	0.16
	p(.) Ψ (PC3)	3	-66.99	141.40	1.54	0.16
	p(.) Ψ (PC1)	3	-67.29	142.00	2.15	0.12
	p(.) Ψ (PC2+PC3)	4	-65.79	142.10	2.24	0.11
Virginia opossum	p(site width) Ψ (PC1+PC2)	5	-102.13	218.30	0.00	0.58
	p(site width) Ψ (PC1+PC2+PC3)	6	-101.47	220.90	2.68	0.15
	p(site width) Ψ (.)	3	-107.38	222.20	3.90	0.08
	p(site width) Ψ (PC2)	4	-105.95	222.40	4.14	0.07
	p(site width) Ψ (PC1)	4	-106.70	223.90	5.63	0.04
	p(.) Ψ (.)	2	-113.18	231.00	12.76	0.00

White-nosed coati	p(.) Ψ (PC2)	3	-121.44	250.30	0.00	0.40
	p(site width) Ψ (PC2)	4	-120.84	252.20	1.88	0.16
	p(effort) Ψ (PC2)	4	-121.00	252.50	2.21	0.13
	p(.) Ψ (PC1+PC2)	4	-121.42	253.30	3.05	0.09
	p(.) Ψ (PC2+PC3)	4	-121.43	253.40	3.06	0.09
	p(.) Ψ (.)	2	-127.38	259.40	9.13	0.00
White-tailed deer	p(effort) Ψ (.)	3	-163.02	333.40	0.00	0.22
	p(effort) Ψ (PC3)	4	-161.58	333.70	0.22	0.20
	p(effort) Ψ (PC2)	4	-161.83	334.20	0.71	0.16
	p(effort) Ψ (PC2+PC3)	5	-160.45	334.90	1.46	0.11
	p(effort) Ψ (PC1)	4	-162.85	336.20	2.76	0.06
	p(.) Ψ (.)	2	-166.16	337.00	3.54	0.04

APPENDIX L
ABUNDANCE MODEL RESULTS

Appendix L. Top 5 abundance models with dot (.) model for medium- and large-bodied mammals in Los Ojos, Sonora, México from October 2018 to April 2019. Only species with occupancy > 0.8 were selected for abundance modeling. Species are listed in alphabetical order.

Species	Abundance Model	df	logLik	AICc	Δ AICc	weight
Hog-nosed skunk	p(.) λ (PC2)	3	-145.06	297.50	0.00	0.22
	p(.) λ (PC1+PC2)	4	-143.78	298.10	0.54	0.17
	p(effort) λ (PC2)	4	-144.11	298.70	1.20	0.12
	p(effort) λ (PC1+PC2)	5	-142.85	299.70	2.17	0.07
	p(.) λ (PC2+PC3)	4	-144.76	300.00	2.49	0.06
	p(.) λ (.)	2	-148.65	302.00	4.45	0.02
Mountain lion	p(.) λ (PC1+PC3)	4	-137.73	286.00	0.00	0.40
	p(.) λ (PC3)	3	-139.63	286.70	0.70	0.28
	p(.) λ (.)	2	-142.27	289.20	3.24	0.08
	p(.) λ (PC2+PC3)	4	-139.39	289.30	3.32	0.08
	p(.) λ (PC1+PC2+PC3)	5	-137.73	289.50	3.50	0.07
Virginia opossum	p(site width) λ (PC2+PC3)	5	-101.77	217.50	0.00	0.19
	p(site width) λ (PC3)	4	-103.75	218.00	0.47	0.15
	p(site width) λ (PC1+PC2+PC3)	6	-100.05	218.10	0.57	0.14
	p(site width) λ (.)	3	-105.55	218.50	0.98	0.12
	p(site width) λ (PC1+PC3)	5	-102.52	219.00	1.52	0.09
	p(.) λ (.)	2	-108.36	221.40	3.85	0.03
White-nosed coati	p(site width) λ (PC3)	4	-122.50	255.50	0.00	0.21
	p(.) λ (PC1+PC3)	4	-122.99	256.50	0.98	0.13
	p(.) λ (PC1)	3	-124.70	256.80	1.31	0.11
	p(.) λ (PC3)	3	-125.30	258.00	2.50	0.06

	p(site width) $\lambda(\text{PC}_2+\text{PC}_3)$	5	-122.14	258.30	2.77	0.05
	p(.) $\lambda(.)$	2	-127.08	258.80	3.32	0.04
White-tailed deer	p(effort) $\lambda(\text{PC}_3)$	4	-138.68	287.90	0.00	0.33
	p(effort) $\lambda(\text{PC}_1+\text{PC}_3)$	5	-137.06	288.10	0.25	0.30
	p(effort) $\lambda(\text{PC}_1+\text{PC}_2+\text{PC}_3)$	6	-135.36	288.70	0.86	0.22
	p(effort) $\lambda(\text{PC}_2+\text{PC}_3)$	5	-137.80	289.60	1.74	0.14
	p(effort) $\lambda(.)$	3	-144.05	295.50	7.65	0.01
	p(.) $\lambda(.)$	2	-150.54	305.80	17.89	0.00