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Abundance and home range of ocelot (*Leopardus pardalis*) in northwestern Mexico

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Abstract

In Mexico, information about ocelots is limited, which hinders the implementation of effective management and conservation measures. The purpose of this research was to provide basic information of population density, relative abundance and home range observed for the species in northwestern Mexico. Systematic sampling was implemented from January to December 2015 using photo-trapping as tool. Fifty-four camera-trap stations (37 double stations) were used, and the resulting grid covered an area of 182 km^2. We applied six sampling periods of 59-62 days in each period. Density analysis was based on spatially explicit models and traditional capture-recapture models. The home range was estimated using the minimum convex polygon method. We obtained 135 photographic records of ocelots, of which 17 individuals were identified (five males, four females and eight individuals of undetermined sex). During six study periods, our sampling effort reached 19 710 trap-days. We estimate a capture rate for the study of 6.84 rec./1000 trap-days. The density of ocelots estimated with the Capture module in the MARK program ranged from 1.38 to 2.93 rec./100 km^2. The results estimate using the SERC method showed a density of 0.93-3.06 individuals per 100 km^2. The ocelots in the Northern Jaguar Reserve (NJR) had an average distribution area of 14.1 km^2. The results of this research illustrate the importance of continuing studies of ocelots on the NJR to maintain a long-term viable population for northwestern Mexico.

Keywords
Camera traps; home range; *Leopardus pardalis*; neotropical cats; Northern Jaguar Reserve; spatially explicit mark-recapture

Introduction

The ocelot (*Leopardus pardali*; Murray & Garner, 1997) is the third largest cat out of the 10 species that inhabit the Neotropical region and is one of the six species of wild cats in Mexico. Historically, the ocelot was found from the southern United States, including Mexico and Central America, to northern Argentina and Uruguay (Oliveira, 1994; Sunquist & Sunquist, 2002; Aranda et al., 2005; Oliveira & Cassaro, 2005). In Mexico, it is distributed along the Pacific and Gulf of Mexico coasts, in eastern Mexico from Tamaulipas to Tabasco and the Yucatan peninsula in western Mexico, from Sonora (López-González et al., 2003) toward the south of the state of Chiapas, and in Central Mexico in Balsas Basin (Murray & Gardner, 1997; Monroy-Vilchis et al., 2019). There are recent records in Zacatecas and Aguascalientes (Bárcenas & Medellín, 2010; Valdez-Jiménez et al., 2013), and it has been reported that 38% of the Mexican territory has potential habitat for this species (Monroy-Vilchis et al., 2019). Ocelot populations declined in the 20th century (between 1950 and 1980) due to international demand for their fur (Nowell & Jackson, 1996; Murray & Gardner, 1997; Sunquist & Sunquist, 2009). Ocelot is listed in appendix 1 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and as of least concern in the IUCN redlist (Oliveira et al., 2015); in Mexico it is in danger of extinction (SEMARNAT, 2010). The main threats are illegal hunting and habitat loss and/or habitat fragmentation (Sunquist & Sunquist, 2002; López-González, 2003; Aranda et al., 2005; Amador-Alcalá et al., 2013). The conservation of this feline is important, as it contributes to shape the ecological niche of small and medium prey (Oliveira, 1994; Leopold, 2000; Sunquist & Sunquist, 2002). A fundamental strategy for ocelot conservation is to generate information on its population dynamics, prey availability and its habitat quality (Krebs, 1999; Garshelis, 2000; Walker et al., 2000).

Information on the ocelot in Mexico has increased, mainly on its distribution and potential habitat (Pozo de la Tijera & Escobedo-Cabrera, 1999; Grigione et al., 2001; Sánchez et al., 2002; Servín et al., 2003; Lorenzana Piña et al., 2004; Iglesias et al., 2008; Bárcenas & Medellín, 2010; Ramírez-Bravo et al., 2010; Martínez-Calderas et al., 2011; Ahumada-Carrillo et al., 2013; Hernández-Flores et al., 2013; Sánchez Hernández et al., 2013; Galindo-Aguilar et al., 2016; García-Bastida et al., 2016; Monroy-Vilchis et al., 2019), although some studies deal on its density, activity pattern and diet (Martínez-Hernández et al., 2014; Pérez-Irineo & Santos-Moreno, 2014; Martínez-Calderas et al., 2015; De la Torre et al., 2016; Torres-Romero et al., 2017). Particularly in northern Mexico there is little knowledge about ocelot populations, making their management and conservation difficult. The objective of this study was to generate information on the population density, relative abundance, and home range in the northwest of Mexico, in the Northern Jaguar Reserve (NJR); this reserve was created with the purpose of preserving wild cat populations.

Materials and methods

The study area is in northern Mexico in the State of Sonora (fig. 1). Its surface is 19 986 ha. The altitude varies from 370 to 1600 meters above sea level. The climate is predominantly semi-arid–semi-warm, with an average annual average temperature of 18°C (from −3 to 48°C; CONABIO, 1992/2004). The NJR presents high floristic diversity; its main plant communities are thorny scrub with species such as: *Lysiloma watsonii* and *Prosopis velutina* (Penington & Sarukhan, 2005). The tropical subdeciduous forest has species such as: *Bursera* spp., *Ipomoea arborescens* and *Ceiba acuminata*. Oak forest is found at more than 1000 meters above sea level, where: *Quercus arizonica* and *Q. emoryi*, *Q. viminea*, *Q. tuberculata* and *Q. albocincta* predominate. The wildlife in the area includes 59 species of mammals; in addition to the ocelot there are other felids such as jaguar (*Panthera onca*), bobcat (*Lynx rufus*) and puma (*Puma concolor*); other mammals are white-tailed deer (*Odocoileus virginianus*), collared peccary. (*Pecari tajacu*) and hare (*Lepus alleni*; Gutiérrez-González et al., 2012). There are 214 species of birds, such as the

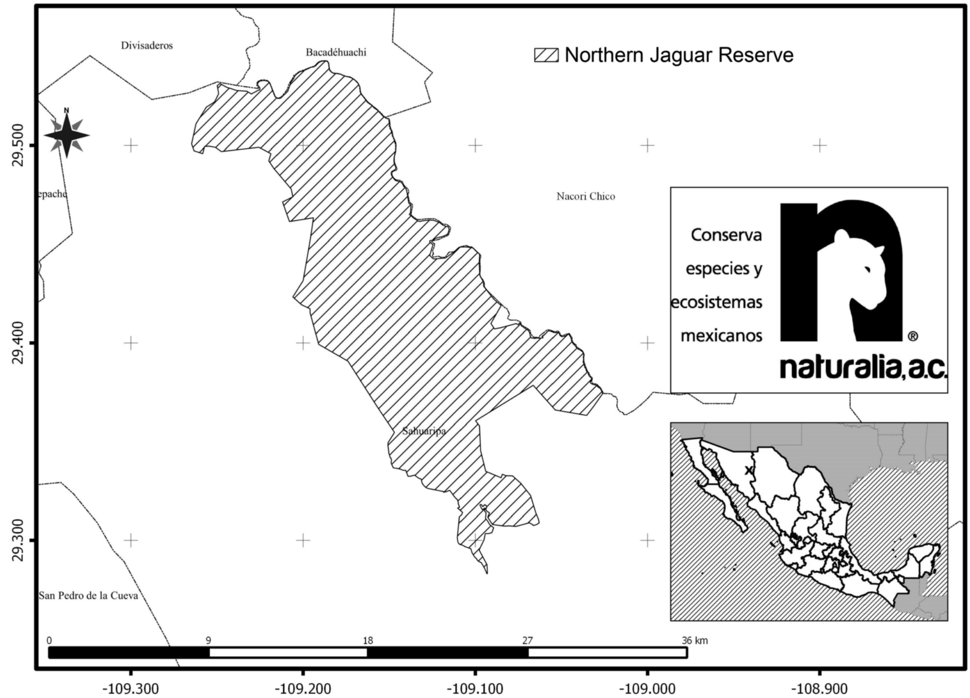

Figure 1. Location of the NJR.

golden eagle (*Aquila chrysaetos*), bald eagle (*Haliaeetus leucocephalus*) and the green macaw (*Ara militaris*; Flesch et al., 2015) to mention some. The herpetofauna presents 41 species; 10 amphibians and 31 reptiles (Rorabaugh et al., 2011).

Sampling design

A systematic photo-trapping sampling (Chávez et al., 2013) was carried out with Cuddeback (Parks Falls, WI, USA) camera traps (digital and Attak) and Stealth Cam (StealthCam LLC, Grand Prairie, TX, USA). Six sampling periods were carried out (from January to December 2015) with 54 stations of which 37 stations had double camera sets. The study comprised approximately 182 km^2, calculated through the convex minimum polygon method, considering the location of the camera traps (fig. 2). Each of the six sampling periods ranged from 59 to 62 days, as in other studies involving felids (Karanth & Nichols, 1998; Trolle & Kéry, 2003; Silver, 2004; Maffei et al., 2005; Di Bitetti et al., 2006; Dillon & Kelly, 2007; Monroy-Vilchis et al., 2011). Each period was considered as a sampling event and a demographically closed population was assumed (Seymour, 1989; Karanth & Nichols, 1998; Trollé et al., 2007). The cameras were installed approximately 50 cm from the ground, attached to tree stumps or stakes. The cameras were programmed to remain active 24 hours a day and were checked every 30 days to replace

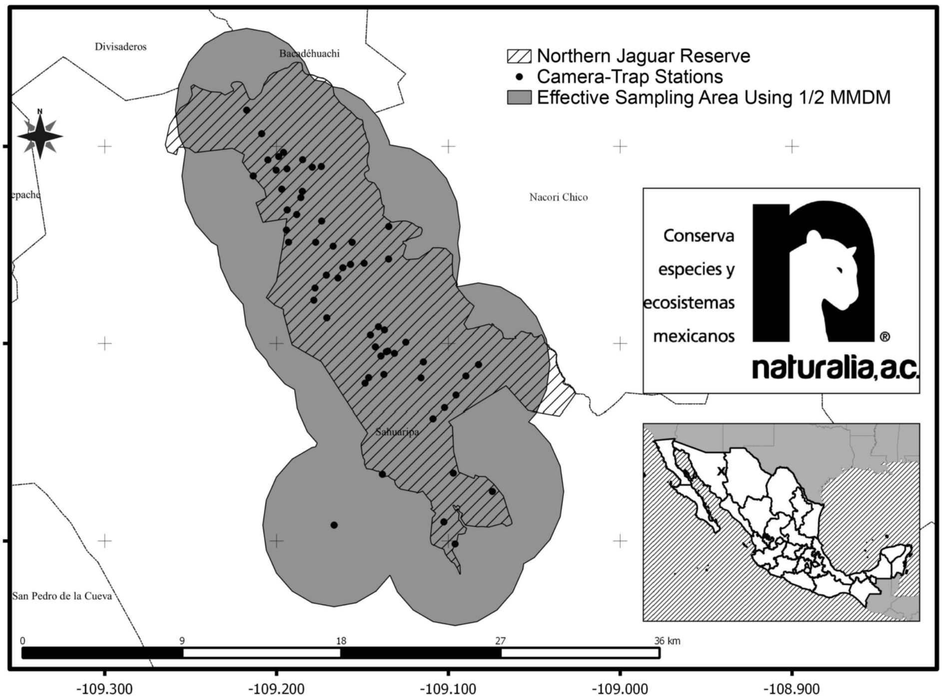

Figure 2. Distribution of camera-trap stations along the NJR. MMDM, maximum mean distance of movement.

batteries, memory cards, and for maintenance. Ocelot individuals were identified by their unique fur, noting the particular pattern of their rosettes. After the identification, each specimen was assigned a name and a code. Subsequently, a capture history matrix per individual was developed (MacKenzie et al., 2002; Trolle & Kéry, 2003).

Estimation of abundance

We calculated the relative abundance index (RAI) with the formula suggested by Maffei et al. (2002) and Sanderson (2004): $\text{RAI} = (C/\text{EM}) \times 1000$ days/trap, where C is the number of independent photographic records; EM is the total sampling effort (number of camera traps multiplied by days of sampling) and the frequency of capture standardized at 1000 days/trap). To avoid overestimations, only independent records were considered. An independent record was considered if: (1) it was not possible to identify the ocelot as a distinct individual in consecutive photographic records; (2) consecutive photographic records were made of different individuals; and (3) photographic records with several individuals were made, in which case every animal was considered one event.

Density estimation

With the use of the Capture module included in the MARK program (Colorado State University, Fort Collins, CO, USA), a capture probability (P) was generated for a closed population, making two assumptions: (1) the population must be closed; and (2) all individuals have the same capture probability (Silver, 2004). To select the model that best fits the data, the one with a value closest to 1 was chosen (the value varies from 0 to 1). Subsequently, the ocelot density was estimated by dividing the relative abundance by the effective sampling area. This was constructed from the convex minimum polygon method (Kernohan et al., 2001), by including all the sampling stations that were at the limits and adding a buffer area to this. The buffer area corresponds to the maximum mean distance of movement (MMDM) traveled by ocelots that were recorded at two or more stations. The density calculated by the previous method presents additional sources of variability generated by the probability of capture associated with the location of the animal with respect to the cameras (Foster & Harmsen, 2012). Therefore, and with the purpose of having more precise estimates, the density was determined based on the spatially explicit capture-recapture model (SERC) with the DENSITY 5.0 program (University of Otago, Dunedin, New Zealand; Efford et al., 2004). DENSITY 5.0 uses data from each organism's detection locations, camera traps, and capture histories to fit a spatial model of the detection process. Inverse predictions (IP SERC) and maximum likelihood (ML SERC) are alternative models to fit the initial spatial detection model (Efford et al., 2004; Borchers & Efford, 2008). In this study, the density was calculated using the ML SERC model, a maximum likelihood approximation which assumes a Poisson distribution, and we used a buffer considering the average home range of the ocelot estimated in this study. Three detection functions were contrasted: Average-Normal, Negative Exponential and Hazard, and three capture probabilities ($g0$): $g0(\cdot)\sigma(\cdot)$, where all individuals have the same capture probability; $g0(b)\sigma(\cdot)$, where individuals show a behavioral response after the first capture; and $g0(h2)\sigma(\cdot)$, where individuals show heterogeneity in the probability of capture.

Home range

The home range was estimated for four ocelots (three males and one female), which were recorded in more than two sampling sites, considering the method of the convex minimum polygon (Kernohan et al., 2001). The estimates of area of activity and overlap were made using all detections and through the convex minimum polygon method – PMC (Mohr, 1947). The individual home range was considered as that in which the individuals carry out their daily activities of feeding, moving and caring for young (Maffei & Taber, 2003).

Results

We obtained 135 photographic records; 128 of these were used for this analysis. Seventeen individuals were identified, five males, four females and eight unidentified individuals. The sampling effort was 19 710 camera-days, the period with the greatest sampling effort was from July to August with 3348 camera-days. The total RAI was 6.84 rec./1000 camera-days, the months with the highest RAI were March and April with 10.62 rec./1000 camera-days (table 1). The estimated ocelot density in the NJR ranged from 1.38 to 2.93 ind./100 km^2, and the average of the maximum travel distances was 3362 m (2208-4741 m). The density models that best fit the data were: the heterogeneity $M(h)$ and the $M(o)$, the latter assuming that the probability of capture is the same for everyone (table 2). With the SERC method, the density was between 0.90 and 3.06 ind/100 km^2; the $g0(\cdot)\sigma(\cdot)$ model was superior

Table 1.
Ocelot (*Leopardus pardalis*) relative abundance indices (RAI) at the Northern Jaguar Reserve, Sahuaripa, Sonora, during the 2015 period.

Sampling period	Records	Sampling effort (trap-days)	RAI (records/camera trap-days × 1000)
January-February	20	3186	6.22 (± 0.90)
March-April	35	3294	10.62 (± 0.69)
May-June	28	3294	8.50 (± 0.78)
July-August	19	3348	5.67 (± 0.95)
September-October	11	3294	3.33 (± 1.24)
November-December	22	3294	6.67 (± 0.88)

Table 2.
Ocelot (*Leopardus pardalis*) densities estimated from the capture-recapture method using CAPTURE + MMDM (mean maximum distance moved) in the Northern Jaguar Reserve, Sonora in 2015.

Biomonthly period*	ESA (km^2)	Density (SE)	Selecting model	CP	Closed population test
I	381	2.09 (0.33)	$M(o)$	0.03	$Z = 0.590$; $P = 0.722$
II	251	2.78 (0.21)	$M(o)$	0.05	$Z = -1.044$; $P = 0.148$
III	379	1.84 (0.12)	$M(o)$	0.05	$Z = 0.634$; $P = 0.736$
IV	504	1.38 (0.41)	$M(h)$	0.03	$Z = -1.123$; $P = 0.130$
V	347	1.72 (0.74)	$M(h)$	0.02	$Z = -0.695$; $P = 0.243$
VI	340	2.93 (0.36)	$M(o)$	0.03	$Z = -0.070$; $P = 0.471$

ESA, effective sampling area; $M(o)$, same capture probability; $M(h)$, heterogeneity of capture probabilities; CP capture probability. Density: ind./100 km^2. *I, January-February; II, March-April; III, May-June; IV, July-August; V, September-October; VI, November-December.

to the other models according to the adjusted Akaike information criterion (AIC; table 3).

The ocelot presented an average home range of 14.1 km^2 in the NJR; for males it was 17.11 km^2 and for females 5.05 km^2 (table 4). Male 2 presented the largest activity area with 37 km^2 whereas male 4 had the smallest with 1.24 km^2 (fig. 3).

Table 3.
Densities of ocelots (*Leopardus pardalis*) individuals/100 km^2 estimated through spatially explicit models with the DENSITY program in the Northern Jaguar Reserve, Sonora in 2014-2015. AICc, adjusted Akaike information criterion, AIC ωi, Akaike weight.

Period[1]	Model[2]	AICc	AIC ωi	Density (SE)
I	HN $g0(\cdot)\sigma(\cdot)$	263.89	0.58	2.24 (1.14)
	EN $g0(\cdot)\sigma(\cdot)$	264.57	0.41	1.95 (1.19)
II	HN $g0(\cdot)\sigma(\cdot)$	350.69	0.71	1.99 (0.82)
	EN $g0(\cdot)\sigma(\cdot)$	352.69	0.26	1.76 (0.77)
III	HN $g0(\cdot)\sigma(\cdot)$	360.78	0.50	1.89 (0.82)
	EN $g0(\cdot)\sigma(\cdot)$	360.86	0.48	1.97 (0.88)
IV	HN $g0(\cdot)\sigma(\cdot)$	285.06	0.71	0.90 (0.51)
	EN $g0(\cdot)\sigma(\cdot)$	286.90	0.28	0.80 (0.49)
V	HN $g0(\cdot)\sigma(\cdot)$	184.57	0.52	2.01 (1.77)
	EN $g0(\cdot)\sigma(\cdot)$	181.81	0.46	2.34 (2.37)
VI	HN $g0(\cdot)\sigma(\cdot)$	324.01	0.61	3.06 (1.08)
	EN $g0(\cdot)\sigma(\cdot)$	325.50	0.29	2.86 (1.06)

[1] I, January-February; II, March-April; III, May-June; IV, July-August; V, September-October; VI, November-December.

[2] Detection function: HN, half normal; EN, negative exponential; model $g0(\cdot)\sigma(\cdot)$: all individuals have the same capture probability.

AICc: adjusted Akaike information criterion; AIC ωi: Akaike weights.

Table 4.
Estimates of home range of ocelot (*Leopardus pardalis*) male and female individuals, this survey versus others research in Mexico.

Location	Individuals (♂, ♀ in km^2)	Method	Author
Sonora	37.0-5.05	Photo-trapping	*This survey study
Quintana Roo	4.63-1.8	Photo-trapping	Torres-Romero et al. (2017)
Jalisco	5.23-5.68	Telemetry	Martínez-Meyer (1997)

*Individuals that presented the maximum dispersion (superficial extension) in their home range estimated in this survey.

Discussion

Photo-trapping is a technique widely used as a non-invasive method to estimate the density and abundance of wild cats such as jaguar, puma and ocelot (Maffei et al., 2005; Di Bitetti et al., 2006; Dillon & Kelly, 2007; Monroy-Vilchis et al., 2011); however, a debate of the precision of the results is ongoing (Dillon & Kelly, 2007). One deficiency is the overestimation of the density when using $\frac{1}{2}$MMDM as a buffer to calculate the effective sampling area, which is why in this study we

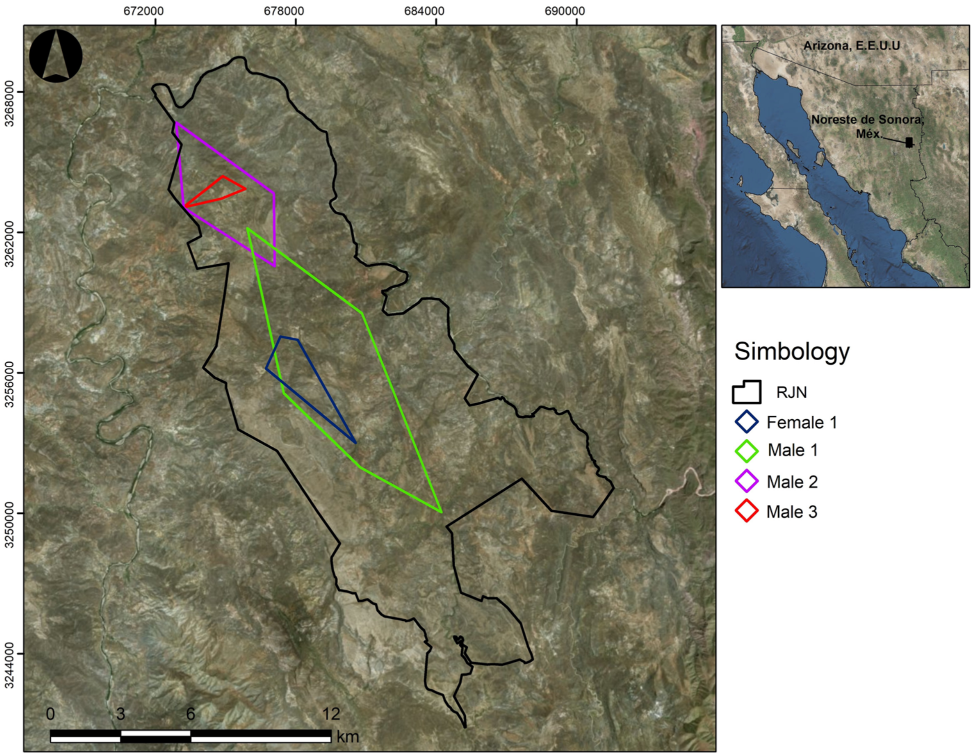

Figure 3. Home range of ocelots in the NJR.

used the MMDM (Soisalo & Cavalcanti, 2006; Maffei & Noss, 2008; Maffei et al., 2011). Another aspect to consider is the effective sampling area covered by the cameras, which, in other studies, is small and less than the activity areas of the species of interest. In this study, 182 km^2 were covered, which is greater than the area of activity found for ocelot; in addition, it is greater than that of previous studies such as Dillon & Kelly (2008; 80 km^2); Kolowski & Alonso (2010; 22 km^2); González-Maya & Cardenal-Porras (2011; 77.45 km^2); Martínez-Hernández et al. (2014; 87 km^2); Pérez-Irineo & Santos-Moreno (2014; 22 km^2); De la Torre et al. (2016; 82 km^2); Torres-Romero et al. (2017; 81 km^2). In this study two models were used (SERC and CR), because the SERC models are more robust when few individuals and few recaptures are registered, compared to traditional models (Gopalaswamy et al., 2012; Tobler & Powell, 2013). However, the density estimates calculated with CR from data generated in large sampling areas, as in this study, are like those obtained with DENSITY (Noss et al., 2012).

The present study presented ocelot's relative abundance with a low variation (6.8 $\pm$ 2.27) in most of the six sampling periods (table 1). These RAIs are lower than those obtained in a tropical subdeciduous forest (20.5 reg./1000 camera-days; Ávila-Nájera et al., 2015) and in a tropical deciduous forest (39-57 reg./1000 camera-days; Monterrubio-Rico et al., 2017). The difference may be because of a smaller sampling area in those studies; because a smaller sampling area can increase the density of the cameras, thus, increasing the recapture rate by altering the abundance and density values (Monroy-Vilchis et al., 2009). Maffei & Noss (2008), mention that, to increase the probability of capturing rare species such as ocelots, it is always better to cover a larger sampling area with a high sampling effort.

Another possible explanation for the variation in values may be the ecological, anthropic or historical factors related to the geographic origin of the species of interest. Two types of vegetation, tropical subdeciduous forest and tropical deciduous forest are environments related to the geographic origin and natural history of the ocelot (tropical environments) unlike temperate forests. However, some sites with conditions more related to the origin of the species have a lower capture rate than this study as in the tropical evergreen and subevergreen forests of Oaxaca where Lira-Torres & Briones-Salas (2012) obtained values of 2.67 reg./1000 camera-days. This may be due to factors such as the intensity of anthropic activities in the study areas (habitat fragmentation and/or hunting). The present study was carried out in a private protected natural area, while the other study was carried out in an open area with greater anthropic disturbance.

Likewise, the RAI estimates in this study are different from those reported in other sites with similar types of vegetation, such as the case of southeast Mexico where RAIs of 1.85 rec./1000 camera-days were calculated in an area of 81 km^2 and with a sampling effort of 2160 days/trap (Torres-Romero et al., 2017). Monterrubio-Rico et al. (2017), in two unprotected areas of central Mexico, obtained 40.7 rec./1000 camera-days with an effort of 4648 camera-days. The samplings of Monterrubio-Rico et al. (2017) and Torres-Romero et al. (2017) installed

29 and 27 stations respectively, the distance between each station was 0.5 to 4 km, and the sampling periods were in selected seasons (dry and rainy season), in contrast to our study that covered a full year of sampling, with 54 camera-trap stations. Furthermore, Pérez-Irineo & Santos-Moreno (2014), in southern Mexico reported 12 rec./1000 camera-days with a coverage of 22 km^2 and a sampling effort of 8529 trap-days. These differences may be related to methodological factors, such as the abundance and density of sampling stations, days/trap and sampling season (rainy or dry).

The maximum density of ocelot estimated in this study was 3.06 ind./100 km^2; higher densities have been documented in other regions, such as in San Luis Potosí (tropical deciduous forest; Martínez-Hernández et al., 2014), Chiapas (tropical evergreen forest; Ávila-Nájera et al., 2015) and Quintana Roo (subdeciduous tropical forest; De la Torre et al., 2016) where it is estimated as 8-14, 20 and 14 ocelots/100 km^2, respectively. Also, the density in the NJR is lower than that obtained by Haines et al. (2006) in Central America, 30/100 km^2 (tropical scrub); Moreno & Bustamante (2007), 67/100 km^2 (tropical evergreen forest); Dillon & Kelly (2007), 26/100 km^2 (high evergreen forest); Bustamante (2008), 18/100 km^2 (evergreen tropical forest); and by Salom-Pérez et al. (2007), 24 ocelots/100 km^2 (high evergreen forest). However, it is like those calculated in the pine forests of Belize (2.3-3.8 ind./100 km^2; Dillon & Kelly, 2007), in subdeciduous forests of Brazil (4 ind./100 km^2; Goulart et al., 2009) and in other ecosystems (subtropical scrub, tropical deciduous forest, pine-oak forest) in the state of Sonora (López-González et al., 2003).

This study strengthens the idea that ocelot densities decrease as precipitation decreases and the distance to the equator increases. Regions close to the equator with high primary productivity and higher rainfall have a higher abundance of ocelot (Carbone & Gittleman, 2002; Karanth & Nichols, 2002; Di Bitetti et al., 2008; Huston & Wolverton, 2009; Kolowski & Alonso, 2010; Oliveira et al., 2010; Hatton et al., 2015).

The ocelot is a meso-predator associated with consolidated native ecosystems, little disturbed, with extensive forest coverage and the presence of bodies of water (Emmons, 1988; Oliveira et al., 2010; Noss et al., 2012). It is also found in places where prey species are present and available (Litvaitis et al., 1986; Carbone & Gittleman, 2002; Pereira et al., 2006; Martínez-Hernández et al., 2014), and can be negatively affected by competitors, like bobcat (Fuller & Sievert, 2001; Donadio & Buskirk, 2006), or by other natural predators such as jaguar and/or puma (Crooks & Soulé, 1999; Monterrubio-Rico et al., 2017); in the NJR these felids live in the same ecosystems as jaguar, puma, lynx and coyote (*Canis latrans*). In addition, the ocelot is a species that prefers habitats with little anthropic activity, since it is hunted for its skin and occasionally because it preys on poultry (Haines et al., 2005; Di Bitetti et al., 2006; Goulart et al., 2009). Areas with vegetation cover have been shown to have a positive influence on the densities of wild cats, since they provide them with resting, shelter, and food availability (Emmons, 1988; Carbone & Gittleman, 2002; Pereira et al., 2006; Oliveira et al., 2010).

The home range estimated for a male individual (Male 2) was 37 km^2, which differs markedly from other values reported in Mexico, Bolivia and the USA (Torres-Romero et al., 2017, 4.63 km^2; Maffei et al., 2005, 3.1 km^2; Laack, 1991, 6.25 km^2); and it is larger to that found in Belize with an estimate of 20 km^2 (Dillon & Kelly, 2007). In this study, it is ruled out that "male 2" is a transient or juvenile in search of a territory, because we record their movements permanently and periodically for a year. The fact that males have made more extensive movements in the NJR is like observations made in other studies that argue that the requirements of males are higher, in addition to defending their territory (Goulart et al., 2009; Maffei et al., 2011; Torres-Romero et al., 2017). Male 2 presented a home range of 37 km^2, showing areas where its occurrences were concentrated at higher and lower intensity (fig. 3). It is likely that the individual has different territories in each season within its home range, so it may be a healthy individual with the ability to cover large areas of land to satisfy its needs (Scognamillo et al., 2003; Azevedo & Murray, 2007).

Our results contribute, together with ecological information on the species in the northwestern areas of its distribution, to implement conservation strategies and favor its dispersion to other areas in the north of Mexico and the southwestern United States (Arizona and New Mexico) as found by López-González et al. (2003) and by Martínez-Calderas et al. (2015). The conservation of the ocelot and that of other emblematic feline species depends on conserving large areas of native territory. In this region of the Sierra Madre Occidental there are large extensions of land with livestock ranching, and in some of those ranches, environmental education activities on the importance of felines are being implemented. However, other territories in the area, that used to be cattle ranches, are now being bought by mining concessions for exploration. Without a doubt, the creation of new protected natural areas and the ecology and conservation studies and management that they might implement will be fundamental to keep ocelot ecosystems protected.

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