DISTRIBUTIONAL ECOLOGY OF WILD FELIDS IN A NEOTROPICAL-NEARCTIC TRANSITION ZONE IN NORTHWEST MEXICO AND IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

UAZ-CONACYT BINATIONAL CONSORTIUM FOR REGIONAL SCIENTIFIC DEVELOPMENT AND INNOVATION – FINAL REPORT

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JANUARY 2020

Introduction

Information on the status and dynamics of populations of large carnivores is essential for guiding effective conservation and management efforts, but such data are challenging to gather and draw reliable inferences from. This is especially true for wild felids such as jaguar (*Panthera onca*), ocelot (*Leopardus pardalis*), and mountain lion (*Puma concolor*) in the southwestern U.S. and northwestern Mexico due to low population densities, the rugged, remote regions they occupy, and varying jurisdictional boundaries and management (Gutiérrez González et al. 2012, Trouwborst 2015, Gómez Ramírez et al. 2017). High metabolic rates linked to endothermy and large body sizes of many felids necessitate high prey availabilities, large prey bases and area requirements, and promote wide-ranging movement behaviors, which can predispose felid populations to conflicts with humans and magnify the impacts of habitat loss and degradation (Carvalho et al. 2015).

Human conflict and habitat loss have greatly augmented extinction risk and global declines in the distribution and abundance of prey populations, habitats, and hence felid populations (Ceballos and Ehrlich 2002, Ripple et al. 2014). Such challenges are magnified in arid and semi-arid environments where small changes in rainfall and temperature can have major impacts on distribution and abundance of critical limiting resources for predators (Issar 2010, Flesch 2014, IPCC 2014). Currently, there is limited information on the ecological factors that drive distribution and abundance of felid populations in these regions of North America or assessments of the influences of inter-annual variation in past weather and future climate on populations. Nonetheless, wild populations of these and other top predators are important components of ecosystems (Estes et al. 2011, Ripple et al. 2014), and innovative strategies guided by data are essential for conservation (Kerr and Kharouba 2007, Yackulic et al. 2011).

In the southwestern U.S. and northwestern Mexico, broad biogeographical transitions promote high biodiversity and the mixing of plants and wildlife species with both Nearctic and Neotropical affinities (Warshall 1995). With regard to felids, this region supports endangered populations of jaguar and ocelot at the northern extent of their ranges, and more widespread populations of mountain lion and bobcat (*Lynx rufus*). The jaguar is the largest felid in the western hemisphere and historically occurred from Argentina into the southwestern U.S. (Seymour 1989). Currently, the jaguar has been extirpated from nearly 40% of its historical range (Quigley et al. 2017), with likely similar range contractions for ocelot (Paviolo et al. 2015). Such distributional contractions of predator populations can be driven by spatiotemporal variations in prey abundance and type, interspecific interactions with competitors, climate change, land-use and land-cover change, and direct persecution by humans (Holmgren et al. 2006, Holt and Barfield 2009, Yackulic et al. 2011, Flesch 2014, Flesch et al. 2015). For felids, there are little to no data on the actual drivers in northern Mexico, which limits conservation efforts.

Given pervasive local and global threats, jaguars and other felids are the focus of multinational efforts to understand their ecology and identify efficient conservation strategies (Rabinowitz and Zeller 2010, Sanderson et al. 2002, Zeller 2007, Rodriguez Soto et al. 2011). In 2018, a comprehensive jaguar recovery plan was developed by a broad team of experts convened by the U.S. Fish and Wildlife Service (USFWS 2018). In 2012, the Northwestern Recovery Unit (NRU) was created that includes portions of the state of Sonora, Sinaloa, Nayarit, and Jalisco in Mexico, and Arizona and New Mexico in the U.S. (Sanderson and Fisher 2013). In 2003, long before those efforts, binational conservation organizations, in collaboration with biologists, established the Northern Jaguar Reserve (NJR) in east-central Sonora, which today covers >23,400 hectares (ha.) of private land and includes an adjacent buffer zone comprised of collaborating ranches that total 30,000 ha. (Figure 1). The NJR is owned by the Mexican non-profit Asociación Conservación del Norte, A.C. (ACN), managed by the Northern Jaguar Project (NJP), and is among the largest private reserves in Mexico. This region supports the northernmost breeding populations

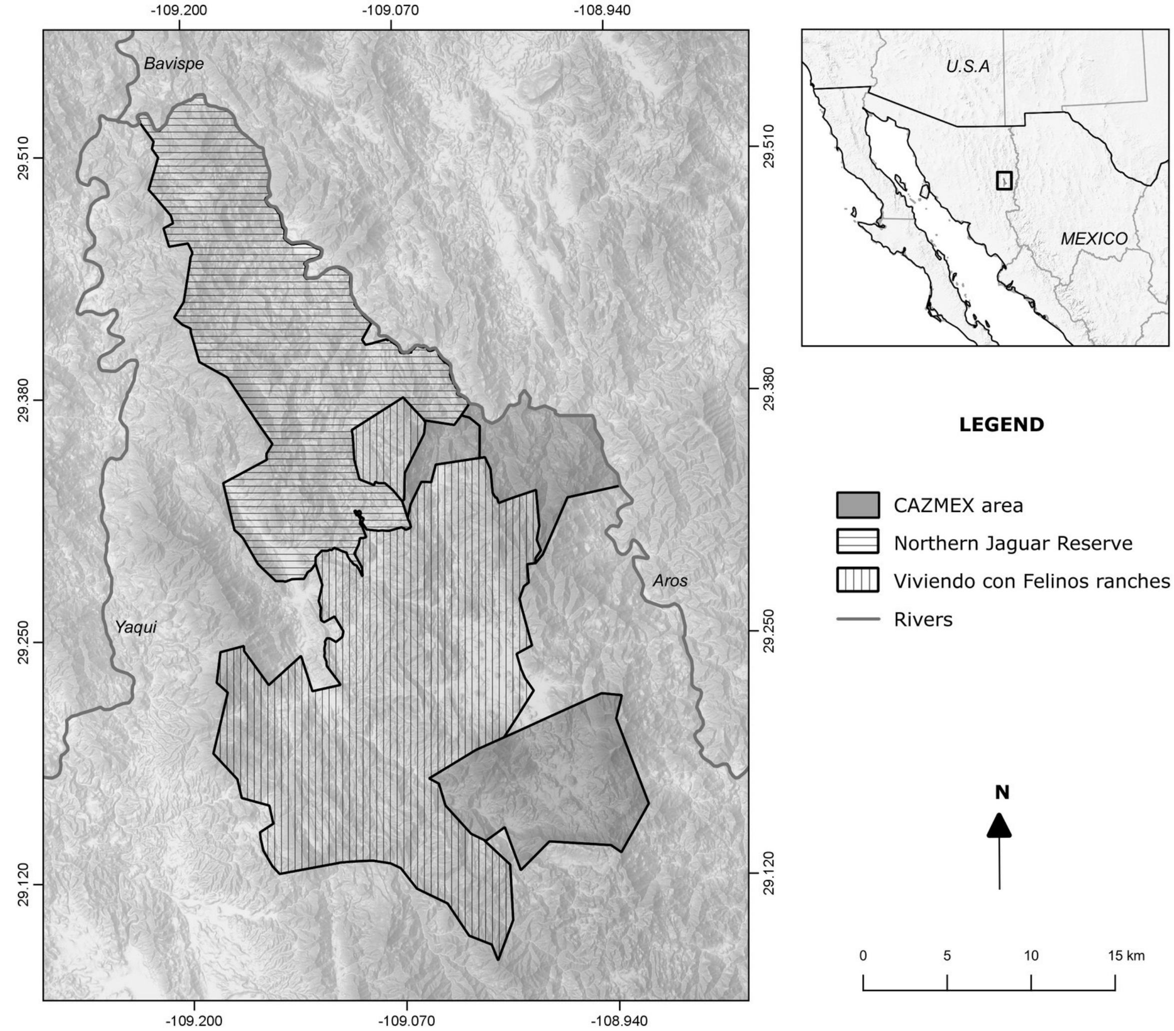

Figure 1. Locations of the Northern Jaguar Reserve and *Viviendo con Felinos* project. We selected three new study areas in the vicinity of the NJR and *Viviendo con Felinos* ranches.

of jaguars and ocelots and provides important source populations for recovery efforts in surrounding regions, including the adjacent U.S. (Gutiérrez González et al. 2015, Gómez Ramírez et al. 2017).Beginning in the year 2000, biologists began monitoring the community of wild felids on lands that would become the NJR. Specific research foci included studies of spatial and temporal variation in felid density and survival, on the influence of management and conservation efforts on these parameters (Gutiérrez González et al. 2015), and on interactions among felids and various prey species (Gutiérrez González et al. 2017). Based on more than 12 years of data gathered by motion-triggered cameras, biologists documented annual survival rates of 56% for jaguars and 64% for ocelots, and densities of 1.87 and 0.79 individuals/100 km^2, respectively. Although abundance and survival rates have varied across time, these do not seem to have declined systematically across time and may be higher on the NJR than on surrounding lands where protection mechanisms are weaker (Gutiérrez González et al. 2012, 2015, Gómez Ramírez et al. 2017). These past efforts combined with a broad network of automated camera traps provided important baselines and resources upon which we built during this project with support from CAZMEX.

To broaden current knowledge on the status and distribution of jaguar, ocelot, and other wild felid populations, we proposed to amalgamate existing data on detections from motion-triggered cameras on the NJR and surrounding private lands to estimate felid distribution. We proposed to use occupancy models to assess adjacent areas within the broader landscape that had not been studied in the past, but may be critical for the expansion of monitoring and conservation efforts. Based on this assessment, we proposed to select two new study areas on nearby private lands that were greater than 10,000 ha. in total area to install networks of motion-triggered cameras and gather data. We also proposed to gather data on biotic and abiotic factors that influence wild felid distribution and population dynamics, including information on existing and past management. Informed by these models and past dynamics, we proposed to forecast potential future changes in felid distribution and apply results to guide conservation.

Objectives

We proposed the following project objectives:

1) Assess how habitat resources and conditions, human disturbance, climatic attributes, conservation mechanisms, and interspecific interactions affect wild felid (jaguar, ocelot, mountain lion, and bobcat) distribution within our study area in northwestern Mexico.
2) Summarize estimates of wild felid distribution and densities in a region of northwest Mexico that has been monitored for more than a decade and in adjacent regions that are the focus of new efforts.
3) Estimate how anticipated climate change will alter the distribution of wild felid populations over 20-, 50-, and 100-year forecast periods.
4) Inform current and future conservation strategies within and beyond the study region.
5) Enhance current and future binational collaboration among project partners and local communities in Mexico and the U.S.

During implementation of this project, some of the data available to us, issues with models, and logistical factors in the field precluded us from addressing minor elements of some objectives. For occupancy analysis, for example, we eliminated prey and other feline densities as covariates due to a lack of prey information for the bobcat and ocelot, which would have precluded comparability among results for each feline species. Lack of prey data also precluded predictions to areas without camera-trap data in the full 4,000 km^2 region we attempted to make inference to. Another small modification included standardizing the spatial sampling unit for occupancy analyses to the camera location for all species. Our proposed approach of basing cell size on home-range area of each species would have significantly reduced sample sizes, generated modeling problems, and reduced comparability of results among species. For climate-change analyses, the 100-year forecast period was reduced to 80 years because Global Circulation Model data were readily available to us only through year 2100. Forecasts were limited to just jaguar and bobcat because full corrected datasets became available just days before the project end date, limiting these and other efforts.

We decided to select sites for the new study area before starting the occupancy analyses for the following reasons. First, our field technicians started looking for potential areas and discovered ranchers that were not interested in participating, which limited the options. Second, we learned of two properties where felines were under direct threat. Through discussions with these landowners, we reached agreement to install cameras on their properties, with ranchers committed to protecting wildlife during our efforts. Finally, a third ranch was also included based on the owner’s interest in wildlife on his property.

Study Area

The Northern Jaguar Reserve (NJR) is located in east-central Sonora, approximately 55 km north of Sahuaripa and 200 km south of the U.S.-Mexico border (Figure 1). The region is situated west of the northern portion of the Sierra Madre Occidental (SMO), surrounded on three sides by deep, lowland canyons of the Aros and Yaqui rivers, and is among the largest and least fragmented wildlands in Mexico. Climate is seasonally arid with hot summers and cool winters. Annual precipitation averages 38 cm in Sahuaripa of which 72% occurs during the summer monsoon from June through September (Brown 1982). Vegetation in uplands is predominantly Foothills Thornscrub (FT), which is drought deciduous, responds rapidly to summer monsoon rains, and dominated by short trees, shrubs, and cacti (Brown 1982). FT covers a large region of foothills and interior valleys west of the SMO and, together with its coastal counterpart (e.g., Coastal Thornscrub; Martin et al. 1998), is the dominant vegetation community in a broad transition zone between Tropical Deciduous Forest and desert-scrub at the northwestern edge of subtropical zones of Mexico. FT is similar to Tropical Deciduous Forest but shorter and less floristically and structurally diverse (Gentry 1982, Búrquez et al. 1999). Dominant plants include the trees *Lysiloma divaricatum, L. watsonii, Bursera fagaroides, Fouquieria macdougalii, Acacia cochliacantha, Ipomoea arborescens, Ceiba acuminata*, and *Parkinsonia praecox* and the columnar cactus *Stenocereus thurberi*. Riparian areas on deep soils and flats are dominated by woodlands of mesquite (*Prosopis veluntina*), acacia (*A. occidentalis*), and Mexican ebony (*Havardia mexicana*). Rocky canyons are dominated by *L. watsonii*, palms (*Sabal uresana and Brahea brandegeei)*, and a drought-deciduous oak known locally as *"encino amarillo"* (*Quercus tuberculata*). More mesic canyons are dominated by willows (*Salix bonplandiana* and *S. gooddingii*), sycamore (*Platanus racemosa*), and button-willow (*Cephalanthus salicifolius*). At higher elevations, oak woodlands and mountain scrub are dominated by *Q. chihuahuensis, Q. toumeyi, Q. alboncinta,* and other oaks that are often mixed with patches of FT or *Dodonaea viscosa*, with extensive open areas dominated by grasses at the ecotone between FT and oak woodland (Warshall and Flesch 2013).

We considered the area on the NJR and 16 surrounding private ranches, including three new ranches where we established networks of motion-triggered cameras with support from CAZMEX. Since the first land acquisition in 2003, the NJR has expanded several times, including in 2008, 2011, 2015, and 2019. Similarly, private ranches monitored around the NJR have expanded starting in 2007 with additions in 2010, 2013, 2014, 2015, 2016, 2017, and finally in 2019 with support of CAZMEX.

Methods

Occupancy Modeling: To address objectives, we used existing camera-trap data for each of the four species of felids and multiple analytical approaches. Inferences were based on 10 years of data (2009-2018) gathered on the NJR and adjacent private ranches that participated in a motion-triggered camera project, *Viviendo con Felinos* (VcF). We used single-season, single-species occupancy models, using each year as a group (Mackenzie et al. 2006). Due to low detection rates of felines, particularly jaguars, we chose the month with the most jaguar observations for analysis (Gutiérrez González and López González 2017). We selected one month (31 days) as a sampling period to best meet the demographic closure assumption of occupancy models (Richmond et al. 2010). For consistency among species, the same month selected for jaguars was used for other species, and each day was considered a sampling session (Gutiérrez González and López González 2017). Months used were as follows 3/9-4/8/2009, 4/9-5/9/2010, 4/1-5/1/2011, 2/27-3/28/2012, 11/28-12/28/2013, 10/29-11/29/2014, 1/1-1/31/2015, 4/29-5/29/2016, 6/3-7/3/2017, 1/30-3/1/2018, and 5/1-5/31/2019. Other authors have used one sampling month with camera traps for analysis of spatiotemporal data for felines (Carter et al. 2015).

To model data, we considered each camera station as a sampling unit and the associated 1 km^2 grid cell into which cameras were placed. We merged all detections from the camera station in one single event per day. We recognize that by using camera station as sampling unit, we violated the geographic closure assumption of occupancy models. We therefore focused on presence in this broader area (Mackenzie et al. 2006). To extrapolate predictions from models across the broader 4,000 km^2 study area, we used the beta values generated from the best approximating model of each species and substituted the covariate value that corresponded to each grid cell of the 4,000 km^2 (see below) in the regression formula to get a logit probability value per cell that we back-transformed to the 0-1 scale. Once we had a probability value per cell we generated maps for the full area.

As explanatory factors, we considered data on annual and seasonal variation in past weather, and vegetation, anthropogenic disturbance, and management. To quantify past variation in weather, we used downscaled, interpolated data from weather stations that were adjusted for elevation from program ClimateNA (version 6.21; Wang et al. 2016). This program generates scale-free estimates of local weather factors from bilinear interpolation and elevation adjustments to improve accuracy. Elevation adjustments are implemented by empirical lapse rates and non-linear models of variables from monthly gridded baseline values from weather stations and latitude, longitude, and elevation (Wang et al. 2016). We extracted monthly values of each weather factor at the center of 1 × 1 km pixels and the associated elevations. We considered both precipitation (P; mm) and temperature (T; °C) during various seasonal periods and lag times that we suspected may influence felid occurrence. We computed annual (Jan.-Dec.; P_{yr}), cool-season (Jan-May and Nov-Dec; P_{cs}), and warm-season (June-Oct.; P_{ws}) P in each calendar year and at lag times of one (-1) and two (-2) years. For T, we computed mean minimum and mean maximum T across all months, of the coldest ($T_{\text{min\_avg}}$, $T_{\text{max\_avg,}}$) and warmest ($T_{\text{min\_month}}$, $T_{\text{max\_month}}$) months of the year in each calendar year, and at a lag time of one year. Lag times of one and two years often test for trophic or food-web mediated effects of weather on predators, whereas estimates with no lag time assess direct effects on predators or prey. To summarize patterns of past change in weather across time, we computed averages among pixels for each attribute in each year and used ordinary least squares regression to estimate average per-year change between 2007-2018 (Appendix A).

To describe vegetation and land cover, we used data from the North American Land Change Monitoring System (NALCMS 2010), which has a spatial resolution of 250 m. This system includes 19 land cover classes for Mexico of which the broader study area included 10 classes, seven of which were in areas we directly monitored with camera (Table 1). For each 1×1 grid cell, we calculated the percentage of each class using QGIS (version 3.2.0; QGIS Development Team 2019). To quantify anthropogenic disturbance, we used the Human Influence Index developed by Venter et al. (2018), which includes eight different variables such as urbanization, population density, crop and pasture lands, roads, and navigable waterways with values ranging from 0 to 50 for Mexico and from 1 to 21 for the study area; increasing values indicate greater intensity of disturbance. To classify management status, we considered the presence or absence of cattle across space and time as an index. Such an index was directly linked to the protection of wildlife and habitat because as new lands were purchased for inclusion into the NJR, removal of cattle was among the first conservation mechanisms. Thus, we predicted NJR expansion and associated cattle removal would have positive impacts on feline occurrence.

Single-season, single-species occupancy models include two parameters, detection probability (p) and occupancy (psi) (Mackenzie et al. 2006). During model building, p was assumed to be either constant across time and space for each species, or to vary annually as could be the case given varying camera placement, field staff, and equipment. Before model selection for psi, we first evaluated correlations between weather and other factors. Because some factors were highly correlated, we first identified the most suitable lag time, fit either $P_{\text{yr-2}}$, $P_{\text{yr-1}}$, or seasonal P, which were weakly correlated, dropping one of the seasonal estimates if it had no explanatory power. For T, we considered only average (e.g., $T_{\text{min\_avg}}$) or monthly values (e.g., $T_{\text{max\_avg}}$) but not both due to high correlations. Following identification of the best weather factors, we considered human influence index and management status, followed by vegetation and landcover type. We then eliminated factors with the lowest model weights, arriving at the most parsimonious, best approximating model that we used for inference. Models were fit in program MARK (version 9.0; White and Burnham 1999) with selection based on AIC (Burnham and Anderson 2002). Low encounter rates of felines and sparse data resulted in occasional convergence issues and

Table 1. Vegetation and land cover classes from the North American Land Change Monitoring System (NALCMS 2010) within the 4,000 km^2 study area on and around the NJR in Sonora, Mexico.

Classification	Type	Description
4	Tropical or sub-tropical broadleaf deciduous forest	Forests generally taller than 5 meters and more than 20% of total vegetation cover. These forests have greater than 75 percent of tree crown cover represented by deciduous species.
5	Temperate or sub-polar broadleaf deciduous forest	Forests generally taller than 3 meters and more than 20% of total vegetation cover. These forests have greater than 75 percent of tree crown cover represented by deciduous species.
7	Tropical or sub-tropical shrubland	Areas dominated by woody perennial plants with persistent woody stems less than 5 meters tall and typically greater than 20% of total vegetation.
8	Temperate or sub-polar shrubland	Areas dominated by woody perennial plants with persistent woody stems less than 3 meters tall and typically greater than 20% of total vegetation. This class occurs across the highlands of Mexico.
9	Tropical or sub-tropical grassland	Areas dominated by graminoid or herbaceous vegetation, generally accounting for greater than 80% of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
10	Temperate or sub-polar grassland	Areas dominated by graminoid or herbaceous vegetation, generally accounting for greater than 80% of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. This class occurs across highlands of Mexico.
15	Cropland	Areas dominated by intensively managed crops. These areas typically require human activities for their maintenance. This includes areas used for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class does not represent natural grasslands used for light to moderate grazing.
16	Barren Lands	Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no “green” vegetation present regardless of its inherent ability to support life. Generally, vegetation accounts for less than 10% of total cover.
17	Urban and Built-up	Areas that contain at least 30 percent or greater urban constructed materials for human activities (cities, towns, transportation, etc.).
18	Water	Areas of open water, generally with less than 25% cover of non-water cover types. This class refers to areas that are consistently covered by water.

overestimates of psi when some factors were considered, and we eliminated these models from consideration during selection. Parameter estimates from the best approximating model of psi were used to estimate occupancy probabilities across the broader 4,000 km^2 study area by using covariate values for each grid cell and the logit probability value per cell back-transformed to the 0-1 scale.

Expand spatial scope of monitoring: We selected two new ranches where felids were threatened and a third ranch interested in learning more about wildlife, and installed cameras in these areas. These three ranches are each adjacent to at least one of the VcF ranches, and two of them are adjacent to the NJR (Figure 1). In the new areas, we placed 50 motion-triggered cameras with the same standardized design (Noss et al. 2013) that we used on the NJR and VcF ranches (Gutiérrez González et al. 2012). Cameras were installed in January and February and stayed active until early August 2019, fulfilling the six-month period we proposed to CAZMEX. Cameras remained in place through December 2019 on the VcF ranches. These new cameras (*n* = 50) were added to the network already installed on the NJR and VcF ranches, with a total of 224 cameras and 175 camera stations across the study area. One camera station consists of one or two cameras depending on camera availability and the potential of the site to obtain jaguar or ocelot photographs (Fonseca et al. 2012, Silver et al. 2004). To make data comparable, we set up all new cameras with the same settings as existing cameras, using a spatial separation of at least 1 km and a one-minute delay between detections. No baits or lures were used, and all CAZMEX and VcF cameras were checked monthly, as has been done since the beginning of the monitoring in the area in 2000 (Gutiérrez González et al. 2012, Gutiérrez González et al. 2015, Gómez Ramírez et al. 2017).

Density and relative abundance: We computed annual estimates of relative abundance for each of the four felid species, and densities of jaguar and ocelot. Estimates of relative abundance (independent events/100 trap days) were based on data from camera traps and unadjusted for variation in p. Estimates of densities (individuals/100 km^2) were based on mark-recapture procedures and limited to two species that could be individually identified based on spot patterns (e.g., jaguar and ocelot). In previous work, we identified photographs between 2009 and September 2012 (Gutiérrez González et al. 2015, Gómez Ramírez et al. 2017), so we identified individuals in photographs from October 2012 thru October 2019 using new data (Silver et al. 2004). We eliminated pictures of animals that could not be individually identified from density (but not relative abundance) estimates. We built detection histories for each individual across years, and censored juveniles because they have highly varying survival and recapture probabilities (Karanth et al. 2006). To estimate abundance, survival, and p, we used Barker Robust Design (Kendall et al. 2013). This capture-recapture approach, combines information from a closed period where abundance and p are estimated, and from an open period where survival is estimated. In the closed period, all individuals are assumed to remain within the study area and are available for detection with no change in populations. In the open period, emigration, immigration, births, and deaths can occur. Despite potential for violating assumptions, most jaguar studies use a 3-4 month closed period for capture-recapture analysis (Foster and Harmsen 2012).

To select models, we used a step-down and backward elimination approaches to model selection that started with a fully specified, time-dependent model and set death recovery parameters to zero (Collins and Doherty 2006). We then modeled detection parameters, followed by availability, fidelity, and survival. We slightly modified model selection by including the number of camera stations per year when estimating p for the open and closed periods (R, p, c respectively). Open periods were from June to January, and closed periods were from February to May, which match the life history of both species. Abundance and density are estimated during closed periods; survival is estimated during open periods, with p estimated for both closed and open periods (Kendall et al. 2013). We also modeled the potential effect of the 2011 intense freeze on survival, and management strategies like NJR expansion in different years and start of the VcF project, to assess if they influenced survival, and compared these models with a model that included year alone as a factor. Akaike's index criterion (AICc) was used for model selection

(Burnham and Anderson 2002). All models were fit in program MARK (version 9.0; White and Burnham 1999).

We estimated effective sampling area (ESA) based on camera locations from each year across time, which we used as a scaling factor to compute density estimates. For more precise density estimation, we modified past approaches (Gutiérrez González et al. 2015, Gómez Ramírez et al. 2017) and estimated the yearly ESA for camera stations in the closed period. For ESA calculations, we used the mean maximum distance movements (MMDM) of each jaguar and ocelot detected in the area (Karanth et al. 1998, Carbone et al. 2001, Silver et al. 2004), which we used as a radius of a circular buffer around each camera station. All buffer areas for each camera station were summed to give an estimate of the ESA per year (Karanth et al. 2006, Silver 2004). We then divided annual estimates of abundance from MARK with ESA and multiplied by 100 to compute the number of individuals per 100 km^2 across time.

We computed relative abundance of all four species, including mountain lion and bobcat, which can rarely be identified individually due the lack of spot patterns. The relative abundance index (RAI) is often used to estimate detection rates and as an index of abundance (O'Brien 2011). We estimated RAI of each species in a year using the number of independent events of each species divided by the trapping nights (e.g., number of camera stations × number of nights cameras were active × 100; O'Brien 2011). For consistency, we used the same sampling period of 31 days used for the occupancy models, although this approach reduced the reliability of trend estimates given unequal spacing among estimates across time, which we treated as equal. For each camera, independent events were defined as only those photos that had temporal separation between photos of the same species of at least 24 hours. For paired camera stations where both cameras took photos of the same individual, only one photograph was considered. Additionally, where it was possible to identify more than one individual in a 24-hour period, all individuals or the photo with the highest number of individuals were counted.

To model time series and assess temporal trends in each parameter (density and RAI) for each species, we used generalized least-squares regression from the nlme library in R (R Core Team 2018, Pinheiro et al. 2019). We first centered and then fit year as a fixed effect and used first-order autoregressive covariance structures (AR[1]) to adjust for temporal autocorrelation in residuals and better meet model assumptions. Where there was no evidence of autocorrelation, models defaulted to ordinary least squares regression. Population estimates for long-lived species such as wild felids are often highly correlated in successive years, and this approach adjusts for non-independence in time series. We used restricted maximum likelihood to select the most appropriate covariance structure based on AIC and based trend estimates on maximum likelihood procedures. Response variables were log transformed so that estimates note annual rates of change on a percent scale when multiplied by 100. Although density estimates for jaguars, but not ocelots, were correlated with estimates of ESA, we did not fit ESA as a covariate because it was used as a weighting factor in density calculations.

Climate, weather, and forecasts of distribution under future climates: We described variation and trends in past weather and future climate. We developed preliminary forecasts of future change scenarios in distribution of jaguar and bobcat across periods of 20, 50, and 80 years. For forecasting, we used the same data inputs for occupancy models (e.g., single month in the same year across 10 years) for comparability. We developed species distribution models for both species with use of separate generalized boosted regressions (GBM; Friedman 2002) because of limited flexibility of occupancy models from MARK. GBMs are flexible, machine-learning approaches to analyze presence/absence data that model non-linear response functions and interactions (Hijmans et al. 2013). We used spatial cross-validation criteria (Roberts et al. 2017) to fit models and extrapolate to the broader 4,000 km^2 spatial domain, and fit an exhaustive list of models containing all possible combinations of 21 covariates. These covariates were the same as those considered for occupancy but also included an index of topographic roughness, which we found to be important for one species. This model list was reduced to those containing at least one uncorrelated ($r \leq 0.6$) temperature and precipitation variable, and a maximum of six covariates. The same models were also fit using a temporal cross-validation procedure to gauge the ability of models to predict to new time periods. The relationship between cross-validated area under the curve (AUC) and number of predictors was then plotted to determine the least number of predictors necessary to provide maximum accuracy within a tolerance of 0.03 on the AUC scale. The list of the top three models was then examined to select the best models with good balance between spatial and temporal accuracy. GBM fits of these models were used to predict future habitat area under 6 potential future climate scenarios. To summarize areas occupied, we first made predictions to the felid observation dataset, ordered observations based on predicted probability, and picked the smallest probability contour containing 95% of observations. Predictions were then made for each scenario in each year from 2020-2100. Numbers of grid cells with predicted probabilities above the 95% threshold were counted to estimate area occupied each year.

To characterize future climate scenarios for the study area, we used monthly data on *P* and *T* for future periods from General Circulation Models (GCMs) of the Climate Model Intercomparison Project 5 (IPCC 2014). We selected three GCMs (CNRM-CM5, CCSM, CanESM2-r11i1p1) that showed varying trajectories in *P* so as to consider various potentialities and high levels of uncertainty in projections. All GCMs were characterized by increasing *T* but of varying magnitudes. We also considered two greenhouse gas concentration trajectories or Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5 (Taylor et al. 2012). For RCP 4.5, emissions peak in the 2040s and then decline, whereas for RCP 8.5, emissions are assumed to continue increasing throughout the century. All GCM data were extracted using the future time-series capabilities in the ClimateNA package. To describe each climate scenario, we computed averages among pixels of each weather factor in each year and fit simple linear models to these data to estimate average per-year changes between 2020-2100.

Results

We used information from camera traps between 2009-2019 on the Northern Jaguar Reserve (NJR) and surrounding private lands that are part of *Viviendo con Felinos* (VcF). With support from CAZMEX, we also added data from three new study areas totaling 13,540 ha to the broader 53,400-ha study area that comprises the NJR and VcF ranches (Figure 1; Appendix B) and merged data across the study area.

Occupancy: For jaguars, capture histories included 120 records over 10 years. We considered 67 models. The best-supported model included positive effects of mean maximum monthly temperature in the current year, presence of temperate shrubland vegetation, and cool-season precipitation in the current year, and a negative effect of increasing human influence index (Table 2, Appendix C). Mean occupancy of jaguar for all years showed much higher probabilities in the northwestern portion of the study area and suggested the southern portion was less used (Figure 2). Moreover, values were generally higher in later years (Appendix D).

For mountain lion, capture histories included 262 records over 10 years. We considered 47 models. The best-supported model had a positive effect of cool-season precipitation in the current year and a negative effect of tropical shrubland vegetation (Table 3, Appendix C). Mean occupancy of mountain lion for all years showed more constant probabilities across the study area but lower values in the southeast and southwest, some inter-annual variation across time (Appendix D), and lower values compared with jaguars (Figure 2).

For ocelot, capture histories included 125 records over the 10 years. We considered 37 models. The best-supported model included a positive effect of mean minimum temperature of the coldest month in the current year and negative effects of cool-season precipitation in the previous year, increasing human influence index, and presence of tropical shrubland vegetation (Table 4, Appendix C). Mean occupancy of ocelot for all years showed higher probabilities in lowland areas in the southwestern portion of the

Table 2. Five best-supported models for jaguar occupancy (Ψ) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	K
Ψ(yr+ $T_{\text{max\_avg}}$ +V_8+HII+ P_{cs})	2007.53	0	0.48	1	24
Ψ (yr+ $T_{\text{max\_month}}$ + V_8+ HII + P_{cs})	2008.05	0.52	0.37	0.77	24
Ψ (yr+ $P_{\text{cs-1}}$ + $T_{\text{max\_month-1}}$+ HII + V_8)	2012.07	4.54	0.05	0.10	24
Ψ (yr+ $P_{\text{cs-1}}$ + $T_{\text{max\_month-1}}$ + HII t+ V_7)	2012.61	5.08	0.04	0.07	24
Ψ (yr+ $P_{\text{cs-1}}$ + $T_{\text{max\_month-1}}$ + HII)	2015.10	7.57	0.01	0.02	23

K: number of parameters, Ψ: occupancy (presence) probability, yr: effect by year, $T_{\text{max\_avg}}$: mean maximum temperature across all months, $T_{\text{max\_month}}$: mean maximum temperature across warmest months, P_{cs}: cool season precipitation, V: vegetation class according to NALCMS 2010, HII: Human Influence Index. -1 subscript corresponds to lag times for one year.

Table 3. Five best-supported models for mountain lion occupancy (Ψ) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	K
Ψ (yr+ P_{cs} +V_7)	4737.43	0	0.11	1	22
Ψ (yr+ P_{cs} + V_7+ V_{18})	4737.66	0.23	0.09	0.89	23
Ψ (yr+ V_7+ Mgmt)	4737.98	0.55	0.08	0.76	22
Ψ (yr+ V_7+ V_{18})	4738.52	1.09	0.06	0.58	22
Ψ (yr+ P_{cs} + V_7+Mgmt)	4738.69	1.26	0.06	0.53	23

K: number of parameters, Ψ: occupancy (presence) probability, yr: effect by year, P_{cs}: cool season precipitation, V: vegetation class according to NALCMS 2010, Mgmt: management status, cattle presence (1) or absence (0).

Table 4. Five best-supported models for ocelot occupancy (Ψ) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	K
Ψ (yr+ $P_{\text{cs-1}}$+ $T_{\text{min month}}$ +HII+ V_7)	2248.42	0	0.64	1	24
Ψ (yr+ $P_{\text{cs-1}}$+ $T_{\text{min month}}$ + V_7)	2250.42	2.01	0.23	0.37	23
Ψ (yr+ $T_{\text{min month}}$ + V_7)	2254.80	6.38	0.03	0.04	22
Ψ (yr+ $T_{\text{min month}}$ + HII +V_7)	2256.83	8.41	0.01	0.01	23
Ψ (yr+ $P_{\text{yr-1}}$)	2256.94	8.52	0.01	0.01	20

K: number of parameters, Ψ: occupancy (presence) probability, yr: effect by year, $P_{\text{cs-1}}$: cool season precipitation from the previous year, $P_{\text{yr-1}}$: precipitation from the previous year, V: vegetation class according to NALCMS 2010, HII: Human Influence Index.

Table 5. Five best-supported models for bobcat occupancy (Ψ) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Model	AICc	Δ AICc	AICc Weights	Model Likelihood	K
Ψ (yr+ P_{ws-1}+ Mgmt +V_{15})	3973.20	0	0.13	1.00	23
Ψ (yr+ P_{ws-1}+ Mgmt + V_{15}+HII)	3973.22	0.02	0.13	0.99	24
Ψ (yr+ P_{ws-1}+ Mgmt)	3973.82	0.62	0.10	0.73	22
Ψ (yr+ P_{ws-1}+ Mgmt + V_{15}+ V_5)	3974.46	1.26	0.07	0.53	24
Ψ (yr+ P_{ws-1}+ Mgmt + V_{18})	3974.78	1.58	0.06	0.45	23

K: number of parameters, Ψ: occupancy (presence) probability, yr: effect by year, P_{ws-1}: warm season precipitation from the previous year, V: vegetation class according to NALCMS 2010, HII: Human Influence Index. Mgmt: management status, cattle presence (1) or absence (0).

study area and in areas along the vast lowland corridor formed by the Aros and Yaqui rivers (Figure 2). Temporal variation in occupancy probabilities was high, although values in the southwestern portion of the study area were high with much less variation (Appendix D).

For bobcat, capture histories included 191 records over the 10 years. We considered 60 models. The best-supported model had a positive effect of precipitation in the prior warm season and negative effects of the management strategy (cattle presence) and of cropland vegetation (Table 5, Appendix C). Mean occupancy of bobcat for all years showed the opposite distribution of that for ocelot with higher occupancy probabilities in the southeastern portion of the study area and away from the vast lowland corridor formed by the Aros and Yaqui rivers, but more constant values overall (Figure 2). Temporal variation in occupancy probabilities was generally low (Appendix D).

Based on mean probabilities of occurrence across all felids combined, probabilities of occurrence of all species in the same areas ranged from 0.1 to 0.5. Higher probabilities generally occurred in the northwestern portion of the study area and were generally high on the NJR and VcF ranches, but were fairly homogeneous across the whole study area (Figure 3).

Density: With the addition of three new ranches to the study area and 50 additional cameras, we monitored a total of 224 cameras at 175 camera stations between January and August 2019. All three new ranches requested to continue with camera traps after fieldwork linked to this project, and we included them as part of VcF. The most recent camera checks were completed in October, and this information was included in capture histories for density analysis to foster more complete inferences for jaguar and ocelot. From January to October 2019, we obtained 94 jaguar, 693 puma, 443 ocelot, and 433 bobcat photographs from this network of camera traps (Appendix B). From those photos, we incorporated jaguar and ocelot photos into capture histories for the capture-recapture analysis.

In 2019, we identified 7 individual jaguars with 2 females, 3 males, and 2 individuals of undetermined sex. With these records, we were able to include 48 individuals in the capture-recapture analysis. We considered 21 Barker Robust Design models. The best-supported model included a constant survival probability over time. The number of camera stations had an effect on detection probability in the open period, and camera type had an effect in the closed period (Table 6). Survival estimates remained constant throughout the study as did detection probabilities in the closed period. Detection probabilities in the rest of the year (open period) were high and close to 1 in most years (Table 7). Jaguar density averaged 0.33 ± 0.06 individuals per 100 km^2 across time.

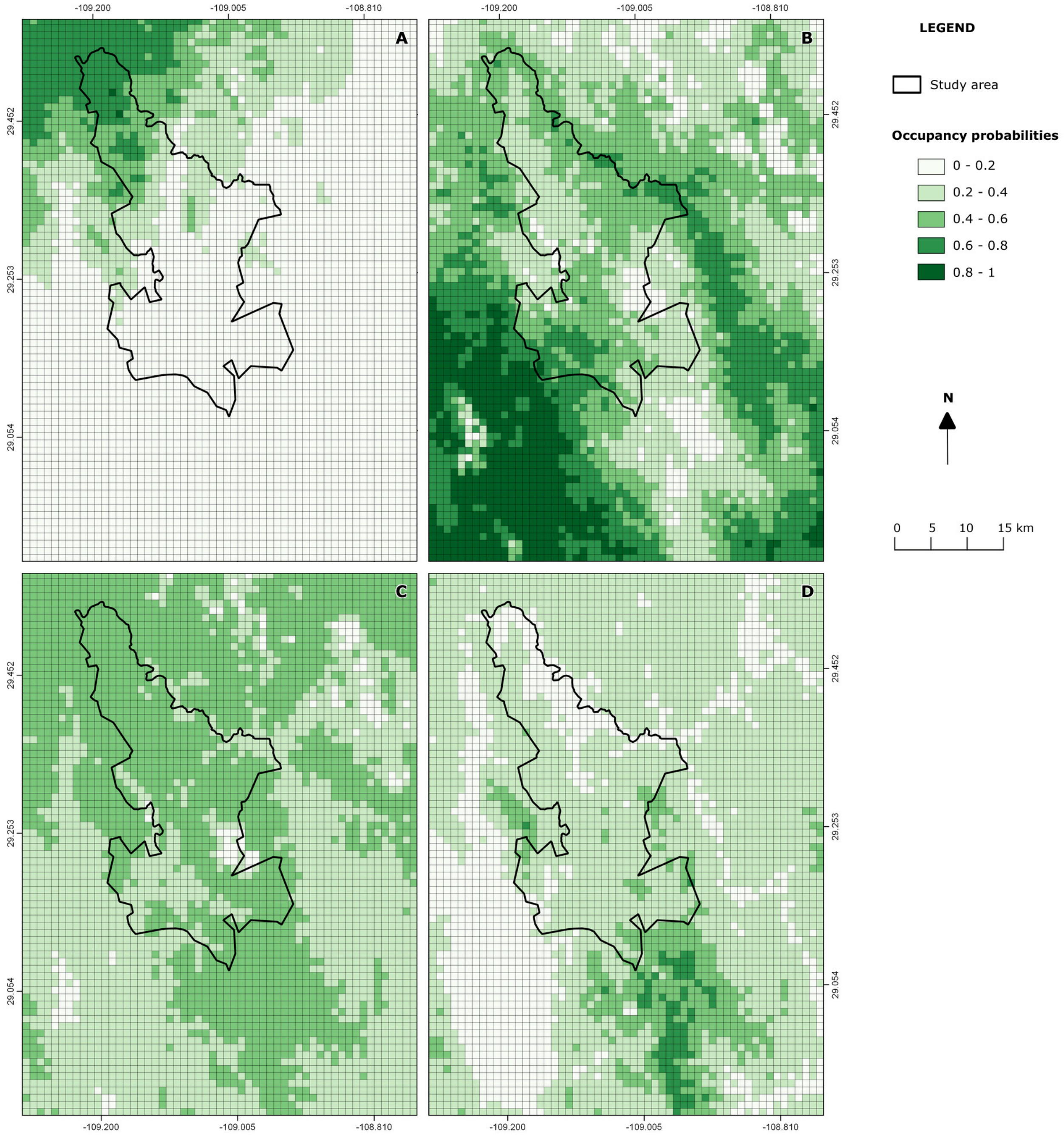

Figure 2. Mean occupancy probabilities of the four feline species in the expanded study area of 4,000 km^2 from 2009-2019. Each pixel has 1x1 km resolution. Darker colors indicate higher probabilities. A) jaguar, B) ocelot, C) mountain lion, D) bobcat.

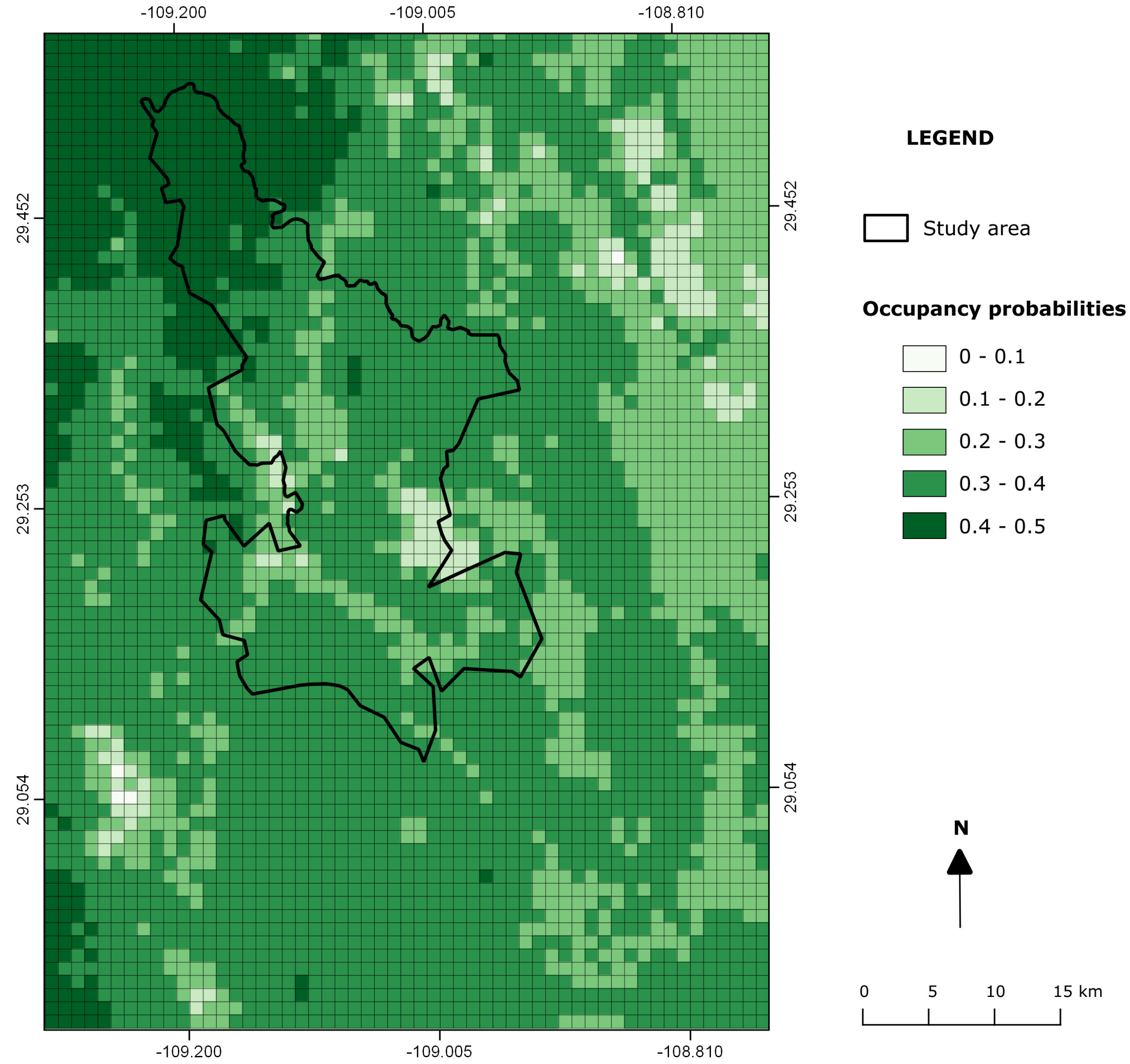

Figure 3. Mean occupancy probabilities among the four feline species in the expanded study area of 4,000 km^2. Each pixel has 1x1 km resolution. Darker colors indicate higher probabilities.

Table 6. List of the four best-supported models for jaguar abundance and survival on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, using the Barker Robust Design (Kendall et al. 2013).

Model	AICc	ΔAICc	AICc Weights	Model Likelihood	K
$\mathrm{phi}_{\mathrm{constant}}\ R_{\mathrm{cam\ stations}}\ p_{\mathrm{cam\ type}}$	574.36	0	0.76	1.00	12
$\mathrm{phi}_{\mathrm{freeze}}\ R_{\mathrm{cam\ stations}}\ p_{\mathrm{cam\ type}}$	576.72	2.36	0.23	0.31	13
$\mathrm{phi}_{\mathrm{reserve\ exp}}\ R_{\mathrm{cam\ stations}}\ p_{\mathrm{cam\ type}}$	583.53	9.17	0.01	0.01	16
$\mathrm{phi}_{\mathrm{yr}}\ R_{\mathrm{cam\ stations}}\ p_{\mathrm{cam\ type}}$	600.19	25.82	0	0	26

K: number of parameters, Phi: apparent survival probability, R: detection probability during open period (June-January), p: detection probability during closed period (February-May), constant: constant probabilities in all years, cam stations: number of camera stations in the open period, cam type: differences in detection due to the camera type, freeze: effect on survival caused by an intense freeze in 2011, reserve exp: changes in size, yr: difference by year. For an explanation of the covariates and model selection, see Gutiérrez González et al. (2015).

Table 7. Parameter estimates ± standard error for apparent survival (phi), detection probabilities (R, p), abundance (N), observed (N_{ob}s) and estimated (N_{model}), density (D), and effective sampling area (ESA) for jaguars identified on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2019.

Year	phi	R	p	N_{obs}	N_{model}	D (ind/100km^2)	ESA (km^2)
2009	0.57 ± 0.05	0.95 ± 0.04	0.47 ± 0.04	6	6.5 ± 0.75	0.21 ± 0.02	3050.38
2010	0.57 ± 0.05	0.96 ± 0.03	0.47 ± 0.04	4	4.33 ± 0.61	0.80 ± 0.11	541.17
2011	0.57 ± 0.05	0.96 ± 0.03	0.47 ± 0.04	9	8.66 ± 0.87	0.50 ± 0.05	1716.38
2012	0.57 ± 0.05	0.89 ± 0.06	0.47 ± 0.04	7	6.50 ± 0.75	0.34 ± 0.04	1930.24
2013	0.57 ± 0.05	0.83 ± 0.08	0.47 ± 0.04	6	5.41 ± 0.68	0.36 ± 0.04	1516.46
2014	0.57 ± 0.05	0.96 ± 0.04	0.47 ± 0.04	4	4.33 ± 0.61	0.29 ± 0.04	1483.92
2015	0.57 ± 0.05	0.87 ± 0.07	0.47 ± 0.04	4	4.33 ± 0.61	0.43 ± 0.06	1012.01
2016	0.57 ± 0.05	0.77 ± 0.09	0.47 ± 0.04	4	4.33 ± 0.61	0.31 ± 0.04	1382.35
2017	0.57 ± 0.05	0.94 ± 0.04	0.47 ± 0.04	2	2.17 ± 0.43	0.06 ± 0.01	3391.91
2018	0.57 ± 0.05	0.97 ± 0.03	0.47 ± 0.04	5	5.41 ± 0.68	0.18 ± 0.02	2971.14
2019	0.57 ± 0.05	0.99 ± 0.01	0.47 ± 0.04	6	5.41 ± 0.68	0.07 ± 0.01	8076.62

In 2019, we identified 37 individual ocelots including 9 females, 8 males, and 20 individuals of undetermined sex. With these records, we were able to include 75 individuals in the capture-recapture analysis. We considered 19 Barker Robust Design models. The best-supported model included a constant survival probability over time. The number of camera stations had an effect on the detection probability in the open period, and year had an effect in the closed period (Table 8). Survival estimates for ocelots remained constant. Detection probabilities in the open period were almost twice that in the closed period but lower than that for jaguar for the same years (Tables 8 and 9). Ocelot density averaged 1.15 ± 0.16 individuals per 100 km^2 across time.

Table 8. List of the five best-supported models for ocelot abundance and survival on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, using the Barker Robust Design (Kendall et al. 2013).

Model	AICc	ΔAICc	AICc Weight	Model Likelihood	K
$\text{phi}_{\text{constant}}\ R_{\text{cam stations}}\ p_{\text{yr}}$	1674.99	0	0.51	1.00	26
$\text{phi}_{\text{yr}}\ R_{\text{cam stations}}\ p_{\text{yr}}$	1676.67	1.68	0.22	0.43	34
$\text{phi}_{\text{yr}}\ R_{\text{cam stations}}\ p_{\text{yr}}$	1677.24	2.25	0.16	0.32	35
$\text{phi}_{\text{freeze}}\ R_{\text{cam stations}}\ p_{\text{yr}}$	1679.33	4.34	0.06	0.11	28
$\text{phi}_{\text{reserve exp}}\ R_{\text{cam stations}}\ p_{\text{yr}}$	1681.35	6.36	0.02	0.04	29

K: number of parameters, Phi: apparent survival probability, R: detection probability during open period (June-January), p: detection probability during closed period (February-May), constant: constant probabilities in all years, cam stations: number of camera stations in the open period, freeze: effect on survival caused by an intense freeze in 2011, reserve exp: changes in size, yr: difference by year. For an explanation of the covariates and model selection, see Gómez Ramírez et al. (2017).

Table 9. Parameter estimates ± standard error for apparent survival (phi), detection probabilities (R, p), abundance (N), density (D), and effective sampling area (ESA) for ocelots detected on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2019.

Year	phi	R	p	N_{obs}	N_{model}	D (ind/100km^2)	ESA (km^2)
2009	0.76 ± 0.03	0.55 ± 0.05	0.04 ± 0.04	6	19.63 ± 17.12	1.72 ± 1.5	0.76 ± 0.03
2010	0.76 ± 0.03	0.55 ± 0.05	0.22 ± 0.05	11	11.64 ± 1.73	0.66 ± 0.10	0.76 ± 0.03
2011	0.76 ± 0.03	0.55 ± 0.05	0.47 ± 0.06	12	10.06 ± 0.25	1.25 ± 0.03	0.76 ± 0.03
2012	0.76 ± 0.03	0.55 ± 0.05	0.44 ± 0.07	6	7.07 ± 0.27	0.64 ± 0.02	0.76 ± 0.03
2013	0.76 ± 0.03	0.55 ± 0.06	0.18 ± 0.04	14	19.92 ± 2.90	1.73 ± 0.25	0.76 ± 0.03
2014	0.76 ± 0.03	0.55 ± 0.05	0.23 ± 0.05	9	14.85 ± 1.78	1.59 ± 0.19	0.76 ± 0.03
2015	0.76 ± 0.03	0.55 ± 0.06	0.30 ± 0.07	6	7.41 ± 0.74	0.45 ± 0.05	0.76 ± 0.03
2016	0.76 ± 0.03	0.55 ± 0.07	0.32 ± 0.04	17	17.85 ± 1.04	1.08 ± 0.06	0.76 ± 0.03
2017	0.76 ± 0.03	0.55 ± 0.05	0.45 ± 0.08	6	5.04 ± 0.22	0.40 ± 0.02	0.76 ± 0.03
2018	0.76 ± 0.03	0.55 ± 0.05	0.07 ± 0.03	6	20.19 ± 8.56	1.56 ± 0.66	0.76 ± 0.03
2019	0.76 ± 0.03	0.56 ± 0.10	0.24 ± 0.03	31	30.54 ± 2.42	1.64 ± 0.13	0.76 ± 0.03

Relative abundance index: From 2009-2019, we obtained 1,573 independent observation events of the four feline species during focal months that we used for estimation. Mountain lion and bobcat had the highest values in all years, except in 2011 when estimates for jaguar were higher than that for bobcat but not for mountain lion, and in 2019 when ocelot had the highest value (Table 10).

Temporal variation in felid abundance: Preliminary trend models indicated declines in relative abundance and density of jaguars across time (Table 11, Figure 4). Estimates varied in magnitude from a 2.6 ± 1.1% annual decline in density to a 3.4 ± 2.3% annual decline in relative abundance, but only the former was statistically significant at the $\alpha = 0.05$ level, in part, due to broad inter-annual variation in relative abundance. Nonetheless, due to wide-ranging movement behaviors by jaguars and a tendency for spatial use to shift across large areas in response to regional changes in resources, such results are not necessarily indicative of large-scale population contractions (see Discussion). For ocelot, trends in relative abundance were positive and highly significant (e.g., 2.7 ± 0.9%/year), but there was no trend in density. In contrast, there were no systematic linear trends in relative abundance of puma or bobcat, but population dynamics suggested some interesting cycles. For puma, there were series of relatively high and low relative

Table 10. Relative abundance index (no. of independent events/100 trap days) of four felid species on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, between 2009-2019. Estimates are for the same 31-day periods within a year as used for occupancy modeling (3/9-4/8/2009, 4/9-5/9/2010, 4/1-5/1/2011, 2/27-3/28/2012, 11/28-12/28/2013, 10/29-11/29/2014, 1/1-1/31/2015, 4/29-5/29/2016, 6/3-7/3/2017, 1/30-3/1/2018, and 5/1-5/31/2019).

	Relative Abundance Index										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jaguar	0.41	0.41	1.09	1.10	0.83	0.43	0.30	0.23	0.08	0.55	0.39
Ocelot	0.18	0.49	0.54	0.65	0.36	0.46	0.50	0.58	0.63	0.57	2.08
Mountain lion	1.00	2.65	2.29	2.25	1.23	1.17	1.24	2.99	3.06	1.66	0.96
Bobcat	0.88	1.02	0.51	1.59	1.67	1.87	1.55	1.22	0.82	0.74	0.83

abundance across two or three consecutive years, whereas for bobcat non-linear cyclical variation suggested a number of deterministic population processes may have driven dynamics, with relatively high relative abundance in middle years and much lower values otherwise (Figure 4). For bobcat, such dynamics were underscored by high levels of correlation (e.g., phi = 0.69) between residuals from neighboring years.

Table 11. Trends in relative abundance (no. independent event/100 trap night) and density (no. individuals/100 km^2) of four wild felid species between 2009 and 2019 on and around the Northern Jaguar Reserve in east-central Sonora, Mexico. Trend estimates are based on generalized least squares regression. AR[1] notes first-order autoregressive covariance structures that adjust for temporal autocorrelation and phi estimates correlations in residuals from successive years. Ordinary least squares (OLS) regression was fit when there was no evidence of autocorrelated residuals. Parameter estimates based on maximum likelihood. Response variables were log transformed so parameter estimates note annual rates of change across on the percent scale when multiplied by 100. Because monthly periods in which relative abundance was estimated varied annually, with periods in neighboring years sometimes just one month apart, trend estimates are biased and may change once analyses are corrected.

Species	Trend				
Parameter	Model; phi	Est.	SE	*t*	*P*
Jaguar					
Relative Abundance	AR[1]; 0.63	-0.034	0.023	-1.50	0.16
Density	OLS	-0.026	0.011	-2.34	0.04
Ocelot					
Relative Abundance	AR[1]; 0.55	0.027	0.009	3.07	0.01
Density	OLS	4.43E-05	0.027	<0.01	1.0
Puma					
Relative Abundance	OLS	0.009	0.026	0.36	0.73
Bobcat					
Relative Abundance	AR[1]; 0.69	0.002	0.026	0.06	0.95

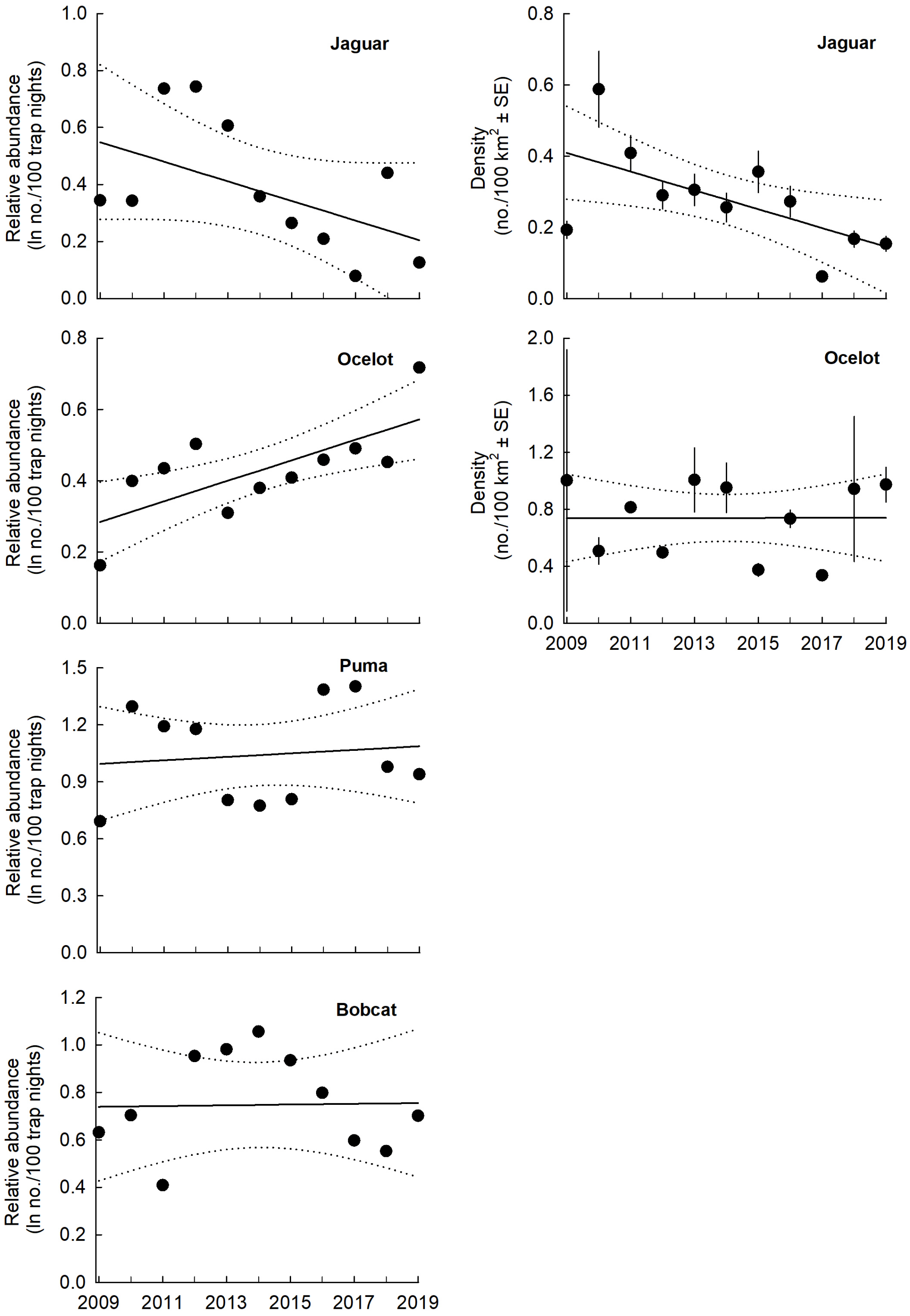

Figure 4. Temporal variation and trends in relative abundance and density of up to four species of wild felids on and around the Northern Jaguar Reserve in east-central Sonora, Mexico 2009-2019. Filled circles are annual estimates of parameters and solid lines are estimated trend models based on these data and generalized least-squares regression; dotted lines are 95% confidence intervals around trend models. Relative abundance estimates are plotted with equal spacing for each year but are for only single and often different months across years, which likely biased estimates.

Climate, weather, and forecasts of distribution under future climates: Past changes in weather indicated annual precipitation (*P*) increased across time by an estimated 17.0 ± 5.0 mm per year due largely to increases in monsoon-influenced warm-season P_{ws}. For annual mean minimum and mean maximum temperatures, there was much stronger evidence of warming T_{min}, which increased by an average of 2.04 ± 0.54 °C over just 12 years. Inter-annual variation in mean monthly T_{max} was higher but increased by a lower magnitude of 1.03 ± 0.48 °C across time (Appendix A).

Future climates under the more optimistic RCP of 4.5 suggested little systematic variation in *P* across the three GCMs (Appendix E). All GCMs showed increasing trends in all *T* variables, but magnitudes of increase were greatest for CanESM2, slightly lower for CNRM-CM5, and much lower for CCSM4. *P* varied widely under the more pessimistic RCP of 8.5, with CNRM-CM5 showing decreases in cool-season *P* and CCSM4 showing increasing annual and warm-season *P*, all of low magnitudes. CanESM2 suggested much greater changes and increasing annual and especially P_{ws}, but inter-annual variation was high (Appendix E). For *T*, relative magnitudes of increase averaged ~2.5-4.0 times greater than at RCP 4.5. Annual trends in past *T* were much greater than those forecasted by GCMs for the future, especially for T_{min}, suggesting future scenarios may be optimistic.

Species distribution models (GBMs) developed for forecasts showed higher probabilities of jaguar occurrence at low and especially moderate, but not high P_{cs} (relative influence = 47.6), strong positive associations with presence of the reserve (29.2), and with moderate T_{min} at a lag of one year (relative influence = 23.2; Appendix F). Bobcat GBMs showed higher probabilities of occurrence in areas with low topographic roughness (relative influence = 43.3), with strong positive associations with increasing T_{min} (relative influence = 39.9), and high P_{cs} (relative influence = 16.8; Appendix F). Spatial coefficient of variation (CV) AUC was >0.704 and temporal CV AUC was >0.739 for all models indicating good fit.

Forecasts across most future climate scenarios predicted major contractions in the distribution of jaguars between 2020 and 2040, but typically less change between this period and 2100 (Figure 5). Forecasts for RCP of 4.5 were not necessarily more pessimistic than those for 8.5. For RCP of 8.5, one scenario showed distribution returning to near original levels by 2100, another showed smaller increases in later years, and one showed the area occupied by jaguars declining to values very similar to the area of the NJR. Forecasts for bobcat, in contrast, showed universally increasing distributions across time with the most rapid periods of increase between 2020 and 2040 (Figure 6). In five of the size scenarios, distribution increases to include 100% of the broader study area by year 2050 or thereafter.

Discussion

Conservation of large predators such as wild felids can provide pervasive and positive umbrella-like effects for biodiversity preservation efforts, which makes felid communities excellent conservation foci (Lindenmayer et al. 2007, Thornton et al. 2016). Our work addressed a series of broad unanswered questions on the status of jaguar and three other species of wild felids, which serve as umbrellas for broad biodiversity preservation efforts in northwest Mexico. Questions we addressed include how occurrences of these four species varied across the landscape over time, how environmental factors such as local weather and land use influenced these patterns, and how climate change may impact distributions in the future. Although more work and questions remain, our efforts provide useful data on felid population ecology and information to support conservation efforts in northern Mexico, which are useful for ensuring the persistence of jaguar and other wildlife populations and their habitats. Additionally, with the support of CAZMEX, we expanded the spatial and temporal scopes of monitoring and outreach, which will enhance our impacts over the long-term. Currently, this effort is likely the longest-running and most extensive wild felid monitoring program of its kind in Mexico, and has great potential to address a range of knowledge gaps and inform conservation.

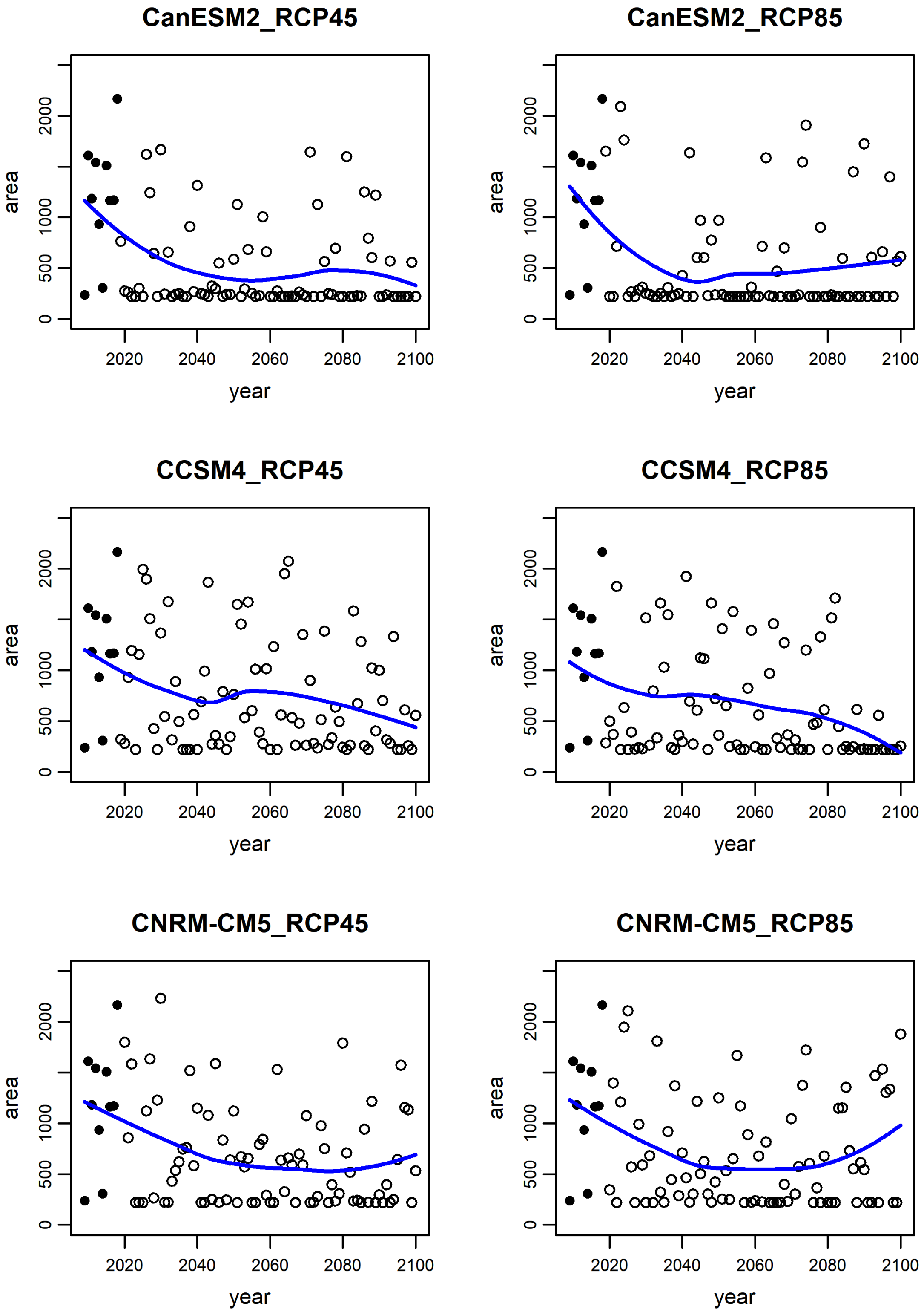

Figure 5. Predicted habitat area for jaguar under 6 future climate scenarios for years 2020-2100. Infilled points are based on gridded weather data for 2009-2018. Trend lines from a non-parametric smoother are shown in blue. Note that the lowest predictions correspond to the area of the Northern Jaguar Reserve.

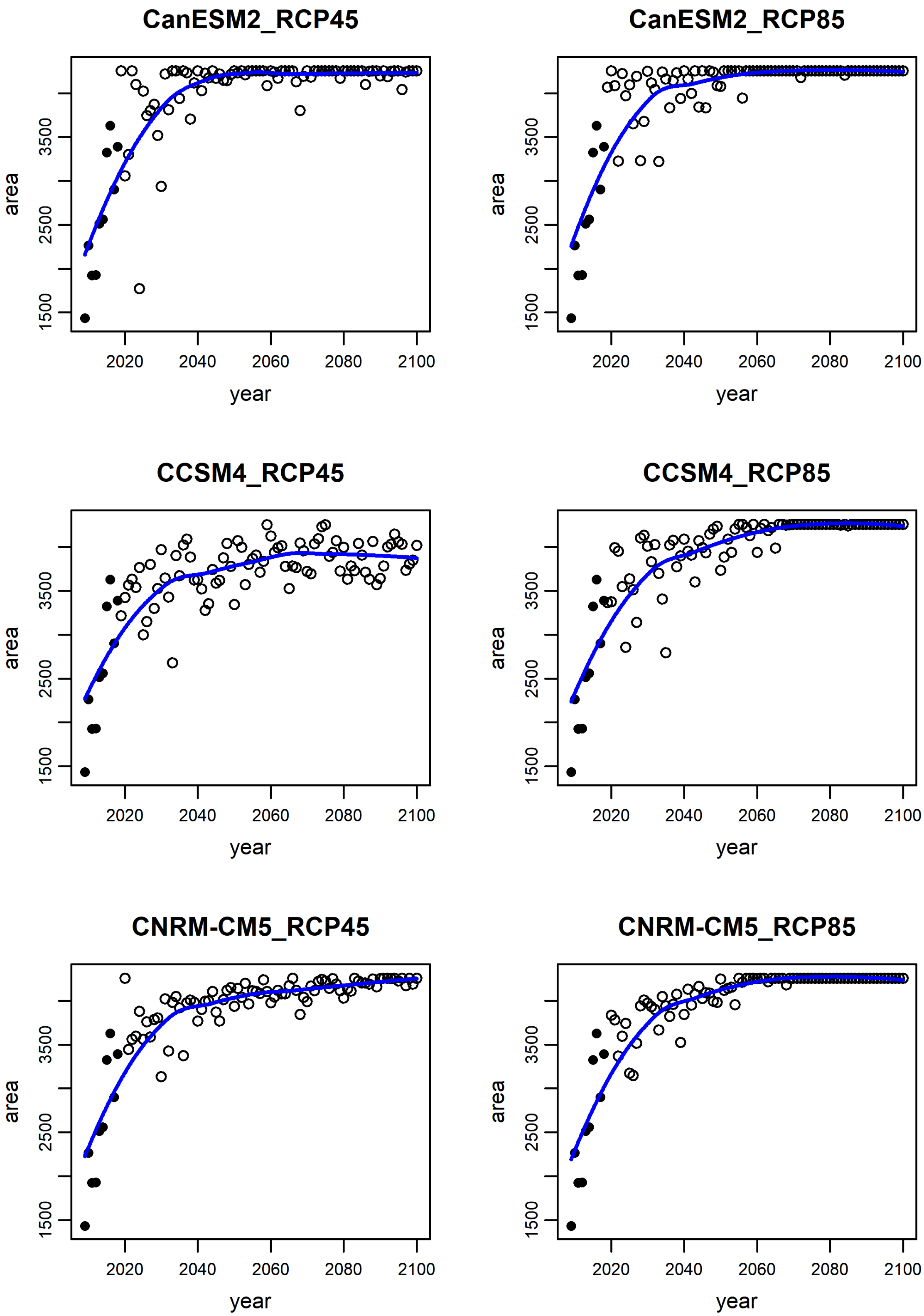

Figure 6. Predicted habitat area for bobcat under 6 future climate scenarios for years 2020-2100. Infilled points are based on gridded weather data for 2009-2018. Trend lines from a non-parametric smoother are shown in blue.

Occupancy analyses we report are the first of their kind for Mexico, and potentially across North America, but should be viewed as preliminary results that will be useful for guiding future work. We merged data from 10 years to model distribution of four species as a function of annual and seasonal weather, vegetation, land cover, human influence index, and management status. Most studies of felid occupancy have considered factors such as vegetation cover, distances to roads, habitat fragmentation, distance to water and human settlements, and interactions with species that are potential competitors (Sollmann et al. 2012, Arroyo Arce et al. 2014, Petracca et al. 2014, Massara et al. 2017). In the northern part of the study area, which coincided with the first area that formed the NJR in 2003, estimates of jaguar occupancy were notably higher, suggesting conservation efforts in this area are important. However, because of the limited temporal scope of data we considered (e.g., only a single month per year with all other occurrence data censored), predictions we report should be viewed as preliminary. In the north, up to the limit of our study area on the NJR, we have matched individual jaguars that have also been recorded on the VcF ranches to the south. Some of these animals were only detected in some years and had gaps of many years between successive detections, indicating variation in movements and large size of home ranges in the region (Morato et al. 2018). Such results highlight the importance of expanding protection across space and applying additional conservation strategies in adjacent areas. Future analysis should include prey distribution and abundance in the region, which can be important factors in estimating use of space by jaguars (Rabelo et al. 2019), and assess whether patterns within the narrow monthly “seasons” we considered are representative of broader periods.

Occupancy of other species also varied across space due likely to a range of processes. Mountain lion occupancy was more homogenous across space, which matches results from other studies (Nielsen et al. 2015). In open, arid regions, occupancy patterns of mountain lions do not vary across seasons (Dellinger et al. 2019), suggesting patterns in other seasons are likely to be consistent. Broad scale colonization of livestock in the early 1800s may help drive these patterns (Sweitzer et al. 1997). Occupancy patterns of ocelot and bobcat suggest these similar-sized species may actively partition space to reduce competition, or have evolved different habitat preferences perhaps as a result of past competition. Ocelots, which are an endangered species (DOF 2010, USFWS 2016), used areas with strong lowland Neotropical affinity along the vast corridors formed by the Aros and Yaqui rivers where bobcats were rare. In contrast, bobcats used areas in the southern portion of the study where ocelots were rare. These areas to the south include more private lands, and bobcats are often more resilient to human transformation of habitats than ocelots (USFWS 2016). Ocelots in our study area are near the northern limit of their global distribution, which may explain low occurrence in the region. More studies of these species can help elucidate the drivers of these patterns.

Among our broader and more important findings are that relative abundances (or density) of three of the four species of wild felids we considered were stable or increasing across a period of 11 years (2009-2019). Although such estimates are preliminary, due in part to unequal spacing in estimates from different months across years, such trends suggest that conservation and outreach mechanisms we have implemented to protect populations in the region since 2003 are working. Similar results were obtained by past studies, but due to the short period covered (Gómez Ramírez et al. 2017), it was important to expand efforts to assess trends in ocelot populations, which we did here. Despite observed increases in relative abundance, ocelot densities remained stable across time. Density estimates we report are among the lowest reported across the range of the ocelot (12.9 individuals/100km^2 in Chiapas, Mexico, de la Torre et al. 2016; 24.84 individuals/100km^2 in Amazonia, Rocha et al. 2016; 3.16 individuals/100km^2 in semiarid areas of Brazil, Penido et al. 2016), which is not surprising given the location of our study area near the northernmost extent of their breeding range (López González et al. 2003). However, the magnitude of these differences could be due more to the sampling area and length of studies than to actual variation in populations (Gómez Ramírez et al. 2017), as suggested by our results for jaguar densities.

Trend estimates for relative abundance and density of jaguars were both negative, indicating some evidence that population size has contracted in our study area across time. Wide-ranging movement behaviors by jaguars and their ability to shift spatial use across large areas in response to resource changes (Núñez Perez and Miller 2018, Ávila Nájera et al. 2019) could have driven these patterns. As such, patterns we documented may not be indicative of contractions in overall population size across the broader region this population inhabits, much of which remains unmonitored. Just north of our study area, a recent non-peer reviewed report also suggested declines in relative abundance of jaguar between 2009 and 2015, which were thought to be driven by active persecution by humans, including illegal baiting of poison-laced carcasses (Childs et al. 2017). If such mechanism were responsible for patterns we observed, one may predict they would drive declines in other wide-ranging felids such as puma, which we did not observe. This is because such poisons kill wildlife indiscriminately rather than targeting single species. Pumas are highly affected by poisoning when other species are targets (Center for Biological Diversity and Mountain Lion Foundation 2019), a pattern that should also be apparent for carrion eaters such as coyotes and some vultures (Ogada 2014). Regardless, additional monitoring is needed to confirm whether patterns we observed are due to natural variation in population sizes or movements, or true declines. More broadly, much has yet to be learned regarding how environmental stressors such as climate, variation in prey populations, persecution by humans, and other factors impact the dynamics of these populations.

Some studies find that jaguar densities are often overestimated in study areas of small size (Tobler and Powell 2013, Jędrzejewski et al. 2018) and recommend larger areas or longer-term studies for reliable estimation. Our study has advantages over many past efforts in that monitoring has occurred in some of the same areas for almost 20 years, and cameras have remained active the full year. Thus, we have been able to detect presence of some of the same individuals in the same areas for many years, and estimate survival probabilities based on capture histories of individual animals. Estimates of demographic parameters such as survival are better indicators of population status than densities, and suggest the long-term stability of jaguar populations in our region, despite what we suspect is high temporal variation in movements.

Among our more important results linked to jaguar survival are estimates of survival of 0.57, which is almost identical to that found in the study area between 2004 and 2012 (Gutiérrez González et al. 2015). Such results indicate jaguar survival has been largely stable since the time we started conservation efforts in the region, and offers good opportunities for future efforts. Linked to these results, we found presence of individuals that have been detected for more than 7 years (NJP unpublished data), which includes two females observed for up to 7.5 years, and another female that has been observed for 6.9 years and detected with cubs in two different years. Given the importance of conserving a viable population into the future in this critical core population area, and the relatively small size of current efforts (at least with regard to known home-range size of jaguars), additional conservation efforts are needed. These efforts should be focused in areas outside the NJR and collaborating ranches and focus on protecting populations, increasing survival, and promoting population persistence over the long-term. To that end, results of occupancy models for jaguar suggest areas in the west and north of our broader study area are good places to focus, but more effort is needed to confirm these results due to issues with the data and modeling process used here.

Ocelot survival was even higher than that estimated for jaguar with values close to 0.76. Such values are almost 20% higher than that reported between 2010 and 2012 in the same areas (Gómez Ramírez et al. 2017), and suggest conservation efforts are producing excellent results. These somewhat more auspicious findings compared to those for jaguar, may be linked to the smaller home-range size of this species, which results in more explicit protections of individuals within, and lower probability of moving beyond, the spatial scope of conservation efforts. Similar to jaguars, there are some individual ocelots that have remained in the study area for many years. Six individuals have been present in the area for more than 7 years, including two females for 9 years, two males for 9 years, one male for 8 years, and another male for 7 years (NJP unpublished data), indicating high levels of permanence by individuals.

Forecast results suggested marked impacts of future climates on jaguar and bobcat populations in as soon as 20 years. For jaguars, predictions of the amount of area occupied across the broader study region declined rapidly to 2040 and generally stabilized thereafter, but some scenarios suggested contractions in range area to the current size of the NJR. For bobcats, predictions suggest marked and rapid increases in distribution that stabilized mid century at size of the entire study area. Such results suggest this region will become increasingly unfavorable to jaguars with the opposite pattern for bobcat, but nonetheless results are highly preliminary and should be viewed with caution despite the robust approach we used. This is because estimates of weather effects on occupancy are likely to be highly sensitive to seasonal changes in occurrence, movements, and inter-annual variation in local weather. Such variation was not considered here because only observations from single months within a year, and variable months across years were used to develop forecast models. Depending on the months selected these factors could influence occupancy differently and in highly complex ways. Future efforts should include all animal observations across years so that pixels with no observations of a given species in a given year can be discriminated from those with observations that were omitted due to the data censoring process used here. This effort will greatly improve forecasts so they can be used for conservation planning.

Conservation strategies: Illuminating factors that drive distribution and distributional change of wild felids can help inform development of new conservation strategies and focus current efforts on key resources and areas. Information reported here should help NJP and other conservation groups refine priority conservation areas for work with surrounding landowners, and potentially direct future land acquisition. To that end, additional effort is required to confirm results of occupancy and trend models we report and refine inferences based on more months and additional years of data. In addition to the approach used here, developing species distribution models for prey species and projecting associated estimates across larger landscapes will aid these efforts, as will explicit incorporation of data on other felid species, which may exhibit competitive or other interactions with focal species. Finally, aided by these tools and inferences, our efforts can enhance cross-border collaboration between researchers and NGOs in Mexico and the U.S., which along with local communities are crucial for realizing conservation goals.

Our efforts in the region include significant community engagement and public outreach to residents surrounding the NJR. These activities include the VcF project, which has grown to the south and east of the NJR. This effort involves collaboration with local communities and landowners, provides individuals with economic incentives for conserving wildlife, and opportunities to gain land management and ecological restoration skills. The goals of VcF are to minimize human-wildlife conflicts, eliminate poaching, restore wildlife habitats, and facilitate education in ranching communities and among schoolchildren. As part of this effort, ranchers sign annual contracts not to hunt, bait, trap, poison, or disturb wildlife, for which participants receive monetary incentives for feline photos taken by motion-triggered cameras placed on their lands. Data from these cameras are then used to monitor felid and prey populations, which formed an important part of the datasets we analyzed as part of this project. Currently, VcF covers 30,000 hectares and involves 14 cooperating private ranches, forming an important buffer area around the core NJR. Research linked to this project and sponsorship from CAZMEX helped us expand VcF to three new ranches, and thereby augmented benefits to human and wildlife communities while expanding the scope of monitoring to an additional 13,000 ha. Results suggest the importance of expanding these and other efforts in various directions, but especially north and west of the NJR for jaguars. Such expansion could be fostered by direct application of the VcF model, incorporating new acquisitions into the NJR, and through active collaborations with other organizations working in portions of these and other areas.

Thanks to recent collaboration and data sharing, we have been able to confirm an individual male jaguar that has moved hundreds of kilometers. This jaguar was first detected in 2008 to the north of our study area and, in 2010, was recorded 50 km south of the Mexico-U.S. border. This same animal was subsequently recorded on the NJR in early 2019 and on one of the CAZMEX ranches in May. Thanks to support from CAZMEX, which allowed the addition of new ranches into the project, we now know this animal uses one of these newly monitored ranches and is at least 11 years old. Collaboration between organizations can greatly enhance the quality and scope of inferences, and thus our understanding of the biology of the species. To this end, expanding modeling with the help of new collaborators can help elucidate north-south movement corridors for jaguars between the NJR and VcF and other areas, and direct conservation strategies at broad spatial scales.

Collaboration between parties, roles, and acknowledgements: This project promoted much-needed collaboration between University of Arizona ecologist Aaron Flesch and Northern Jaguar Project lead biologist Carmina Gutiérrez González. Carmina, with help from reserve biologist Miguel Gómez Ramírez, largely managed and implemented this project and took a lead role in data analyses, management, and supervision of field staff. By providing datasets on relative abundance, density, and occupancy to Aaron and project consultant Alan Swanson, of the University of Montana College of Forestry and Conservation, such collaborations fostered trend, forecasting, and other analyses. Carlos López González provided important guidance to Carmina on methods, commented on findings presented in this report, and provided administrative support and funding for field operations in Mexico. Our efforts also revealed a number of challenges linked to communication and coordination of methods, data inputs, and assumptions, and these issues greatly affected the scope and quality of inferences linked to trend and forecasting analyses we reported. Through these experiences, all parties gained greater knowledge, understanding, and capacity to conduct collaborative research in Mexico that has the potential to advance future conservation and research. Our efforts were also aided by two Mexican field technicians, Federico Mora and Martín Torres, and by NJP Coordinator Megan Southern, who assisted with project administration and reporting.

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Appendix A

Description of recent past variation in weather attributes within the study area in northwest Mexico.

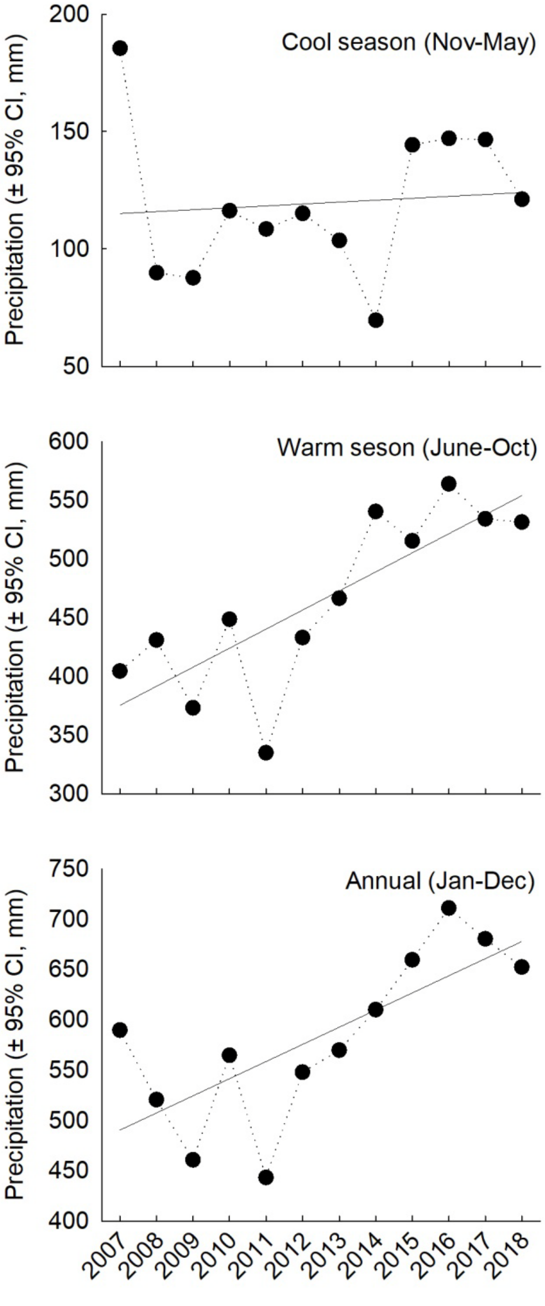


Figure A1. Trends and variation in past precipitation across the study area between 2007-2018 in northwest Mexico.

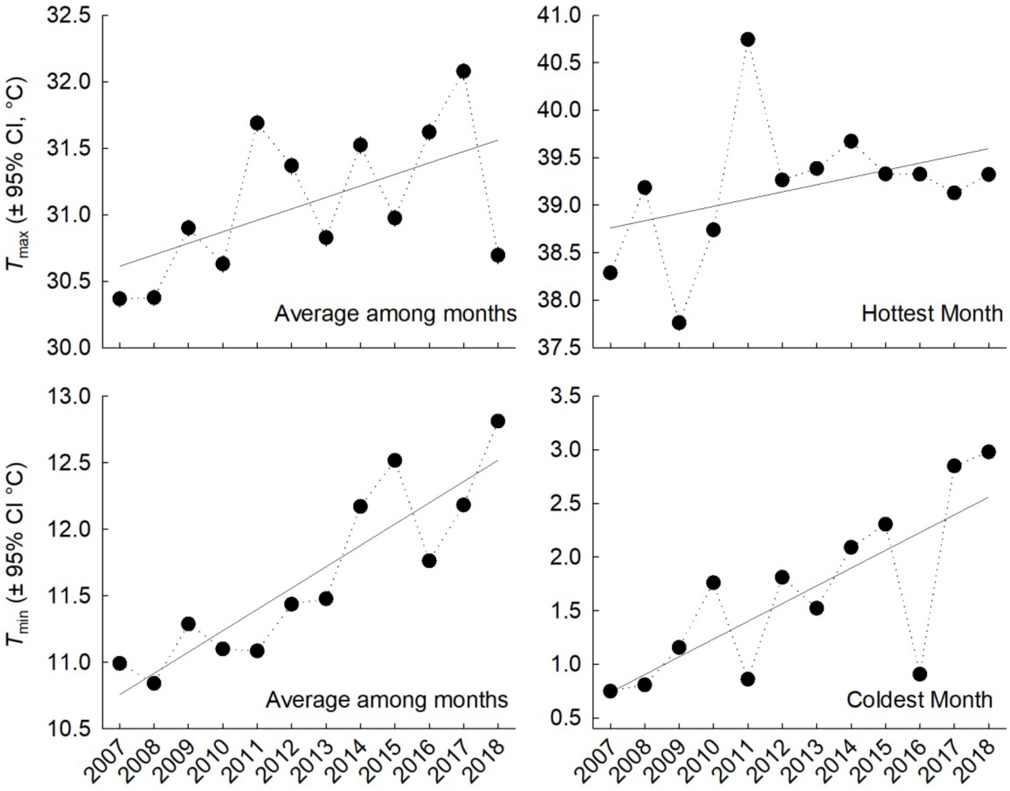


Figure A2. Trends and variation in past temperature across the study area between 2007-2018 in northwest Mexico.

Table A1. Trends in precipitation and temperature factors considered when assessing the effects of climatic variation on wild felids in east-central Sonora between 2007-2018. Trends are based on simple linear models of mean annual values from among 4,256 1 x 1 km sq. pixels across the study area. Weather values are from downscaled and interpolated weather-station data adjusted for elevation (see Wang et al. 2016).

Factor (units)	Trend			
Period	Est.	SE	*t*	*P*
Precipitation (mm)				
Annual (calendar year)	17.04	5.01	3.40	0.0067
Warm season (June-Oct)	16.24	3.83	4.24	0.0017
Cool season (Jan-May, Nov-Dec)	0.81	2.79	0.29	0.78
Temperature - mean minimum (°C)				
Average among months	0.16	0.025	6.33	<0.0001
Coldest month	0.17	0.045	3.66	0.0044
Temperature - mean maximum (°C)				
Average among months	0.086	0.040	2.13	0.059
Hottest month	0.076	0.059	1.29	0.23

Appendix B

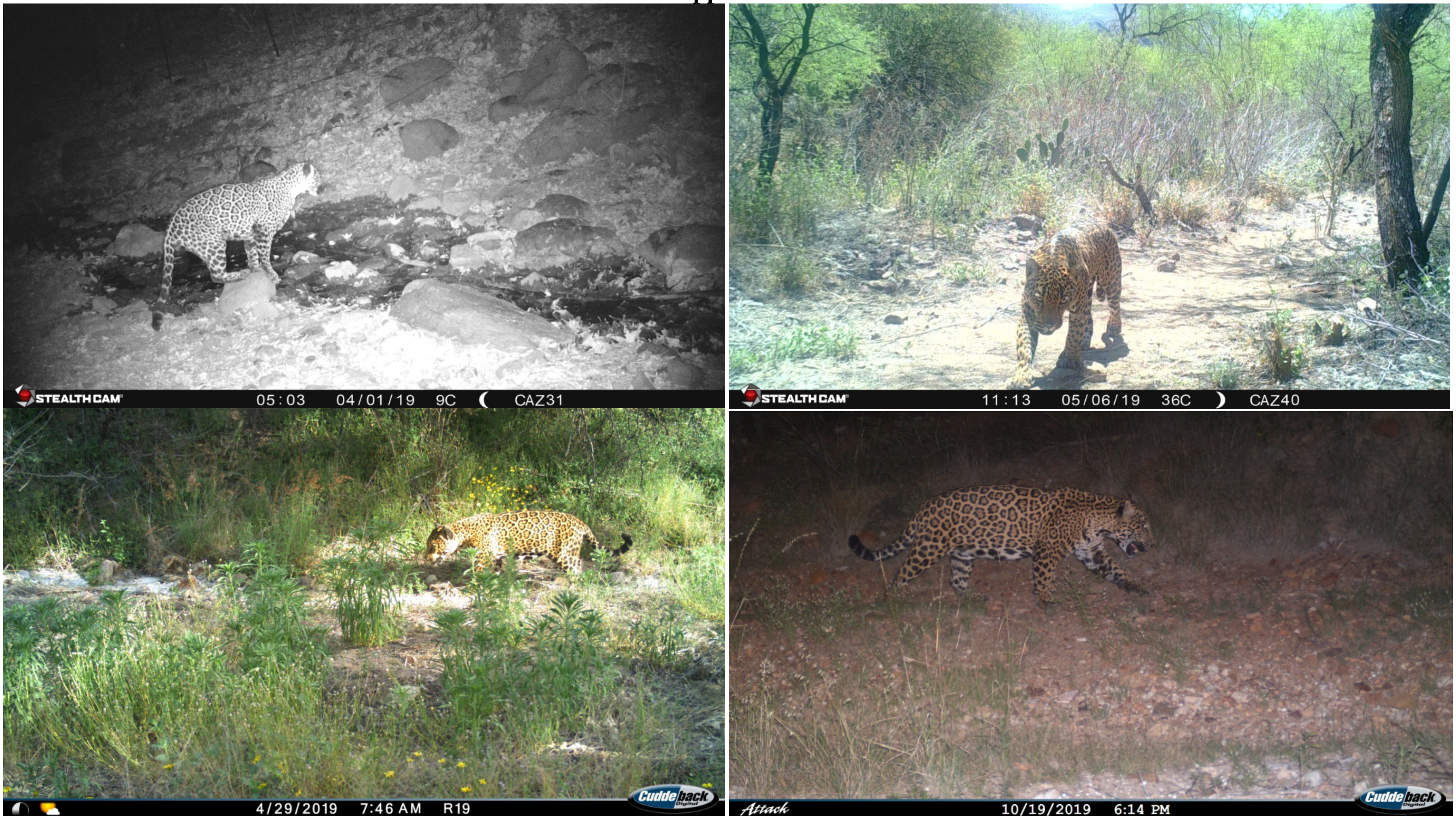


Figure B1. 2019 Jaguar photographs from new ranches included with CAZMEX support (top) and on the Northern Jaguar Reserve (bottom).

Figure B2. 2019 Mountain lion photographs from new ranches included with CAZMEX support (top) and on *Viviendo con Felinos* ranches (bottom).

Figure B3. 2019 Ocelot photographs from new ranches included with CAZMEX support (top) and on the Northern Jaguar Reserve (bottom).

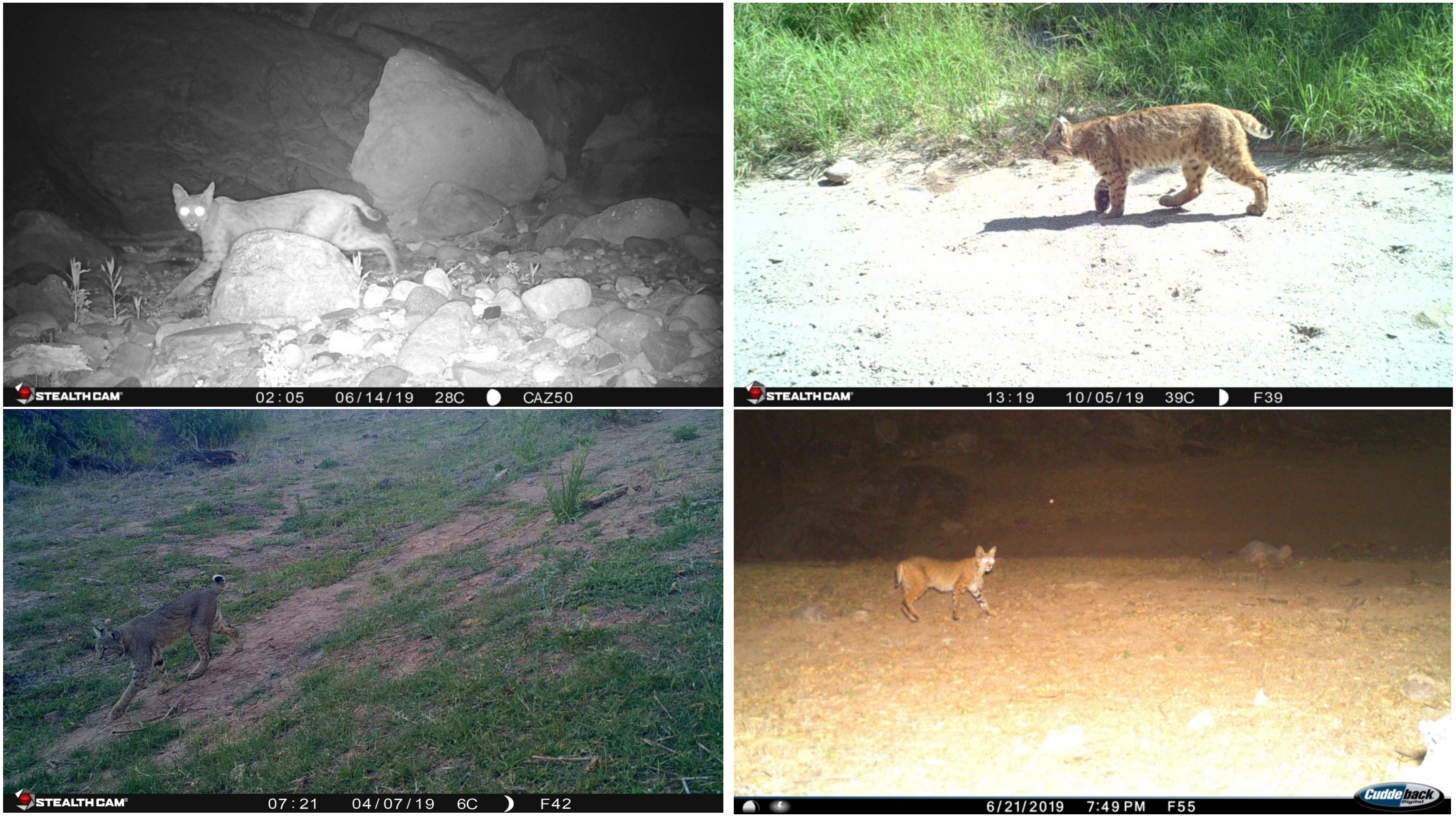


Figure B4. 2019 Bobcat photographs from new ranches included with CAZMEX support (top left) and on *Viviendo con Felinos* ranches (top right, bottom).

Figure B5. Fieldwork in the study area. Upper left: cowboy guiding field technicians in the area. Upper right: field technician setting up motion-triggered camera. Bottom left: tracks of jaguar (left) and coyote. Bottom right: field technician photographing a cat scratch on a palm tree.

Figure B6. Upper left: perennial river landscape, Río Aros. Upper right: ephemeral stream on the Northern Jaguar Reserve. Bottom: comparison of landscape change between dry (left) and wet seasons (right).

Appendix C

Beta estimates of the best-fitted models for jaguar occupancy on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Table C1. Beta estimates of the best-fitted model for jaguar occupancy (Ψ(yr+ T_{max_avg} +V_8+HII+ P_{cs}) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.70	0.25	-4.20	-3.20
2	p 2009	-0.98	0.76	-2.48	0.51
3	p 2010	-0.70	0.57	-1.82	0.42
4	p 2011	0.18	0.36	-0.54	0.89
5	p 2012	0.82	0.36	0.12	1.52
6	p 2013	0.62	0.39	-0.16	1.39
7	p 2014	-0.25	0.51	-1.24	0.74
8	p 2015	-1.06	0.51	-2.05	-0.07
9	p 2016	-1.36	0.65	-2.64	-0.09
10	p 2017	-1.24	0.42	-2.07	-0.41
11	Ψ intercept	-46.80	9.44	-65.29	-28.30
12	Ψ 2009	5.85	1.69	2.53	9.16
13	Ψ 2010	-0.06	1.01	-2.03	1.92
14	Ψ 2011	0.01	0.73	-1.42	1.44
15	Ψ 2012	-2.06	0.73	-3.50	-0.62
16	Ψ 2013	0.75	0.78	-0.77	2.27
17	Ψ 2014	7.04	1.86	3.39	10.70
18	Ψ 2015	-4.51	1.62	-7.69	-1.33
19	Ψ 2016	-5.04	1.91	-8.80	-1.29
20	Ψ 2017	-5.93	1.66	-9.19	-2.67
21	$T_{max\ avg}$	0.83	0.19	0.46	1.21
22	V_8	0.02	0.01	0.00	0.04
23	HII	-0.12	0.08	-0.27	0.03
24	P_{cs}	0.16	0.04	0.09	0.23

p: detection probability, Ψ: Occupancy (presence) probability, T_{max_avg}: mean maximum temperature across all months, P_{cs}: cool-season precipitation, V: vegetation class according to NALCMS NALCMS 2010, HII: Human Influence Index.

Table C2. Beta estimates of the second best-fitted model for jaguar occupancy (Ψ (yr+ T_{max_month} + V_8+ HII + P_{cs}) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.70	0.26	-4.20	-3.20
2	p 2009	-0.98	0.76	-2.48	0.51
3	p 2010	-0.70	0.57	-1.82	0.41
4	p 2011	0.18	0.36	-0.53	0.89
5	p 2012	0.83	0.36	0.13	1.53
6	p 2013	0.61	0.39	-0.16	1.39
7	p 2014	-0.25	0.51	-1.24	0.74
8	p 2015	-1.05	0.51	-2.04	-0.05
9	p 2016	-1.33	0.64	-2.59	-0.07
10	p 2017	-1.23	0.43	-2.07	-0.39
11	Ψ intercept	-45.96	9.23	-64.06	-27.86
12	Ψ 2009	5.45	1.65	2.22	8.68
13	Ψ 2010	0.17	1.00	-1.80	2.13
14	Ψ 2011	-0.24	0.74	-1.68	1.21
15	Ψ 2012	-1.40	0.68	-2.72	-0.07
16	Ψ 2013	0.59	0.77	-0.92	2.10
17	Ψ 2014	6.94	1.84	3.33	10.56
18	Ψ 2015	-3.99	1.56	-7.05	-0.94
19	Ψ 2016	-4.03	1.81	-7.57	-0.49
20	Ψ 2017	-4.32	1.51	-7.29	-1.35
21	$T_{max\ month}$	0.66	0.15	0.36	0.96
22	V_8	0.02	0.01	0.00	0.04
23	HII	-0.12	0.08	-0.27	0.03
24	P_{cs}	0.15	0.03	0.09	0.22

p: detection probability, Ψ: occupancy (presence) probability, T_{max_month}: mean maximum temperature across warmest months, P_{cs}: cool-season precipitation, V: vegetation class according to NALCMS 2010, HII: Human Influence Index.

Table C3. Beta estimates of the best-fitted model for mountain lion occupancy (Ψ (yr+ P_{cs} +V_7)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.34	0.18	-3.70	-2.98
2	p 2009	-0.59	0.56	-1.68	0.50
3	p 2010	0.14	0.27	-0.38	0.67
4	p 2011	-0.10	0.29	-0.67	0.47
5	p 2012	0.29	0.26	-0.23	0.80
6	p 2013	-0.12	0.35	-0.81	0.56
7	p 2014	0.57	0.31	-0.03	1.18
8	p 2015	-0.22	0.33	-0.87	0.43
9	p 2016	0.42	0.26	-0.08	0.92
10	p 2017	0.63	0.22	0.19	1.07
11	Ψ intercept	-1.99	1.23	-4.40	0.41
12	Ψ 2009	-0.13	0.87	-1.85	1.58
13	Ψ 2010	-0.16	0.50	-1.13	0.82
14	Ψ 2011	0.06	0.55	-1.02	1.14
15	Ψ 2012	-0.47	0.48	-1.40	0.46
16	Ψ 2013	-0.64	0.56	-1.73	0.46
17	Ψ 2014	-0.81	0.67	-2.12	0.50
18	Ψ 2015	-0.38	0.80	-1.94	1.18
19	Ψ 2016	-1.07	0.57	-2.19	0.05
20	Ψ 2017	-1.16	0.59	-2.31	-0.01
21	P_{cs}	0.02	0.01	0.00	0.04
22	V_7	-0.02	0.01	-0.04	0.00

p: detection probability, Ψ: occupancy (presence) probability, P_{cs}: cool-season precipitation, V: vegetation class according to NALCMS 2010.

Table C4. Beta estimates of the second best-fitted model for mountain lion occupancy (Ψ (yr+ P_{cs} + V_7+ V_{18})) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.33	0.18	-3.68	-2.97
2	p 2009	-0.59	0.55	-1.67	0.48
3	p 2010	0.12	0.27	-0.40	0.65
4	p 2011	-0.12	0.29	-0.68	0.45
5	p 2012	0.27	0.26	-0.24	0.79
6	p 2013	-0.13	0.35	-0.81	0.55
7	p 2014	0.56	0.31	-0.04	1.17
8	p 2015	-0.22	0.33	-0.87	0.42
9	p 2016	0.41	0.25	-0.09	0.90
10	p 2017	0.62	0.22	0.19	1.05
11	Ψ intercept	-1.77	1.23	-4.19	0.65
12	Ψ 2009	-0.18	0.87	-1.88	1.52
13	Ψ 2010	-0.15	0.50	-1.12	0.83
14	Ψ 2011	0.07	0.55	-1.02	1.15
15	Ψ 2012	-0.47	0.47	-1.40	0.45
16	Ψ 2013	-0.66	0.55	-1.75	0.42
17	Ψ 2014	-0.91	0.67	-2.22	0.40
18	Ψ 2015	-0.34	0.79	-1.89	1.21
19	Ψ 2016	-1.02	0.57	-2.14	0.09
20	Ψ 2017	-1.11	0.58	-2.25	0.03
21	P_{cs}	0.02	0.01	0.00	0.03
22	V_7	-0.02	0.01	-0.04	0.00
23	V_{18}	-0.16	0.12	-0.40	0.08

p: detection probability, Ψ: occupancy (presence) probability, P_{cs}: cool-season precipitation, V: vegetation class according to NALCMS 2010.

Table C5. Beta estimates of the third best-fitted model for mountain lion occupancy (Ψ (yr+ V_7+ Mgmt)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.35	0.19	-3.73	-2.98
2	p 2009	-0.55	0.55	-1.62	0.52
3	p 2010	0.17	0.27	-0.37	0.70
4	p 2011	-0.07	0.29	-0.64	0.50
5	p 2012	0.32	0.27	-0.21	0.84
6	p 2013	-0.13	0.36	-0.83	0.58
7	p 2014	0.59	0.32	-0.03	1.20
8	p 2015	-0.27	0.35	-0.95	0.41
9	p 2016	0.43	0.26	-0.08	0.94
10	p 2017	0.65	0.23	0.21	1.10
11	Ψ intercept	0.48	0.42	-0.34	1.30
12	Ψ 2009	-0.89	0.81	-2.48	0.70
13	Ψ 2010	-0.27	0.52	-1.29	0.75
14	Ψ 2011	-0.16	0.56	-1.26	0.95
15	Ψ 2012	-0.55	0.50	-1.52	0.42
16	Ψ 2013	-0.93	0.58	-2.06	0.20
17	Ψ 2014	-1.79	0.52	-2.82	-0.77
18	Ψ 2015	0.36	0.82	-1.24	1.97
19	Ψ 2016	-0.54	0.49	-1.49	0.41
20	Ψ 2017	-0.52	0.45	-1.41	0.36
21	V_7	-0.02	0.01	-0.04	0.00
22	Mgmt	-0.35	0.20	-0.74	0.04

p: detection probability, Ψ: Occupancy (presence) probability, V: vegetation class according to NALCMS 2010, Mgmt: management status, cattle presence (1) or absence (0).

Table C6. Beta estimates of the fourth best-fitted model for mountain lion occupancy (Ψ (yr+ V7+ V18)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.30	0.17	-3.64	-2.96
2	p 2009	-0.65	0.56	-1.74	0.45
3	p 2010	0.07	0.27	-0.45	0.59
4	p 2011	-0.16	0.29	-0.73	0.40
5	p 2012	0.23	0.26	-0.27	0.74
6	p 2013	-0.16	0.34	-0.84	0.51
7	p 2014	0.53	0.30	-0.06	1.13
8	p 2015	-0.30	0.33	-0.95	0.36
9	p 2016	0.37	0.25	-0.12	0.86
10	p 2017	0.60	0.21	0.18	1.02
11	Ψ intercept	0.26	0.33	-0.39	0.92
12	Ψ 2009	-0.71	0.83	-2.34	0.91
13	Ψ 2010	-0.09	0.49	-1.06	0.88
14	Ψ 2011	0.01	0.55	-1.07	1.09
15	Ψ 2012	-0.42	0.45	-1.31	0.47
16	Ψ 2013	-0.85	0.53	-1.88	0.19
17	Ψ 2014	-1.70	0.47	-2.63	-0.77
18	Ψ 2015	0.35	0.73	-1.09	1.79
19	Ψ 2016	-0.46	0.44	-1.33	0.41
20	Ψ 2017	-0.44	0.40	-1.22	0.34
21	V_7	-0.02	0.01	-0.04	0.00
22	V_{18}	-0.19	0.12	-0.43	0.06

p: detection probability, Ψ: occupancy (presence) probability, V: vegetation class according to NALCMS 2010.

Table C7. Beta estimates of the fifth best-fitted model for mountain lion occupancy (Ψ (yr+ P_{cs} + V_7+Mgmt)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.36	0.19	-3.73	-2.98
2	p 2009	-0.55	0.55	-1.62	0.52
3	p 2010	0.17	0.27	-0.36	0.71
4	p 2011	-0.07	0.29	-0.64	0.50
5	p 2012	0.32	0.27	-0.21	0.84
6	p 2013	-0.11	0.36	-0.81	0.58
7	p 2014	0.59	0.31	-0.03	1.21
8	p 2015	-0.22	0.34	-0.89	0.44
9	p 2016	0.44	0.26	-0.07	0.95
10	p 2017	0.65	0.23	0.20	1.10
11	Ψ intercept	-1.23	1.49	-4.16	1.70
12	Ψ 2009	-0.40	0.91	-2.18	1.38
13	Ψ 2010	-0.24	0.52	-1.26	0.78
14	Ψ 2011	-0.05	0.57	-1.17	1.07
15	Ψ 2012	-0.54	0.50	-1.51	0.44
16	Ψ 2013	-0.75	0.59	-1.91	0.41
17	Ψ 2014	-1.12	0.76	-2.62	0.38
18	Ψ 2015	-0.19	0.87	-1.90	1.51
19	Ψ 2016	-0.95	0.60	-2.13	0.23
20	Ψ 2017	-1.01	0.62	-2.23	0.20
21	P_{cs}	0.01	0.01	-0.01	0.03
22	V_7	-0.02	0.01	-0.04	0.00
23	Mgmt	-0.21	0.23	-0.66	0.24

p: detection probability, Ψ: occupancy (presence) probability, P_{cs}: cool-season precipitation, V: vegetation class according to NALCMS 2010, Mgmt: management status, cattle presence (1) or absence (0).

Table C8. Beta estimates of the best-fitted model for ocelot occupancy (Ψ (yr+ $P_{cs\text{-}1}$+ T_{min_month} +HII+ V_7)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.12	0.24	-3.59	-2.65
2	p 2009	-3.27	0.82	-4.89	-1.66
3	p 2010	-0.09	0.49	-1.06	0.87
4	p 2011	-0.28	0.47	-1.20	0.65
5	p 2012	-0.55	0.47	-1.47	0.36
6	p 2013	-2.50	0.52	-3.51	-1.49
7	p 2014	-0.93	0.49	-1.89	0.03
8	p 2015	-0.50	0.44	-1.36	0.37
9	p 2016	-1.28	0.51	-2.27	-0.28
10	p 2017	-0.49	0.39	-1.25	0.26
11	Ψ intercept	3.37	3.40	-3.29	10.02
12	Ψ 2009	2.66	6.44	-9.95	15.28
13	Ψ 2010	-2.71	1.54	-5.74	0.31
14	Ψ 2011	0.54	1.55	-2.51	3.58
15	Ψ 2012	-0.53	1.04	-2.58	1.51
16	Ψ 2013	3.91	3.76	-3.45	11.28
17	Ψ 2014	0.10	1.39	-2.62	2.82
18	Ψ 2015	-3.38	1.52	-6.37	-0.40
19	Ψ 2016	3.70	1.52	0.71	6.69
20	Ψ 2017	0.33	0.52	-0.68	1.34
21	$P_{cs\text{-}1}$	-0.05	0.02	-0.08	-0.02
22	$T_{min\ month}$	1.25	0.58	0.11	2.38
23	HII	-0.10	0.05	-0.20	0.00
24	V_7	-0.06	0.03	-0.12	0.00

p: detection probability, Ψ: occupancy (presence) probability, $P_{cs\text{-}1}$: cool-season precipitation from the previous year, T_{min_month}: mean minimum temperature across coldest months, V: vegetation class according to NALCMS 2010, HII: Human Influence Index.

Table C9. Beta estimates of the second best-fitted model for ocelot occupancy (Ψ (yr+ $P_{cs\text{-}1}$+ T_{min_month} + V_7)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.12	0.24	-3.59	-2.65
2	p 2009	-3.34	0.78	-4.86	-1.82
3	p 2010	-0.11	0.50	-1.09	0.87
4	p 2011	-0.29	0.48	-1.23	0.65
5	p 2012	-0.58	0.48	-1.51	0.36
6	p 2013	-2.42	0.58	-3.56	-1.28
7	p 2014	-0.96	0.51	-1.95	0.03
8	p 2015	-0.51	0.45	-1.38	0.37
9	p 2016	-1.22	0.50	-2.19	-0.25
10	p 2017	-0.46	0.38	-1.20	0.28
11	Ψ intercept	-0.01	2.90	-5.70	5.68
12	Ψ 2009	5.01	14.91	-24.21	34.23
13	Ψ 2010	-1.39	1.38	-4.09	1.31
14	Ψ 2011	1.26	1.52	-1.71	4.24
15	Ψ 2012	0.28	0.97	-1.63	2.19
16	Ψ 2013	3.88	2.96	-1.91	9.68
17	Ψ 2014	1.07	1.34	-1.56	3.70
18	Ψ 2015	-1.83	1.29	-4.35	0.70
19	Ψ 2016	3.65	1.46	0.78	6.52
20	Ψ 2017	0.40	0.50	-0.58	1.37
21	$P_{cs\text{-}1}$	-0.03	0.01	-0.05	-0.01
22	$T_{min\ month}$	1.25	0.58	0.12	2.38
24	V_7	-0.06	0.03	-0.12	0.00

p: detection probability, Ψ: occupancy (presence) probability, $P_{cs\text{-}1}$: cool-season precipitation from the previous year, T_{min_month}: mean minimum temperature across coldest months, V: vegetation class according to NALCMS 2010.

Table C10. Beta estimates of the best-fitted model for bobcat occupancy (Ψ (yr+ P_{ws-1}+ Mgmt +V_{15})) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.55	0.25	-4.03	-3.06
2	p 2009	-0.34	0.56	-1.44	0.76
3	p 2010	0.29	0.39	-0.47	1.05
4	p 2011	-0.20	0.52	-1.21	0.81
5	p 2012	0.65	0.32	0.03	1.28
6	p 2013	0.31	0.33	-0.33	0.95
7	p 2014	0.80	0.31	0.20	1.40
8	p 2015	0.32	0.32	-0.30	0.95
9	p 2016	0.42	0.32	-0.22	1.05
10	p 2017	0.00	0.43	-0.84	0.84
11	Ψ intercept	-7.43	2.42	-12.17	-2.69
12	Ψ 2009	1.58	0.99	-0.35	3.52
13	Ψ 2010	1.63	0.98	-0.28	3.54
14	Ψ 2011	0.31	0.72	-1.10	1.73
15	Ψ 2012	1.96	1.00	-0.01	3.93
16	Ψ 2013	1.18	0.66	-0.11	2.47
17	Ψ 2014	0.21	0.55	-0.87	1.29
18	Ψ 2015	-0.22	0.44	-1.08	0.65
19	Ψ 2016	-0.04	0.45	-0.93	0.84
20	Ψ 2017	-1.13	0.53	-2.18	-0.09
21	P_{ws-1}	0.01	0.00	0.00	0.02
22	Mgmt	-0.36	0.18	-0.72	0.00
24	V_{15}	-0.11	0.08	-0.27	0.04

p: detection probability, Ψ: occupancy (presence) probability, P_{ws-1}: warm-season precipitation from the previous year, V: vegetation class according to NALCMS 2010, Mgmt: management status, cattle presence (1) or absence (0).

Table C11. Beta estimates of the second best-fitted model for bobcat occupancy (Ψ (yr+ $P_{\text{ws-1}}$+ Mgmt + V_{15}+HII)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.55	0.25	-4.04	-3.06
2	p 2009	-0.33	0.56	-1.43	0.77
3	p 2010	0.29	0.39	-0.47	1.06
4	p 2011	-0.21	0.52	-1.23	0.81
5	p 2012	0.66	0.32	0.04	1.29
6	p 2013	0.32	0.33	-0.32	0.96
7	p 2014	0.81	0.31	0.20	1.41
8	p 2015	0.33	0.32	-0.30	0.96
9	p 2016	0.42	0.33	-0.22	1.06
10	p 2017	0.01	0.43	-0.83	0.84
11	Ψ intercept	-5.94	2.63	-11.09	-0.79
12	Ψ 2009	1.29	1.00	-0.68	3.25
13	Ψ 2010	1.18	1.03	-0.83	3.20
14	Ψ 2011	0.10	0.74	-1.35	1.56
15	Ψ 2012	1.46	1.07	-0.63	3.55
16	Ψ 2013	0.90	0.69	-0.45	2.25
17	Ψ 2014	0.01	0.57	-1.12	1.13
18	Ψ 2015	-0.21	0.44	-1.08	0.66
19	Ψ 2016	-0.11	0.46	-1.01	0.79
20	Ψ 2017	-1.10	0.54	-2.15	-0.05
21	$P_{\text{ws-1}}$	0.01	0.00	0.00	0.02
22	Mgmt	-0.25	0.20	-0.64	0.14
24	V_{15}	-0.14	0.08	-0.30	0.03
25	HII	-0.04	0.03	-0.10	0.02

p: detection probability, Ψ: occupancy (presence) probability, $P_{\text{ws-1}}$: warm-season precipitation from the previous year, V: vegetation class according to NALCMS 2010, HII: Human Influence Index, Mgmt: management status, cattle presence (1) or absence (0).

Table C12. Beta estimates of the third best-fitted model for bobcat occupancy (Ψ (yr+ $P_{\text{ws-1}}$+ Mgmt)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.55	0.25	-4.04	-3.06
2	p 2009	-0.33	0.56	-1.43	0.76
3	p 2010	0.30	0.39	-0.46	1.06
4	p 2011	-0.20	0.51	-1.20	0.81
5	p 2012	0.66	0.32	0.03	1.28
6	p 2013	0.31	0.33	-0.33	0.96
7	p 2014	0.81	0.31	0.20	1.41
8	p 2015	0.33	0.32	-0.30	0.96
9	p 2016	0.42	0.32	-0.21	1.06
10	p 2017	-0.01	0.43	-0.85	0.84
11	Ψ intercept	-8.26	2.37	-12.90	-3.61
12	Ψ 2009	1.76	0.98	-0.15	3.68
13	Ψ 2010	1.92	0.96	0.04	3.80
14	Ψ 2011	0.45	0.72	-0.96	1.85
15	Ψ 2012	2.27	0.99	0.33	4.21
16	Ψ 2013	1.34	0.65	0.06	2.62
17	Ψ 2014	0.33	0.55	-0.75	1.40
18	Ψ 2015	-0.24	0.44	-1.10	0.63
19	Ψ 2016	0.00	0.45	-0.89	0.88
20	Ψ 2017	-1.16	0.54	-2.22	-0.11
21	$P_{\text{ws-1}}$	0.01	0.00	0.01	0.02
22	Mgmt	-0.41	0.18	-0.77	-0.06

p: detection probability, Ψ: occupancy (presence) probability, $P_{ws\text{-}1}$: warm-season precipitation from the previous year, Mgmt: management status, cattle presence (1) or absence (0).

Table C13. Beta estimates of the fourth best-fitted model for bobcat occupancy (Ψ (yr+ P_{ws-1}+ Mgmt + V_{15}+ V_5)) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.55	0.25	-4.04	-3.06
2	p 2009	-0.32	0.55	-1.41	0.76
3	p 2010	0.30	0.39	-0.46	1.06
4	p 2011	-0.19	0.51	-1.20	0.81
5	p 2012	0.66	0.32	0.03	1.28
6	p 2013	0.32	0.33	-0.33	0.96
7	p 2014	0.80	0.31	0.20	1.41
8	p 2015	0.32	0.32	-0.31	0.95
9	p 2016	0.42	0.32	-0.21	1.06
10	p 2017	0.00	0.43	-0.84	0.84
11	Ψ intercept	-8.44	2.67	-13.69	-3.20
12	Ψ 2009	1.79	1.00	-0.17	3.75
13	Ψ 2010	1.99	1.05	-0.08	4.05
14	Ψ 2011	0.47	0.74	-0.98	1.92
15	Ψ 2012	2.34	1.09	0.20	4.49
16	Ψ 2013	1.38	0.70	0.01	2.74
17	Ψ 2014	0.36	0.58	-0.77	1.49
18	Ψ 2015	-0.24	0.44	-1.10	0.63
19	Ψ 2016	0.00	0.46	-0.89	0.90
20	Ψ 2017	-1.19	0.54	-2.24	-0.13
21	P_{ws-1}	0.01	0.00	0.00	0.02
22	Mgmt	-0.32	0.19	-0.69	0.04
23	V_{15}	-0.11	0.08	-0.27	0.04
24	V_5	-0.01	0.01	-0.02	0.01

p: detection probability, Ψ: occupancy (presence) probability, P_{ws-1}: warm-season precipitation from the previous year, V: vegetation class according to NALCMS 2010, Mgmt: management status, cattle presence (1) or absence (0).

Table C14. Beta estimates of the fifth best-fitted model for bobcat occupancy (Ψ (yr+ P_{ws-1}+ Mgmt + V_{18})) on and around the Northern Jaguar Reserve in east-central Sonora, Mexico, from 2009-2018 using the single-season, single-species occupancy model.

Index	Label	Estimate	SE	LCI	UCI
1	p intercept	-3.55	0.25	-4.03	-3.06
2	p 2009	-0.34	0.56	-1.45	0.77
3	p 2010	0.29	0.39	-0.47	1.05
4	p 2011	-0.20	0.52	-1.21	0.81
5	p 2012	0.66	0.32	0.03	1.28
6	p 2013	0.31	0.33	-0.33	0.96
7	p 2014	0.80	0.31	0.20	1.41
8	p 2015	0.32	0.32	-0.30	0.95
9	p 2016	0.42	0.32	-0.21	1.05
10	p 2017	0.00	0.43	-0.85	0.84
11	Ψ intercept	-7.32	2.53	-12.28	-2.37
12	Ψ 2009	1.56	1.00	-0.41	3.53
13	Ψ 2010	1.59	1.01	-0.39	3.57
14	Ψ 2011	0.30	0.73	-1.14	1.73
15	Ψ 2012	1.92	1.04	-0.13	3.96
16	Ψ 2013	1.15	0.68	-0.17	2.48
17	Ψ 2014	0.19	0.56	-0.91	1.30
18	Ψ 2015	-0.22	0.44	-1.08	0.64
19	Ψ 2016	-0.05	0.45	-0.94	0.84
20	Ψ 2017	-1.13	0.53	-2.18	-0.08
21	P_{ws-1}	0.01	0.00	0.00	0.02
22	Mgmt	-0.38	0.18	-0.74	-0.02
23	V_{18}	-0.09	0.09	-0.27	0.09

p: detection probability, Ψ: occupancy (presence) probability, P_{ws-1}: warm-season precipitation from the previous year, V: vegetation class according to NALCMS 2010, Mgmt: management status, cattle presence (1) or absence (0).

Appendix D

Feline occupancy probabilities from 2009 to 2018.

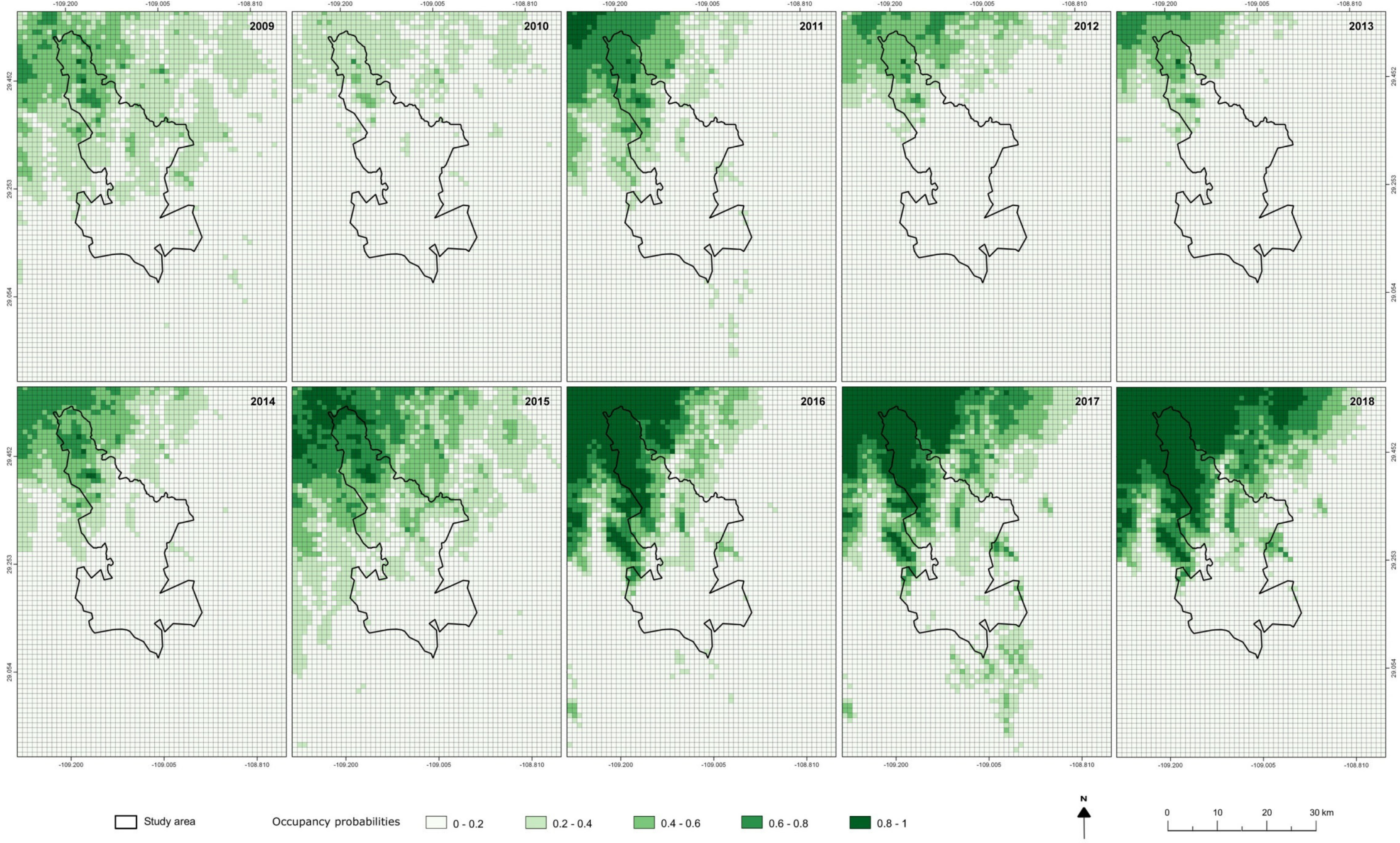


Figure D1. Jaguar occupancy probabilities 2009-2018 in the study area and extrapolated to the expanded study area of 4,000 km^2. Darker colors indicate higher probabilities.

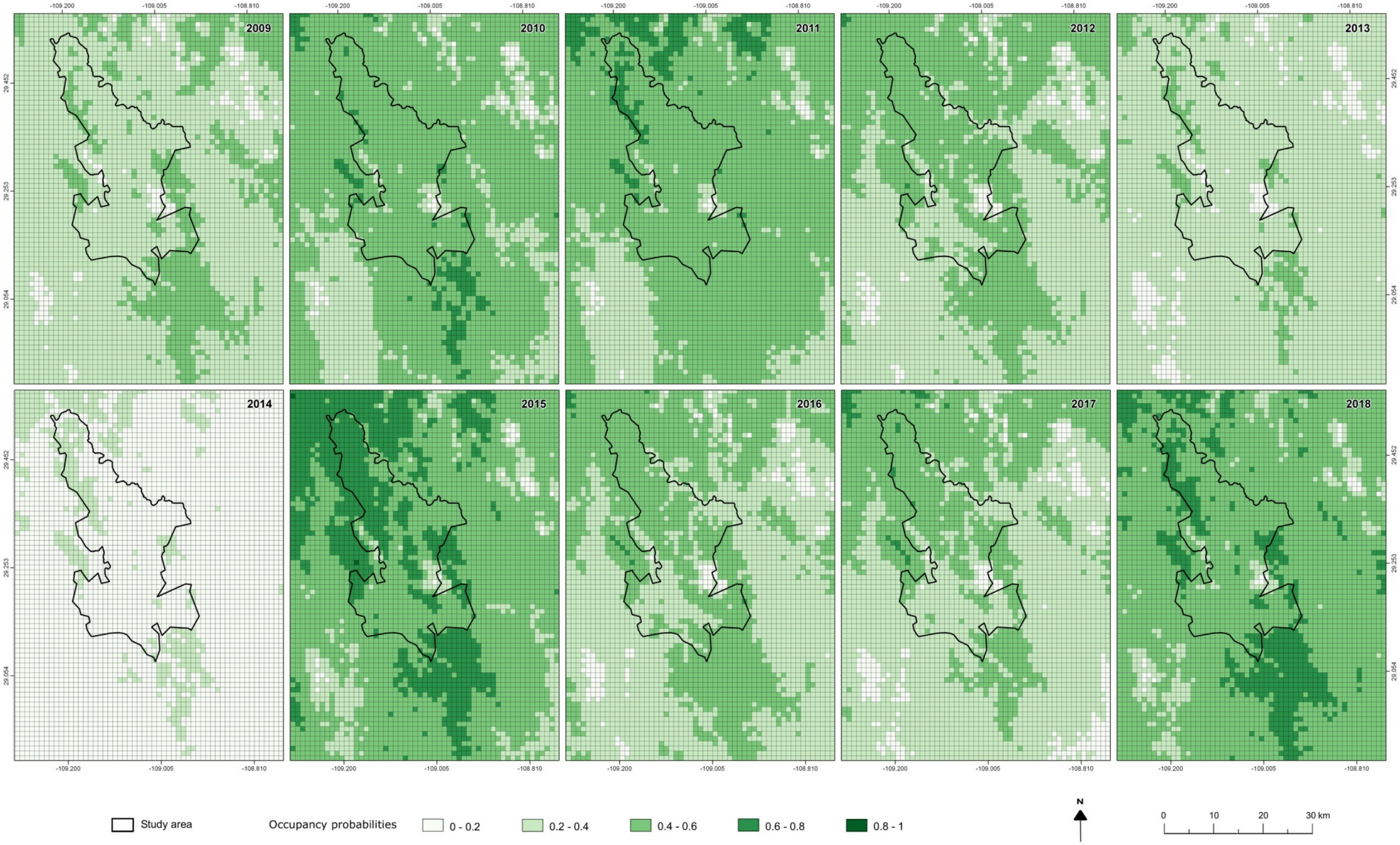


Figure D2. Mountain lion occupancy probabilities 2009-2018 in the study area and extrapolated to the expanded study area of 4,000 km^2. Darker colors indicate higher probabilities.

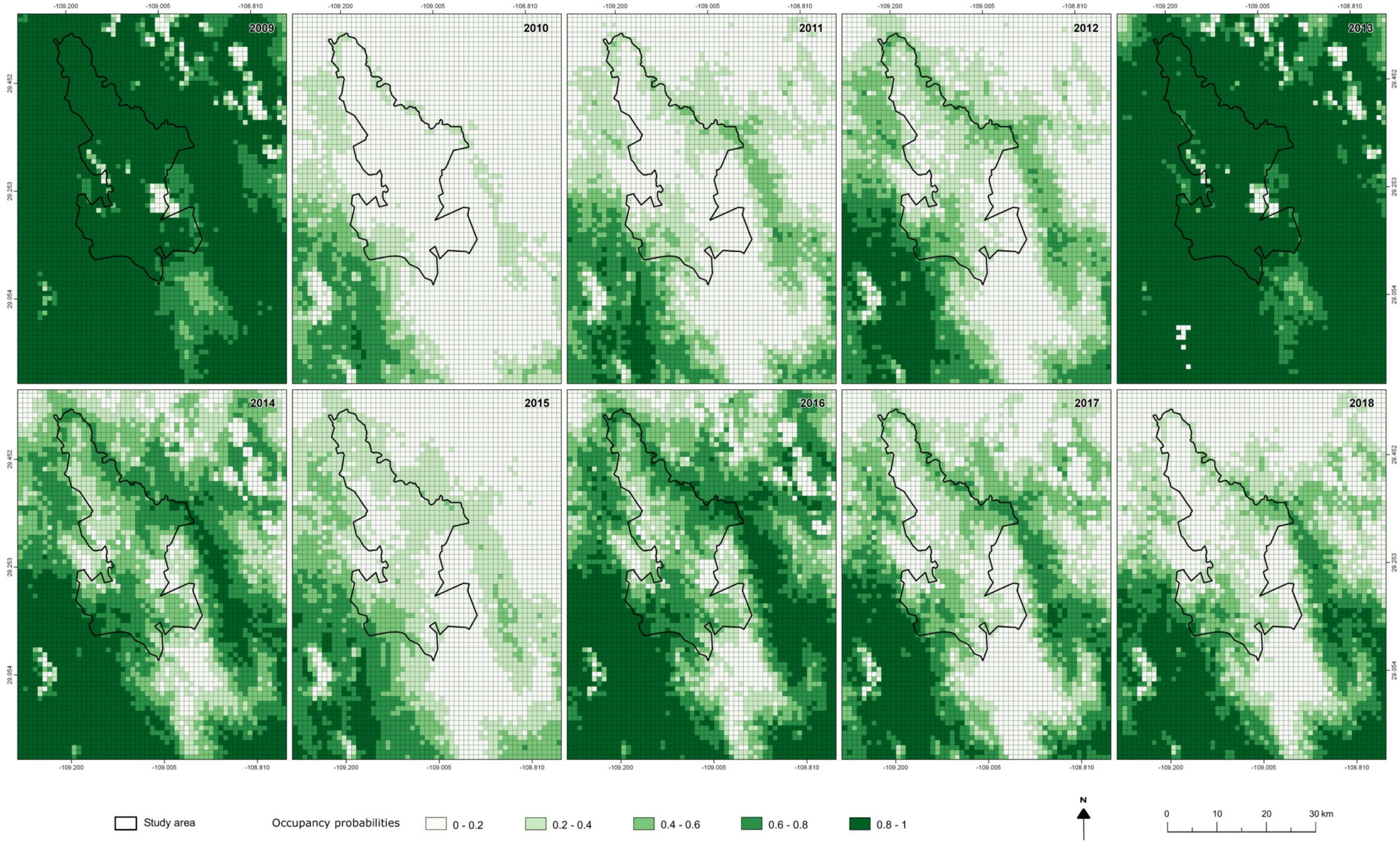


Figure D3. Ocelot occupancy probabilities 2009-2018 in the study area and extrapolated to the expanded study area of 4,000 km^2. Darker colors indicate higher probabilities.

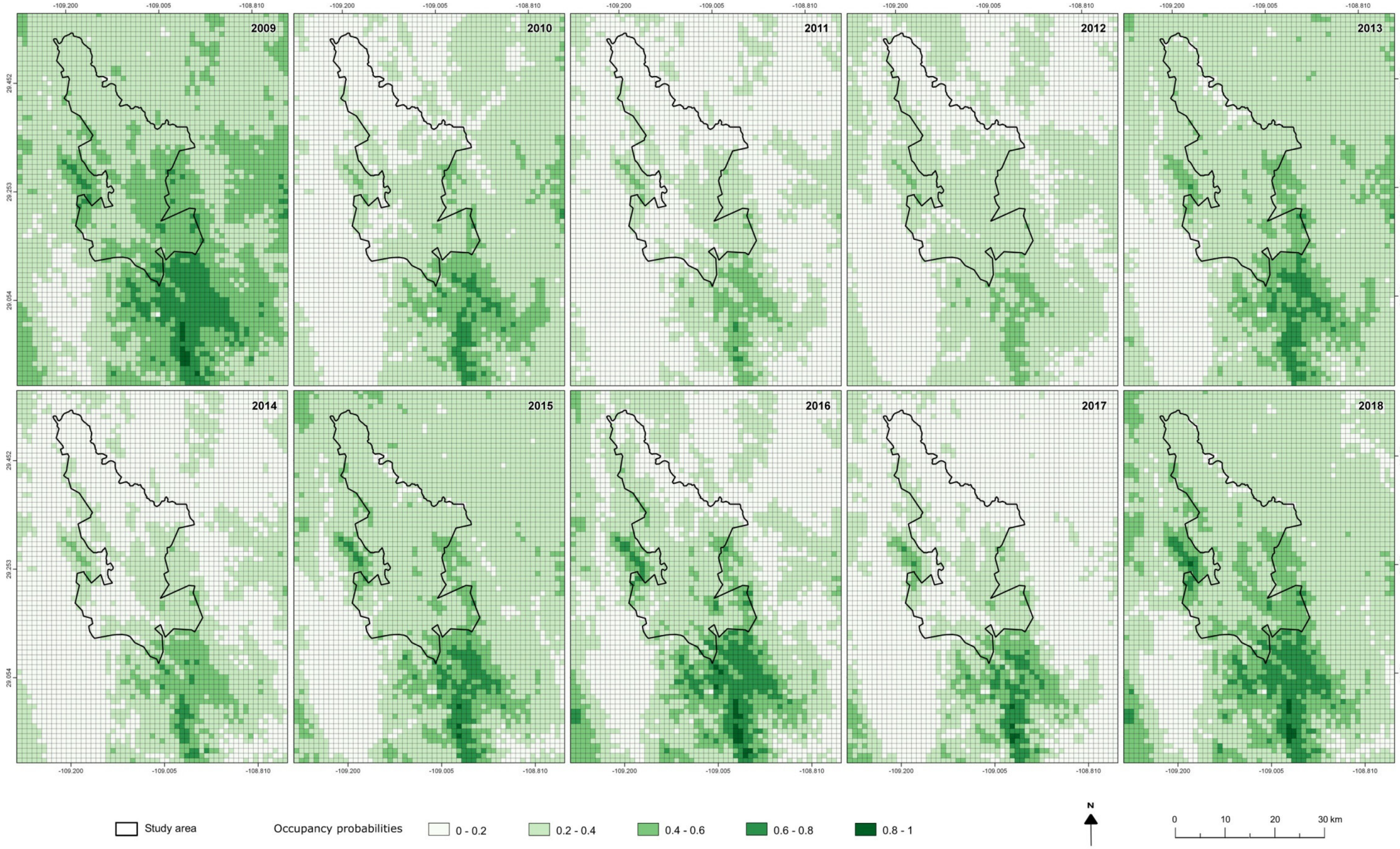


Figure D4. Bobcat occupancy probabilities 2009-2018 in the study area and extrapolated to the expanded study area of 4,000 km^2. Darker colors indicate higher probabilities.

Appendix E

Description of future estimated variation in weather attributes across the study area based on three General Circulation Models (GCMs; CNRM-CM5, CCSM, CanESM2-r11i1p1) at two greenhouse gas concentration trajectories or Representative Concentration Pathways (RCPs; 4.5 and 8.5).

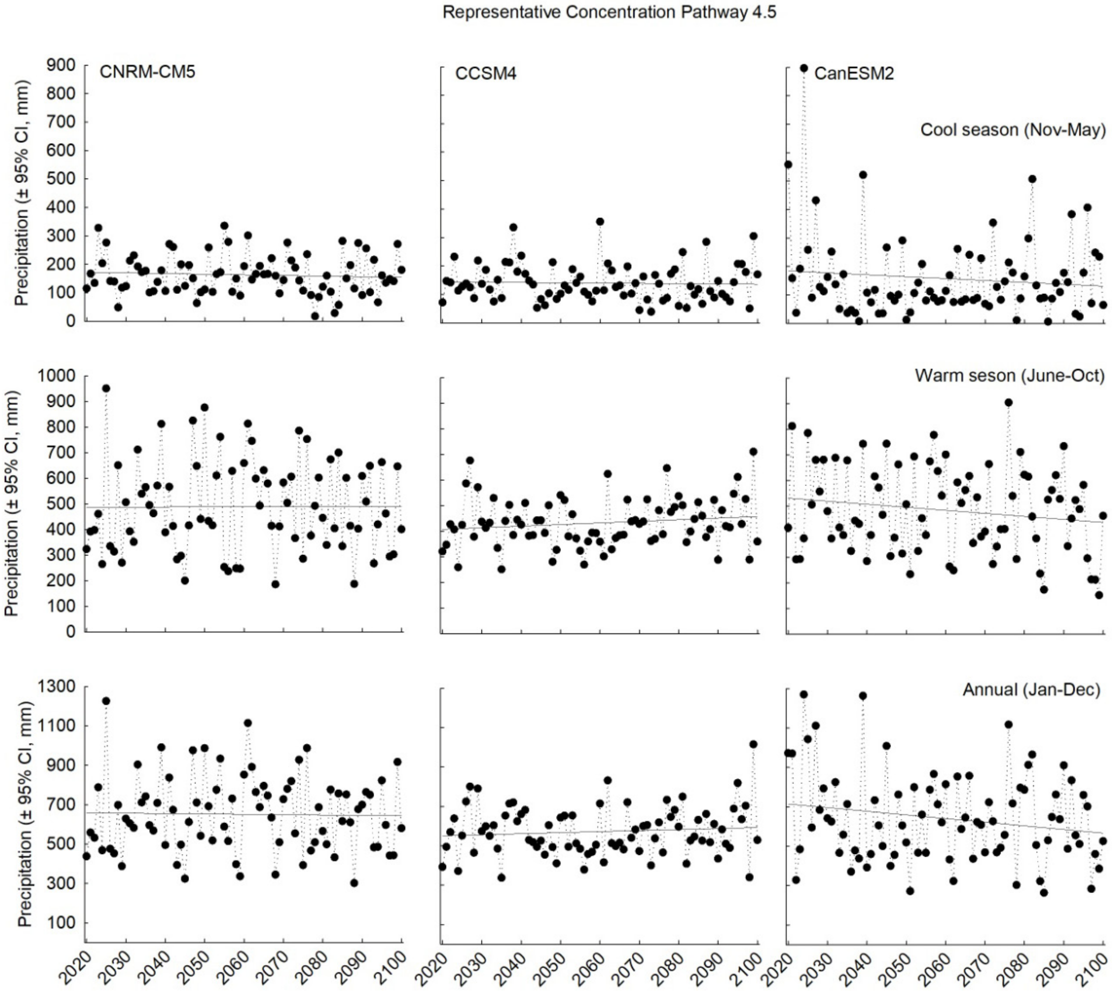


Figure E1. Trends and variation in estimated future precipitation across the study area between 2020-2100 in northwest Mexico. Estimates are for three different GCMs at RCP 4.5.

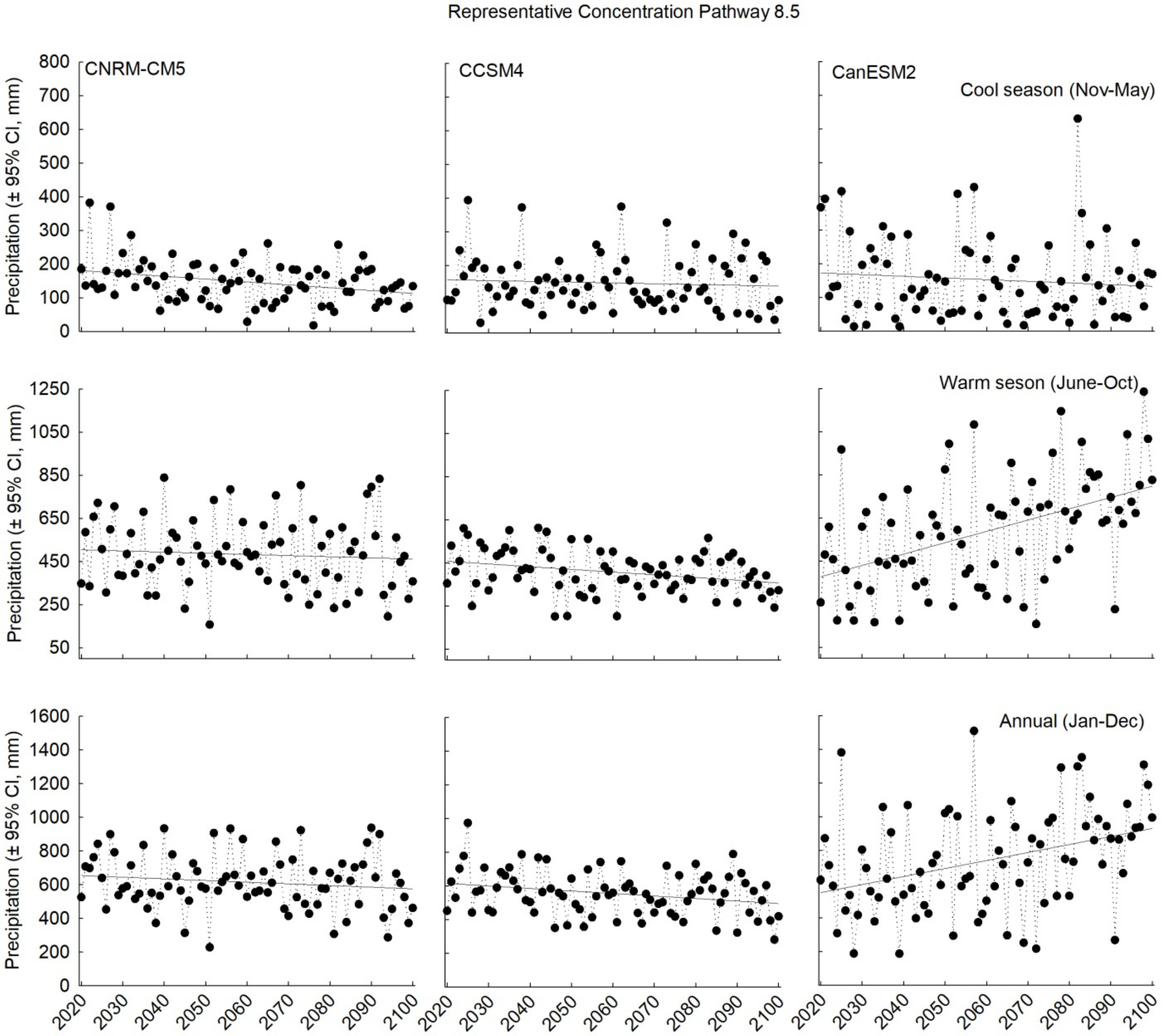


Figure E2. Trends and variation in estimated future precipitation across the study area between 2020-2100 in northwest Mexico. Estimates are for three different GCMs at RCP 8.5.

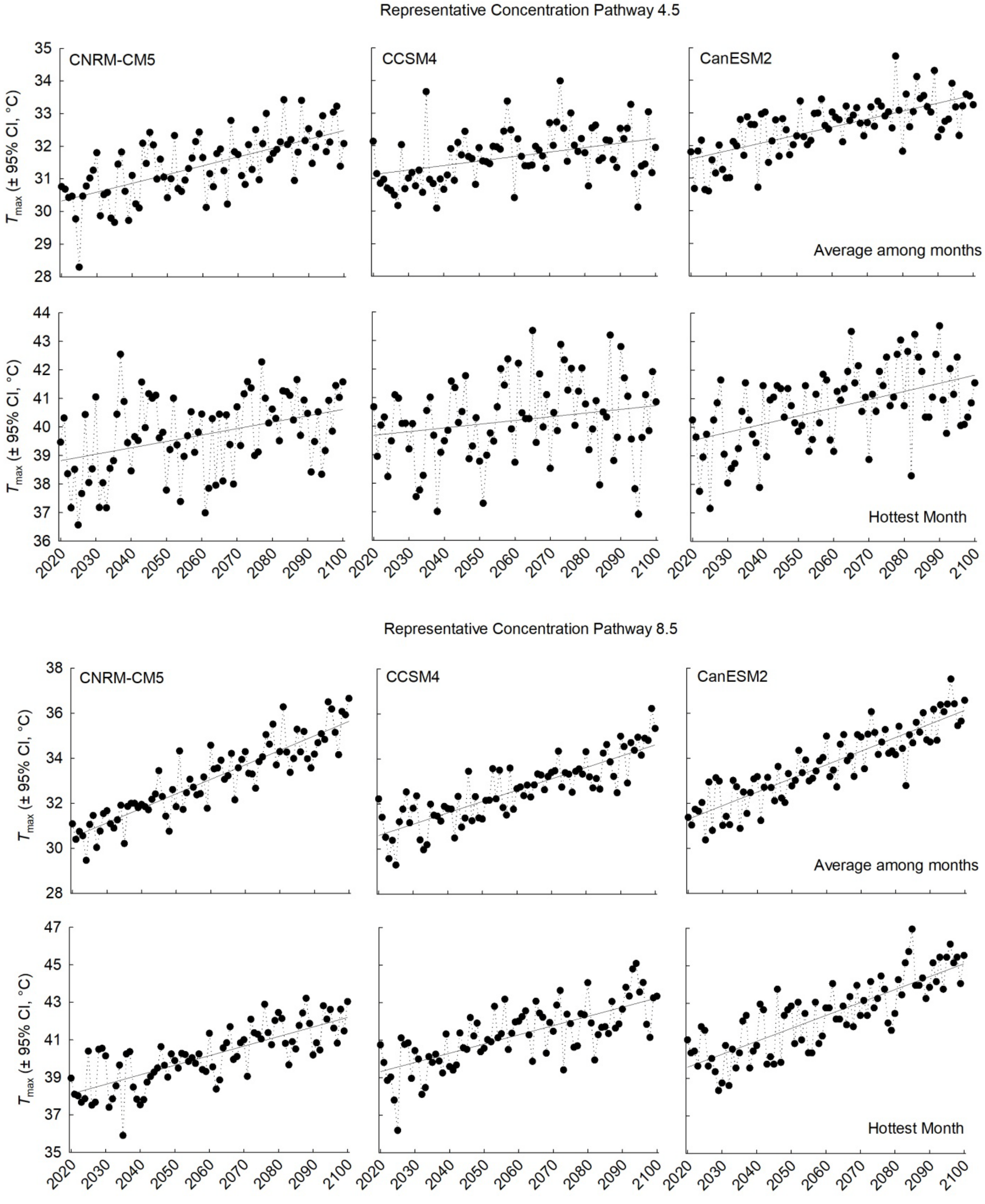


Figure E3. Trends and variation in estimated future mean maximum temperature across the study area between 2020-2100 in northwest Mexico. Estimates are for three different GCMs at RCP 4.5 (top) and 8.5 (bottom).

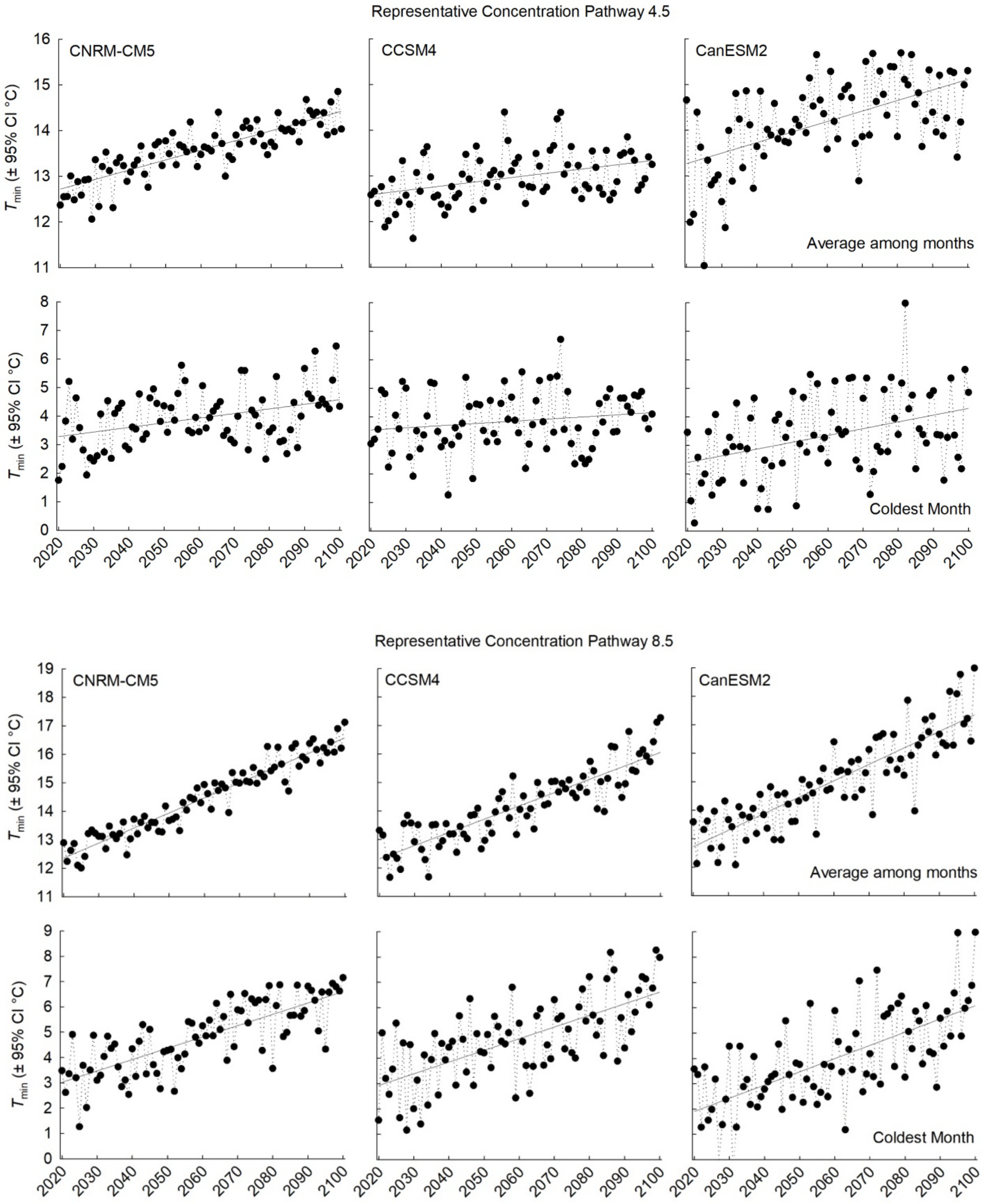


Figure E4. Trends and variation in estimated future mean minimum temperature across the study area between 2020-2100 in northwest Mexico. Estimates are for three different GCMs at RCP 4.5 (top) and 8.5 (bottom).

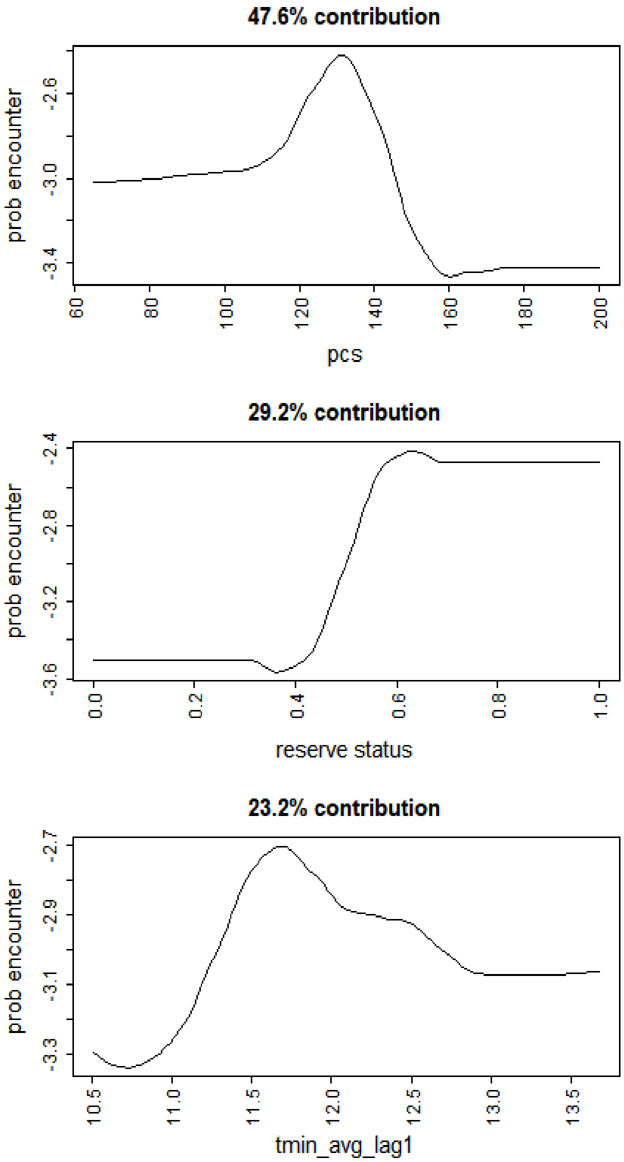
Table E1. Trends in anticipated future precipitation and temperature factors considered when assessing the effects of climatic variation on wild felids in east-central Sonora between 2020-2100. Trends are based on simple linear models of mean annual values from among 4,256 1 x 1 km sq. pixels across the study area. Weather values are from three Global Circulation Models (GCM) at the 4.5 greenhouse gas concentration trajectory or Representative Concentration Pathway (RCP).

GCM Factor (units) Period	Trend			
	Est.	SE	*t*	*P*
CNRM-CM5				
Precipitation (mm)				
Annual (calendar year)	-0.196	0.920	-0.21	0.83
Warm season (June-Oct)	0.025	0.855	0.03	0.98
Cool season (Jan-May, Nov-Dec)	-0.221	0.331	-0.67	0.51
Temperature - mean minimum (°C)				
Average among months	0.021	0.002	13.57	<0.0001
Coldest month	0.016	0.004	3.73	0.0004
Temperature - mean maximum (°C)				
Average among months	0.027	0.003	7.73	<0.0001
Hottest month	0.022	0.006	3.71	0.0004
CCSM4				
Precipitation (mm)				
Annual (calendar year)	0.520	0.589	0.88	0.38
Warm season (June-Oct)	0.631	0.449	1.41	0.16
Cool season (Jan-May, Nov-Dec)	-0.111	0.312	-0.36	0.72
Temperature - mean minimum (°C)				
Average among months	0.009	0.002	3.92	0.0002
Coldest month	0.008	0.005	1.57	0.12
Temperature - mean maximum (°C)				
Average among months	0.014	0.004	3.86	0.0002
Hottest month	0.013	0.007	1.95	0.055
CanESM2				
Precipitation (mm)				
Annual (calendar year)	-1.919	1.015	-1.89	0.062
Warm season (June-Oct)	-1.224	0.768	-1.59	0.11
Cool season (Jan-May, Nov-Dec)	-0.694	0.659	-1.05	0.30
Temperature - mean minimum (°C)				
Average among months	0.024	0.004	6.52	<0.0001
Coldest month	0.024	0.006	4.01	0.0001
Temperature - mean maximum (°C)				
Average among months	0.024	0.003	8.76	<0.0001
Hottest month	0.029	0.005	5.36	<0.0001

Table E2. Trends in anticipated future precipitation and temperature factors considered when assessing the effects of climatic variation on wild felids in east-central Sonora between 2020-2100. Trends are based on simple linear models of mean annual values from among 4,256 1 x 1 km sq. pixels across the study area. Weather values are from three Global Circulation Models (GCM) at the 8.5 greenhouse gas concentration trajectory or Representative Concentration Pathway (RCP).

GCM Factor (units) Period	Trend			
	Est.	SE	*t*	*P*
CNRM-CM5				
Precipitation (mm)				
Annual (calendar year)	-0.991	0.775	-1.28	0.21
Warm season (June-Oct)	-0.545	0.767	-0.71	0.48
Cool season (Jan-May, Nov-Dec)	-0.848	0.300	-2.83	0.0059
Temperature - mean minimum (°C)				
Average among months	0.053	0.002	28.62	<0.0001
Coldest month	0.045	0.004	10.78	<0.0001
Temperature - mean maximum (°C)				
Average among months	0.064	0.004	18.14	<0.0001
Hottest month	0.051	0.005	10.49	<0.0001
CCSM4				
Precipitation (mm)				
Annual (calendar year)	-1.489	0.608	-2.45	0.017
Warm season (June-Oct)	-1.261	0.458	-2.75	0.0073
Cool season (Jan-May, Nov-Dec)	-0.228	0.377	-0.61	0.55
Temperature - mean minimum (°C)				
Average among months	0.047	0.003	16.02	<0.0001
Coldest month	0.046	0.006	8.14	<0.0001
Temperature - mean maximum (°C)				
Average among months	0.050	0.004	13.75	<0.0001
Hottest month	0.049	0.005	8.99	<0.0001
CanESM2				
Precipitation (mm)				
Annual (calendar year)	4.754	1.352	3.52	0.0007
Warm season (June-Oct)	5.250	1.082	4.85	<0.0001
Cool season (Jan-May, Nov-Dec)	-0.496	0.569	-0.87	0.39
Temperature - mean minimum (°C)				
Average among months	0.058	0.004	15.14	<0.0001
Coldest month	0.052	0.006	8.04	<0.0001
Temperature - mean maximum (°C)				
Average among months	0.060	0.004	16.51	<0.0001
Hottest month	0.069	0.005	12.78	<0.0001

Appendix F



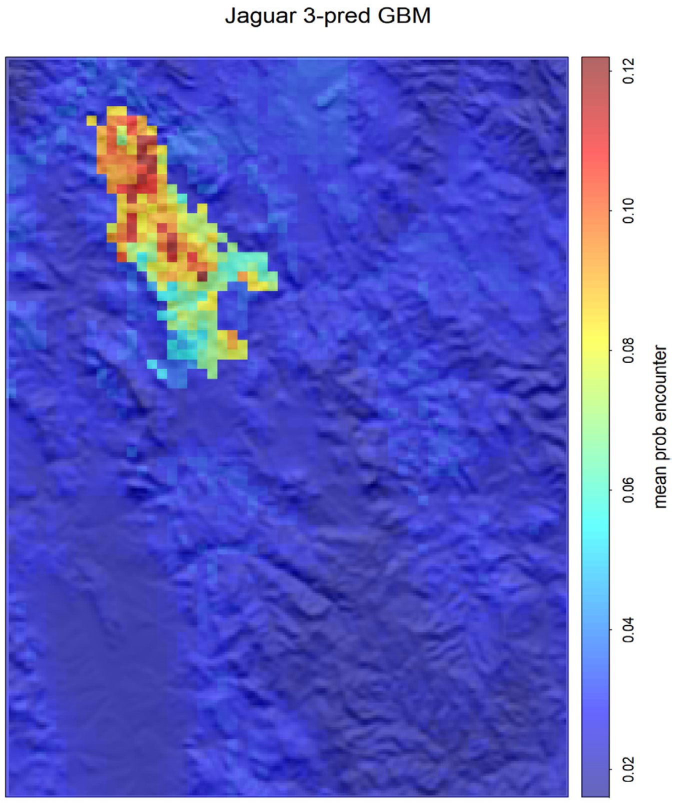
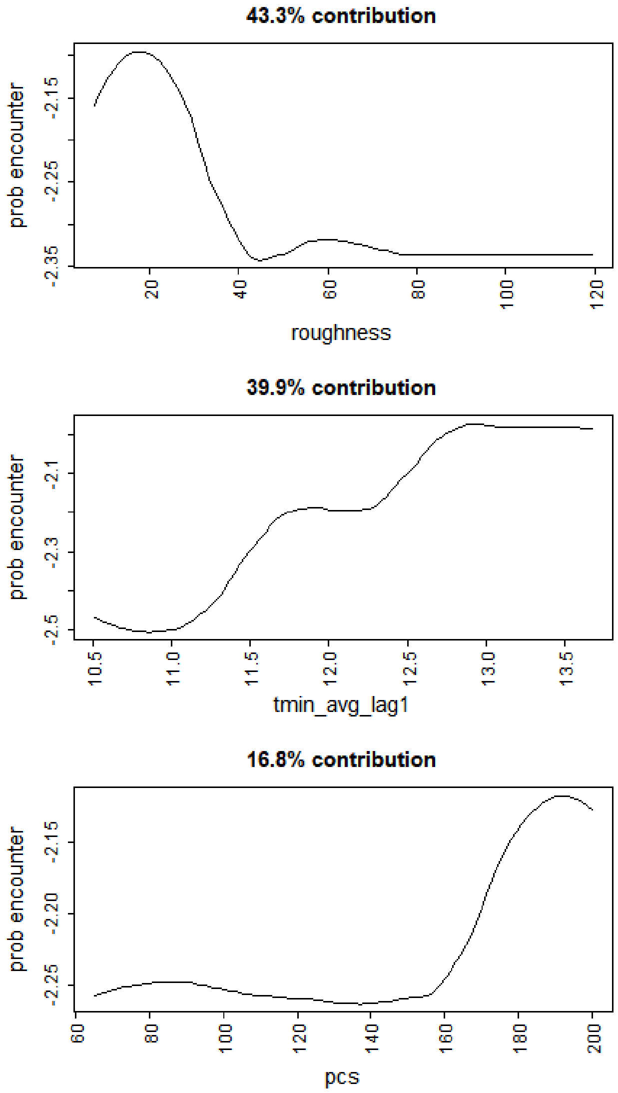


Figure F1: GBM response curves of the selected model for jaguar, and map of mean 2009-2018 predictions from the selected GBM for jaguar.



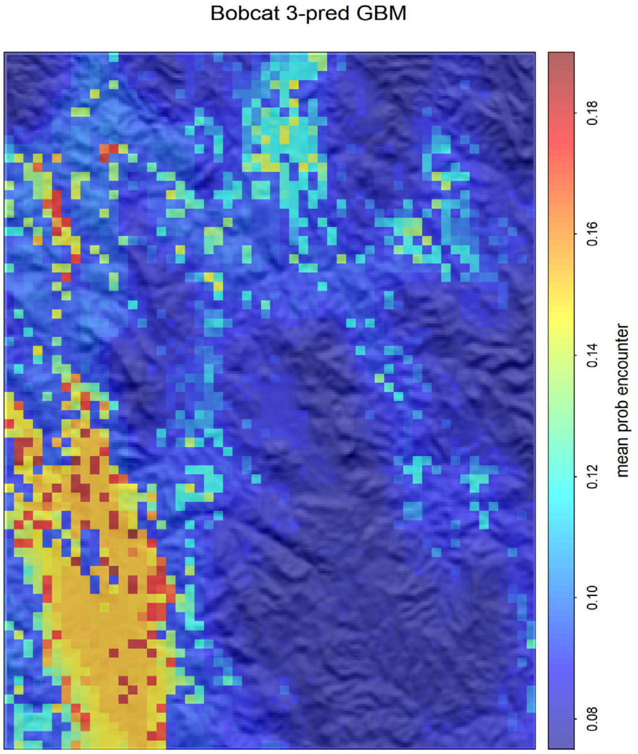


Figure F2. Response curves from the selected model for bobcat, and map of mean bobcat predicted probability of detection for 2009-2018.