Density of threatened ocelot *Leopardus pardalis* in the Sierra Abra-Tanchipa Biosphere Reserve, San Luis Potosí, Mexico

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Abstract There is little information on the population status of the ocelot *Leopardus pardalis* in Mexico. In the Sierra Abra-Tanchipa Biosphere Reserve, in San Luis Potosí, ocelots are affected by habitat loss and fragmentation as a result of increased agricultural development. We used photographic identification in camera-trapping capture–recapture surveys to determine population abundance and density during the dry season and subsequent early and late humid seasons during April 2011–March 2012. We recorded 80 photographs of 15 individuals (10 males, one female, and four of undetermined sex) in 7,786 camera-days. Abundance was estimated using a closed capture heterogeneity model, yielding an estimated population of 9 ± SE 3 in the dry season and 21 ± SE 8 and 15 ± SE 5 during the subsequent early and late humid seasons, respectively. Spatially explicit density estimates were 0.04 and 0.03–0.18 individuals per km^2 for the dry and humid seasons, respectively, and were similar ($P > 0.612$) among seasons. Peaks in ocelot activity occurred during 20.00–04.00. We conclude that the ocelots of the Sierra Abra-Tanchipa Reserve have a low population density and may face geographical and biological isolation as a result of habitat conversion. Continued monitoring and improved understanding of the movements and habitat preferences of ocelots are necessary to ensure their continued persistence, and connectivity between this population and others in north-east Mexico.

Keywords Abundance, activity, camera-trapping, density, *Leopardus pardalis*, spatially explicit mark–recapture

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Introduction

The ocelot *Leopardus pardalis* is the third largest of 10 felid species in the Neotropics (de Oliveira, 1994; Sunquist & Sunquist, 2002; de Oliveira & Cassaro, 2005). It occurs in a variety of habitats, including tropical and subtropical forest, wetland, savannah and mangrove swamps (Kitchener, 1991; Murray & Gardner, 1997) and historically the species was distributed from Arizona, Arkansas, Louisiana and Texas in the United States to Argentina (Tewes & Schmidly, 1987; Brown, 1990). Ocelot distribution has decreased considerably during the last century (Caso et al., 2008). The species is included in Appendix I of CITES but categorized as Least Concern on the IUCN Red List (Caso et al., 2008). Ocelots are listed as endangered in Mexico (Norma Oficial Mexicana, 2010), where the greatest threats to their survival are habitat loss and illegal hunting (López-González et al., 2003; Aranda, 2005).

A population of ocelots has been confirmed in the Sierra Abra-Tanchipa Biosphere Reserve (Martínez-Calderas et al., 2011), the only such reserve in eastern San Luis Potosí, Mexico, which is becoming isolated from other areas of suitable habitat as a result of significant land-use changes, including slash-and-burn cropping and clearing for livestock grazing. This may pose a significant threat to this population of ocelots, the only documented population in eastern San Luis Potosí (Villordo-Galván et al., 2010; Martínez-Calderas et al., 2011).

Although multiple international studies of ocelot ecology, biology, behaviour and status have been undertaken, there is little information regarding ocelot population status and trends in Mexico, or valid techniques for monitoring population trends (de Oliveira et al., 2010). Baseline information is needed to develop management strategies for conservation of ocelots (Aranda, 1991). Hence, our objective was to estimate the abundance and density of ocelots in the Sierra Abra-Tanchipa Biosphere Reserve to provide a basis for the development of informed management strategies for the monitoring and conservation of ocelots in the Reserve and throughout Mexico.

Study area

Our study area encompassed 21,464 ha, at altitudes of 114–810 m, within and adjacent to the Sierra Abra-Tanchipa

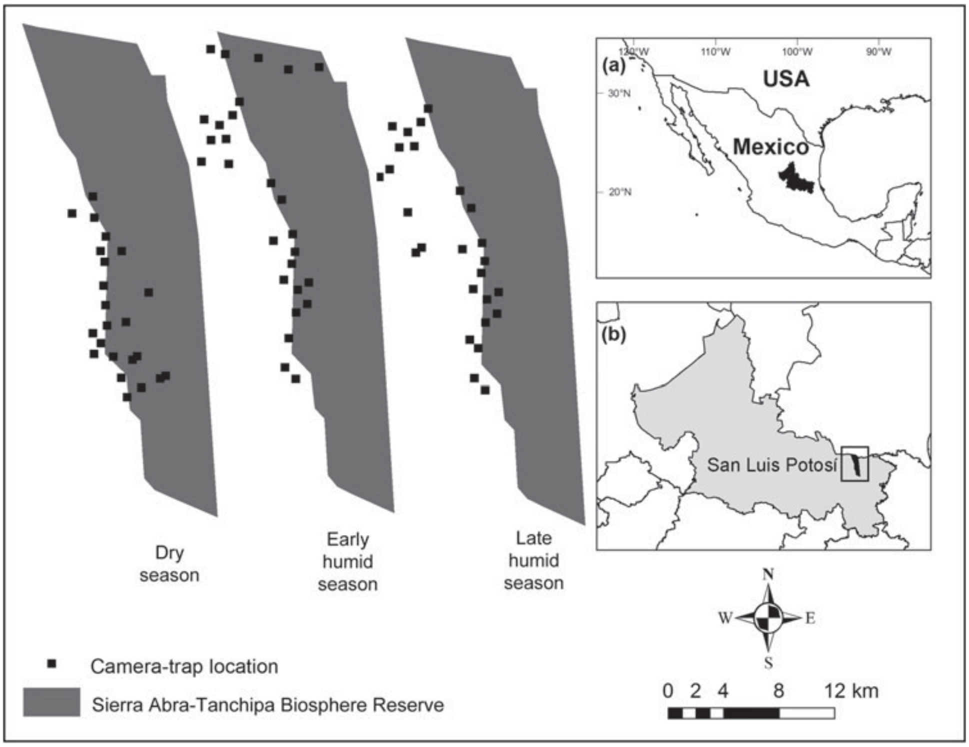

FIG. 1 Location of camera-trapping sites for the three surveys carried out in the greater Sierra Abra-Tanchipa Biosphere Reserve region, San Luis Potosí, Mexico. The shaded area in (a) indicates the location of San Luis Potosí state, and the rectangle in (b) indicates the location of the main map.

Biosphere Reserve (Fig. 1), a federal protected area located in the Huasteca region in eastern San Luis Potosí, between Ciudad Valles and Tamuin townships. The climate in the area is predominantly warm and sub-humid, with a mean annual temperature of 25.3 °C and mean annual precipitation of 1,017 mm (INEGI, 2011). The primary vegetation type in the Reserve is tropical deciduous forest, with tropical forest, oak woodlands (*Quercus* spp.), palms, and secondary vegetation also present (Sánchez-Ramos et al., 1993; Chapa & Monzalvo, 2012). Wildlife includes puma *Puma concolor*, white-tailed deer *Odocoileus virginianus*, brocket deer *Mazama temama*, collared peccary *Pecari tajacu*, and coati *Nasua narica*, and several threatened species, including the jaguar *Panthera onca*, margay *Leopardus wiedii*, and military macaw *Ara militaris* (Villordo-Galván et al., 2010). Slash-and-burn agriculture, cattle ranching, and forestry are the predominant land-uses (Sánchez-Ramos et al., 1993). Ibarra & Galindo (2010) reported a loss of c. 9,360 ha of original habitat types in the study area over a 32-year period (1973–2005).

Methods

We used photographic recaptures from camera-trapping grids to develop mark–recapture models to estimate ocelot abundance (Karanth, 1995; Karanth & Nichols, 1998). We established camera-trapping grids in three seasons during April 2011–March 2012, with one survey during the dry season, a second at the beginning of the following humid season and a third at the end of the humid season, deploying 22, 27 and 26 camera stations, respectively (Table 1). Cameras used included 31 WildView Xtreme (Stealth Cam LLC, Grand Praire, USA), 16 digital Stealth Cam (Stealth Cam LLC, Grand Prairie, USA), 11 DeerCam 200 (DeerCam, Park Falls, USA), and four Bushnell Trophy Cam (Bushnell, Overland Park, USA). Within the grid, stations were placed systematically on trails, streams and other routes where there was evidence of ocelot sign (scat, tracks), to maximize the capture probability of individuals. Most stations were located outside the protected area because a previous study within the protected area yielded a low number of photographic captures of ocelot (Martinez-Calderas et al., 2011; Fig. 1). In most cases (60, 67 and 58% for the dry, early and late humid seasons, respectively), we used two cameras at each station to increase the likelihood of obtaining photographs of both sides of each animal. Each camera was placed 0.45 m above ground level and stations were spaced at a mean spacing of 1.5 km, based on the area of activity of ocelots in Mexico (Caso, 1994; Martínez-Meyer, 1997). Cameras were programmed to be active for 24 hours and record the time and date of each capture. Our camera grids covered > 45 km^2, following the recommendations of Dillon & Kelly (2007) and Maffei & Noss (2008). We limited seasonal surveys to < 90 days to meet the assumption of a closed population, following Karanth & Nichols (1998). We checked cameras every 15 days to change batteries, and film or memory cards.

TABLE 1 Details of camera-trap surveys for the ocelot *Leopardus pardalis* in the Sierra Abra-Tanchipa Biosphere Reserve, San Luis Potosí, Mexico (Fig. 1), during the dry and early and late humid seasons, with survey duration and numbers of cameras, camera-trap stations and trap-days.

Season (date)	Duration (days)	No. of cameras	No. of camera-trap stations	No. of trap-days
Dry (April–July 2011)	84	34	22	2,856
Early humid (November 2011–February 2012	82	45	27	3,690
Late humid (February–March 2012)	31	40	26	1,240

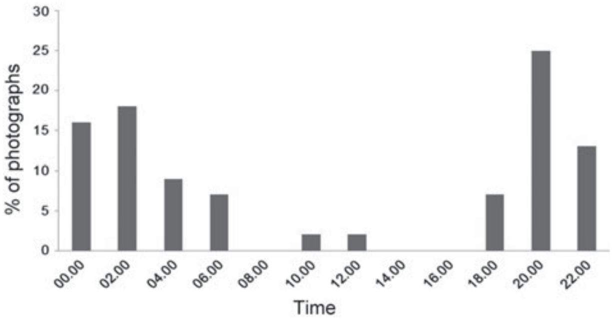

FIG. 2 Activity patterns of all ocelots *Leopardus pardalis* (n = 55) documented in the greater Sierra Abra-Tanchipa Biosphere Reserve region, San Luis Potosí, Mexico.

TABLE 2 Model selection criteria scores and goodness-of-fit tests of hypothesis of M_h vs not-M_h for ocelot mark–recapture models for three camera-trap surveys in the greater Sierra Abra-Tanchipa Biosphere Reserve region (Fig. 1).

Season	Model	Model selection criterion	χ^2	*P*	df
Dry	M_o	1.00			
	M_h	0.99	20.5	0.200	16
	M_{bh}	0.91			
Early humid	M_o	1.00			
	M_{bh}	0.96	15.5	0.410	15
	M_h	0.94			
Late humid	M_o	1.00			
	M_h	0.78	1.1	0.958	5
	M_{bh}	0.66			

We identified individual ocelots by their morphological characteristics, as described by Trolle & Kéry (2003), and identified gender by the presence or absence of a testicular sack. We excluded distorted pictures or those that lacked clarity for individual identification.

We used *CAPTURE* (Otis et al., 1978; White et al., 1982) to estimate abundance, under the assumption of a closed population (Otis et al., 1978; White et al., 1982; Rexstad & Burnham, 1991). We used 5-day intervals to develop capture histories for each ocelot photographed during sampling, which resulted in 17, 16 and 6 potential capture events for the dry, early and late humid seasons, respectively. We selected the most appropriate model for each survey season, using the discriminant model selection function of *CAPTURE* (Otis et al., 1978; Rexstad & Burnham, 1991).

We determined population density, using full maximum likelihood spatially-explicit capture–recapture (Borchers & Efford, 2008) in *DENSITY 5.0* (University of Otago, New Zealand). We assumed a Poisson distribution of home range centres and used a buffer distance of 7,500 m, corresponding with home range estimates in Mexico (Caso, 1994). We contrasted half normal, hazard, and negative exponential detection functions and three alternative capture probabilities (g_o): $g_o(.)\sigma(.)$, where all individuals have the same capture probability; $g_o(b)\sigma(.)$, where individuals show a behavioural response to first capture; and $g_o(h2)\sigma(.)$, where individuals exhibit heterogeneity in capture probability. We did not consider more complex models because our data were sparse. We compared models, using AICc (Burnham & Anderson, 1998), and considered models with AICc < 5 competing models. Lastly, we compared resultant density estimates, using parametric bootstrapping (Efron & Tibshirani, 1993).

Results

We obtained 80 photographic captures of ocelots during 7,786 camera-days. Of these, 22 were recorded in the dry season, 24 in the early humid season and 34 in the late humid season. Most captures were nocturnal, with most activity during 18.00–06.00 (Fig. 2), which was consistent among surveys ($\chi^2 = 0.56$, $P < 0.05$, df = 2). Peak activity was during 20.00–02.00 (Fig. 2).

We identified 15 individuals: 10 males, one female and four of indeterminate sex. Models M_o and M_h were usually the best-supported models (Table 2). We report abundance using estimates from M_h because of the robustness of the jackknife estimator to violations of model assumptions, following Karanth & Nichols (1998), in combination with goodness-of-fit tests that did not reject M_h as a candidate model (Table 2). The low capture rate of females suggests heterogeneity in capture probabilities among ocelots, leading us to favour M_h. We estimated there were 9 ± SE 3, 21 ± SE 8 and 15 ± SE 5 ocelots during the dry, early and late humid season surveys, respectively. Our data fit the assumption of closure ($z < |0.28|$, $P > 0.610$; Otis et al., 1978; White et al., 1982).

TABLE 3 Camera-trapping and model data for three surveys of ocelots in the Sierra Abra-Tanchipa Biosphere Reserve (Fig. 1), with total numbers of captures and recaptures, number of individuals captured, estimated population size from closed mark–recapture, and estimated density from model-averaged full maximum likelihood spatially-explicit capture–recapture.

Season	Total captures	Total recaptures	No. of individuals	Estimated population size	Estimated density (km^{-2})
Dry	22	3	6	9 ± SE 3	0.04 ± SE 0.03
Early humid	24	3	6	21 ± SE 8	0.03 ± SE 0.02
Late humid	34	2	7	15 ± SE 5	0.18 ± SE 0.46
Total	80	8	15		

TABLE 4 Candidate models for full maximum likelihood spatially explicit capture–recapture models of ocelot density in three seasons in the Abra-Tanchipa Biosphere Reserve (Fig. 1), with model selection criteria and number of parameters.

Season	Model*	AICc	AICc	AICc weight	No. of parameters
Dry	NE $g_0(.)\sigma(.)$	112.15	0	0.55	3
	HN $g_0(.)\sigma(.)$	112.53	0.38	0.45	3
Early humid	HN $g_0(.)\sigma(.)$	116.24	0	0.50	3
	NE $g_0(.)\sigma(.)$	116.24	0	0.50	3
Late humid	HN $g_0(.)\sigma(.)$	84.41	0	0.53	3
	NE $g_0(.)\sigma(.)$	84.63	0.22	0.47	3

*NE, negative exponential detection function; HN, half normal detection function

Model $g_0(.)\sigma(.)$ using either half normal or negative exponential detection functions was clearly superior to other models of ocelot density (for all others ΔAICc ≥ 14) and both detection functions were approximately equally supported (Table 4). Model-averaged estimates of ocelot density were 0.04 ± SE 0.03 (95% CI 0.01–0.15), 0.03 ± SE 0.02 (95% CI 0.01–0.11) and 0.18 ± SE 0.46 (95% CI 0.01–2.78) ocelots per km^2 for the dry, early and late humid surveys, respectively (Table 3). Density of ocelots was similar among surveys ($P > 0.612$) because of large variance in the late humid season estimate. Capture probabilities at the home range centre were 0.05 ± SE 0.06, 0.01 ± SE 0.01 and 0.03 ± SE 0.05 for the dry, early and late humid season surveys, respectively.

Discussion

Density of ocelots reported throughout the Americas is variable (Table 4), with differences associated with habitat type, number of camera-trap stations, and the distance between them, the calculation of the effective area of sampling, sampling effort, and the method of estimation (e.g. camera-trapping vs radio-telemetry). Although comparison between studies is difficult for these reasons our density estimates are towards the lower range of published estimates (Table 5). This supports the hypothesis that ocelot density decreases with decreasing precipitation and increasing distance from the equator (Di Bitetti et al., 2008). This relationship is probably attributable to decreased primary productivity and, consequently, prey base. The habitat quality in our study area was probably reduced by fragmentation as a result of increased slash-and-burn agriculture and conversion of grassland for cattle ranching (Villordo-Galván et al., 2010). Furthermore, the Sierra Abra-Tanchipa Biosphere Reserve is becoming increasingly isolated from the mountain massif of the Sierra Madre Oriental, where ocelots are common (Ávila-Nájera et al., 2011). Isolation and fragmentation of habitat together limit dispersal movements of ocelots (and prey) as well as decreasing the availability and quality of suitable habitat (Di Bitetti et al., 2008).

Similar to other camera-trapping studies of carnivores (Silver et al., 2004; Gray & Prum, 2012), we had fewer detections of female ocelots than males. Our traps were spaced at c. 1.5 km intervals, and only three ocelots were photographed at more than one station, all of which were males. Thus, the distance between traps may have been too great, particularly for females. However, trap spacing was set in accordance with the movement parameters of our density models ($\sigma = 1.1–5.0$ km, seasonally) and ocelot home range sizes recorded in Mexico (8–10 km^2; Caso, 1994), indicating that the lower capture rate for females is probably not attributable to the trap spacing (Efford et al., 2005; Gray & Prum, 2012). Thus, differences in the number of individuals of each sex that were photographed may be related to differing movement patterns of males and females

TABLE 5 Density of ocelots recorded in studies in North, Central and South America.

Country	Study area	Density (per 100 km^2)	Reference
USA	Lower Rio Grande Valley	30.0	Haines et al. (2006)
	Laguna Atascosa National Wildlife Refuge	9.0	Sternberg & Mays (2011)
Mexico	Sierra Abra-Tanchipa	3.0–18.0	Present study
Belize	Chiquibul	25.8–25.9	Dillon & Kelly (2007)
		2.3–3.8	
Guatemala	Mirador Río Azul	14.7	Moreira et al. (2007)
Costa Rica	Talamanca-Caribe	6.4–10.2	González & Cardenal (2011)
Panama	Darien	67.0	Moreno & Bustamante (2009)
Colombia	Llanos Colombianos	5.5	Díaz-Pulido & Payán-Garrido (2011)
Peru	Peruvian Amazon	43.5–58.5	Kolowski & Alonso (2010)
		75.2–94.7	
	Cocha Cashu	80.0	Emmons (1988)
Venezuela	Llanos	40.0	Ludlow & Sunquist (1987)
Bolivia	Gran Chaco	24.0–66.0	Maffei et al. (2005)
Argentina	Iguazú	12.8–19.1	Di Bitteti et al. (2006)
	Yabotí	8.64	Di Bitteti et al. (2008)
Brazil	South-east Pantanal	56.0	Trolle & Kéry (2003)
	North-east Pantanal	11.0	Trolle & Kéry (2005)
	Caraguatá	4.0	Goulart et al. (2009)

and the elusive behaviour of female ocelots (Silver et al., 2004; Gray & Prum, 2012). Males have a higher probability of being captured because they have larger territories, they tend to use higher-use roads and trails, where camera traps are located, and they are more active than females (Martínez-Meyer, 1997). These behaviours limit captures of females in studies of felids. Consequently, we recommend that sampling be designed and conducted in a way that will maximize the potential for capturing females in the study area, such as including all possible unpaved roads and trails (Sterenberg & Mays, 2011; Foster & Harmsen, 2012). Additionally, spacing of camera grids should be conservative in cases where home ranges are unknown.

We also observed differences in the probability of detection of ocelots between the dry and humid seasons. Based on mean population estimates, the probability of photographing an ocelot in the dry season was 0.67 (i.e. six individuals of an estimated nine were photographed) but in the late humid season was < 0.50 (i.e. six of an estimated 21 and seven of an estimated 15 were photographed in the early and late humid season, respectively). These differences may be related to decreased movement during the dry season. In similar habitats in Jalisco, Mexico, Martínez-Meyer (1997) found that males and females had smaller home ranges during the dry season, with overlap in activity patterns. In areas where the dry season is severe, such as the Sierra Abra-Tanchipa Biosphere Reserve, predators such as ocelots tend to concentrate in areas close to permanent water, where vegetation density remains relatively high and prey are likely to be more abundant and vulnerable (Martínez-Meyer, 1997). This behaviour may explain the higher detection rate during the dry season.

Differences in detection between the dry and wet seasons indicate that long-term monitoring must be seasonally consistent over time. Otherwise, differences in ocelot numbers between years may be confounded by seasonal differences. Because of the higher probability of detection and the more conservative density estimate we observed, we recommend that long-term monitoring be conducted using camera-trapping during the dry season in Sierra Abra-Tanchipa and similar areas.

Ocelots in the Reserve were mainly nocturnal, as reported in other studies (Ludlow & Sunquist, 1987; Emmons, 1988; Maffei et al., 2005; Di Bitetti et al., 2006; Dillon & Kelly, 2007; Goulart et al., 2009). This corresponds to a strategy of avoiding high temperatures during the day (Stoner & Timm, 2010). Nocturnal activity coincides with the period of activity of much of the ocelot's prey (Ludlow & Sunquist, 1987; Emmons, 1988).

Ocelot abundance is influenced by prey density, habitat quality, presence of competitors, predators, and environmental variables, especially those related to primary production and prey availability (Di Bitetti et al., 2008; de Oliveira et al., 2010). Land conversion for agriculture and cattle ranching in the Reserve is resulting in increased soil erosion, changes in vegetation cover type, and the loss or fragmentation of natural habitats. Similar to other species, the ocelot is susceptible to this kind of disturbance. Given their need for dense vegetation cover (Harveson et al., 2004), the persistence of the ocelot could be threatened by the opening of habitats for agricultural development (Martínez-Calderas et al., 2011). These challenges may be especially critical in our study area, given the small, relatively low-density ocelot population, because Sierra Abra-Tanchipa is the only reserve in eastern San Luis Potosí and our small study population is the only known population. Increasing fragmentation could further isolate this population and decrease connectivity with other viable habitats, both of which would increase the likelihood of extirpation (Martínez-Calderas et al., 2011). We recommend continued dry-season monitoring of the status of this population, surveys of adjacent areas to determine presence or absence of ocelots, as well as studies of movement and habitat associations of ocelots in this and adjacent populations (if present). This information is needed to determine the viability of this population, identify adjacent populations and identify areas necessary to maintain connectivity between populations and habitats to conserve the ocelot in eastern Mexico.

Since 2012 ocelots have been monitored, by camera-trapping, in and south of the Sierra Abra-Tanchipa Biosphere Reserve to estimate abundance and identify suitable habitat. There appears to be a lack of habitat connectivity in states such as Hidalgo and Puebla, where ocelots are less common. Long-term monitoring, including genetic studies in southern regions, is necessary to investigate connectivity for ocelots in north-east Mexico.

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