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Research Article

Ocelot (*Leopardus pardalis*) breeding effort and productivity in seasonal tropical forests of the central Mexican Pacific

Tiberio C. Monterrubio-Rico[1], Leticia Núñez-Landa[1], Juan F. Charre-Medellín[2,3]

1 *Laboratorio de Ecología de Vertebrados Terrestres Prioritarios, Facultad de Biología, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán 58194, Mexico*
2 *National School of Higher Studies, Universidad Nacional Autónoma de México, Morelia, Michoacán 58341, Mexico*
3 *Laboratorio Sistemas de Información Geográfica y Percepción Remota, Facultad de Biología, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán 58194, Mexico*

Corresponding author: Leticia Núñez-Landa (1226976h@umich.mx)

Abstract

Camera trap studies on ocelots in Mexico have focused on abundance, habitat use, and activity patterns, mainly within Protected Areas of tropical humid forests in southern regions. However, their ecology, including breeding effort and productivity in seasonal dry Pacific forests and areas outside Protected Areas, has received less attention. The species' low reproductive rates make their populations vulnerable to decline. In evaluating the reproduction, the species' breeding activity was examined for two survey periods performed during 2010–2016. We estimated the percentage of females raising young in the surveys and their associated fecundity–"productivity". The overall results revealed a population of 26 males and 46 females that included 10 females (21%) rearing 12 young, defined as kittens, cubs, or juveniles, for an effective sample area (ESA) of 200 km^2. Overall, the productivity averaged 2.05/100 km^2 per season. All parameters varied between the two areas, and productivity was not constant in time in either area or site. Information on species breeding activity in combination with density estimations may facilitate determining the minimum area required for a viable ocelot population in the region. Protected Areas are required in the studied region for the ocelot in order to maintain a viable local population. This is due to the increasing fragmentation caused by agriculture, cattle ranching, and forest fires, and it is hypothesized that ocelots do not tolerate disturbance or severe fragmentation.

Key words: Camera trap, felines, female generational replacement, tropical dry forests

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Introduction

The ocelot (*Leopardus pardalis* Linnaeus, 1758) is considered the most abundant feline in neotropical forests (Caso et al. 2008). Its broad distribution range extends from southern Texas through Mexico and Central America to Ecuador, Peru, and northern Argentina in an altitudinal range between 0 and 3000 m (Emmons and Feer 1997; Murray and Gardner 1997; Iglesias et al. 2009; De Oliveira et al. 2015). The distribution in Mexico includes the tropical and subtropical lowlands, the Sierra Madre Oriental, the Sierra Madre Occidental, and the Sierra

Madre del Sur, from the Texas-Mexico border to the Yucatán peninsula and the Belize and Guatemalan borders in the south (Leopold 1959; Aranda 2005).

The ocelot is considered a key species for tropical forest dynamics, as it regulates populations at lower trophic levels through predation (Moreno et al. 2012). Ocelot affinity for dense vegetation cover makes them an adequate indicator species (Emmons 1988; Emmons and Feer 1997; Murray and Gardner 1997). It is a medium-sized predator, with a mass of 11–14.5 kg; the males are larger and heavier (11–12 kg) than females (8–9 kg). Sexual maturity is achieved in ≥ 24 months, or as early as 16 months, with longevity around 10 years (Emmons 1988; Murray and Gardner 1997).

The ocelot is solitary, polygynous, and polyestrous, with male home ranges overlapping the home ranges of several females. Mating occurs any season of the year, with a higher breeding effort during the September–November period. The gestation period lasts between 78 and 82 days and occurs every two years. The first litter may occur within 18–45 months, with an average litter of one to two kittens. The observed sex ratio at birth is 50:50 (Tewes 1986; Emmons 1988; Laack 1991; Murray and Gardner 1997; de La Rosa and Nocke 2000; Dillon 2005; Laack et al. 2005).

Ocelots present low reproductive rates and slow recovery potential, as their populations cannot overcome annual reductions of ≥ 3%, making them vulnerable to reduction numbers caused by habitat degradation and human hunting (Murray and Gardner 1997; Satter et al. 2019). It is estimated that 71% of males and 75% of females reproduce in a generation; in captivity, only 63% raise their cubs (Mellen 1989; Murray and Gardner 1997). In the absence of human disturbance, ocelot populations tend to present high, constant annual survival rates, low recruitment rates, and little population turnover, as documented in a 12-year data analysis in the tropical humid landscapes of Belize (Satter et al. 2019).

The ocelot is listed as an endangered species in Mexico (Norma Oficial Mexicana, 2010), but the current distribution and viability of their populations are unknown, even with current studies evaluating ocelot ecology using camera traps (Torres-Romero 2009; Silva-Magaña and Santos-Moreno 2020). However, most studies have been focused on Protected Areas of southern Mexico, determining abundance, activity patterns, or habitat use (Martínez-Hernández et al. 2014; Ávila-Nájera et al. 2015) in humid tropical forests that have higher productivity and a more diverse potential prey base (e.g., Ávila-Nájera et al. 2015; De la Torre et al. 2016; Silva-Magaña and Santos-Moreno 2020).

Notably, estimations on ocelot breeding activity such as proportion of breeding females, productivity rates, renewal rates, and influential environmental and ecological factors have not been examined. This information is needed, considering the high forest fragmentation rates in the region, for better population assessment. Few studies in Mexico present results on breeding activity. One study in the tropical and cloud forests of Sierra Norte, Oaxaca, resulted in two females, three males, and one cub in July with an estimated population density of 7.8 individuals per 100 km^2 (Pérez-Irineo et al. 2017). In eastern México, a study documented four ocelots, including three males and a female with a cub, during November in the tropical dry forests of Ciudad Valles (Cacelin-Castillo, 2015). Another report from the cloud forests of the western Manantlán Biosphere Reserve in Jalisco registered a female with a kitten whose birth occurred during July–August (Aranda 2012) (Table 1).

Table 1. Regions in Mexico where ocelot populations were studied documenting density, vegetation, annual average precipitation in mm, protection status, sex ratio, and productivity (months evidenced). RF= Rainforest, TDF= Tropical Dry Forest, STF= Semideciduous Tropical Forest, TS= Tropical Scrub.

State (Number in map)	Density /100 km²	Vegetation (rain in mm)	Area status	M/F	Juveniles or cubs (Months recorded)	Source
Chiapas (1)	12.9/5.3	RF (3000)	Protected	4/10	0	De la Torre et al. 2016.
Oaxaca (2)	38.0	RF (2500)	Unprotected	5/3	0	Pérez-Irineo and Santos-Moreno 2014.
Oaxaca (3)	7.8	RF (2500)	Protected	2/2	1 (July)	Pérez-Irineo et al. 2017.
San Luis Potosí-Oaxaca (4)	NA	TDF (1800)	Protected	6/2	2 (Nov-Dec.)	Cacelin Castillo, L. A. 2015.
Quintana Roo (5)	2.5/13.8	STF (1511)	Protected	6/3	0	Avíla-Nájera et al. 2015.
Tamaulipas (6)	131.0	TDF (1441)	Protected	19/19	2 (NA)	Ocañas García, 2019.
Michoacán (7)	18.8-24.8	TDF (1300)	Unporotected	26/46	12 (Nov.-March)	Monterrubio-Rico et al. 2017; Guzmán-Díaz 2019, this study
Quintana Roo (8)	13.98	STF (1200)	Protected	5/6	0	Torres-Romero 2009.
Jalisco (9)	NA	TDF (1150)	Protected	0	1 cub (Jul/Ag.)	Aranda et al. 2012.
San Luis Potosí (10)	NA	TDF (1017)	Protected	10/1	0	Martínez-Hernández et al. 2014.
Tamaulipas (11)	17.5- 59	TDF (1000)	Protected	23/24	NA	Sternberg et al. 2023.
Sonora (12)	0.63-0.65	TS (400)	Unprotected	16/8	0	Gómez-Ramírez et al. 2017.

Although some information is available on ocelot densities (Monterrubio-Rico et al. 2017; Gómez-Ramírez et al. 2017), it is unknown the degree to which ocelot's reproductive activity occurs in the Pacific range. Therefore, it is necessary to determine this parameter and compare it with the existing information on stable and viable ocelot populations (Kendall et al. 1997; Satter 2017; Satter et al. 2019). The western Pacific slope is important for the ocelot and other Neotropical felines, as it constitutes the largest relatively continuous forested habitat in Mexico, representing 14% of the country's area. In comparison, the more humid tropical forest of the Atlantic and southern México is experiencing ongoing area reduction and fragmentation in an overall smaller area (Ceballos and Valenzuela 2010; Monterrubio-Rico et al. 2017).

The long-term conservation of ocelots resides in maintaining viable populations in their original ranges, identifying areas with high densities and adequate productivity-recruitment levels to function as "source populations" for Protected Area designation (Shaffer 1981; Meffe and Carroll 1997). Evidence from the analysis of the endangered Psittacidae along the Pacific slope of Mexico (Sonora-Chiapas) (Monterrubio-Rico et al. 2010; Marín-Togo et al. 2012) shows a low availability of Protected Areas for all endangered species, as primary forest fragments are becoming restricted to inaccessible mountain areas with steep slopes along rivers and canyons (Trejo and Dirzo 2000; Ortega-Rodríguez and Monterrubio-Rico 2008).

In the absence of countrywide population assessments and productivity data and considering the broad environmental variation in the species distribution (Guzmán-Díaz 2019; Di-Bitetti et al. 2006), it is necessary to evaluate the species' reproductive activity, in particular for seasonal dry forests in the central Pacific in Mexico. We aimed to estimate the ocelot population breeding activity by examining camera-trapping records over the years 2010–2016. In addition, we examined reproduction in the context of other population parameters.

Materials and methods

Study site

The study was conducted in two localities from the Sierra Madre del Sur and Jalisco dry forests (coastal lowlands) ecoregions (Olson et al. 2004), located on the central Pacific coast within Michoacán state in Mexico (Fig. 1). The landscape includes "sierras" facing the Pacific coast, which constitute an orographic barrier capturing oceanic humidity on the facing slopes, creating a humidity gradient (dry) from near the sea to the interior, where dry and semi-dry climates prevail (Monterrubio-Rico et al. 2017). The vegetation alternates from sea level to 1700 m, from tropical dry deciduous forests to tropical semi-deciduous forests in humid areas, creating complex ecotone areas where agricultural expansion has reduced all kinds of forests (Mas et al. 2017). At higher elevations, in a temperate climate, pine-oak ecotones mix with tropical vegetation, and pine and conifer forests cover higher elevations. Both mountain systems present rugged terrain, canyons, riparian forests, and ecological ecotones at elevation gradients where undisturbed wildlife populations remain, including several endangered species, for example, jaguars, river otters, and margays (Ceballos and Valenzuela 2010; Monterrubio-Rico and Charre-Medellín 2014; Monterrubio-Rico et al. 2017; Charre-Medellín et al. 2021; Monterrubio-Rico et al. 2021). Human density is low, and settlements (50–200 inhabitants) are dispersed across the region; however, many young men practice hunting ungulates for self-consumption and hunt large felines as a retaliatory response to cattle loss from predation, which was documented in interviews and evidenced with skins shown by local guides and hunters-villagers (Charre-Medellín 2009; Charre-Medellín et al. 2015).

Sampling designs and data analysis

The data came from two survey designs (2010–2011; 2014–2016) over five years. Sampling in each year was concentrated during the dry season and after the rainy season, with a total sampling of 27 months. Data were analyzed in three-month periods considering the closed population assumption in capture-recapture studies (Charre-Medellín 2012; Monterrubio-Rico et al. 2017; Guzmán-Díaz 2019). The localities differed between surveys, as research expanded from 2011 to 2015 to include new sites in search of endangered species (Monterrubio-Rico et al. 2011; Monterrubio-Rico and Charre-Medellín 2014; Charre-Medellín et al. 2015; Monterrubio-Rico et al. 2021).

The first survey included three sampling seasons: March to June 2010; November 2010 to February 2011; and March to May 2011; involving 10 to 15 camera stations (a site where one or two cameras were placed), with an Effective Sampled Area (ESA) averaging 119 km^2 in the community of El Naranjal, Aquila. Detailed descriptions of the localities and specific sampling efforts by locality are available in Charre-Medellín (2012). The second survey design included four sampling seasons: March to May 2014; November 2014 to February 2015; March to May 2015; and November 2015 to February 2016 for an estimated ESA of 81 km^2 in the community of San Jose de los Pinos, Arteaga. The design included 27 camera stations (18 double camera stations and 9 single camera stations). For a detailed description, see Charre-Medellín et al. (2021) and Guzmán-Díaz (2019). Cameras in photograph format were programmed for a

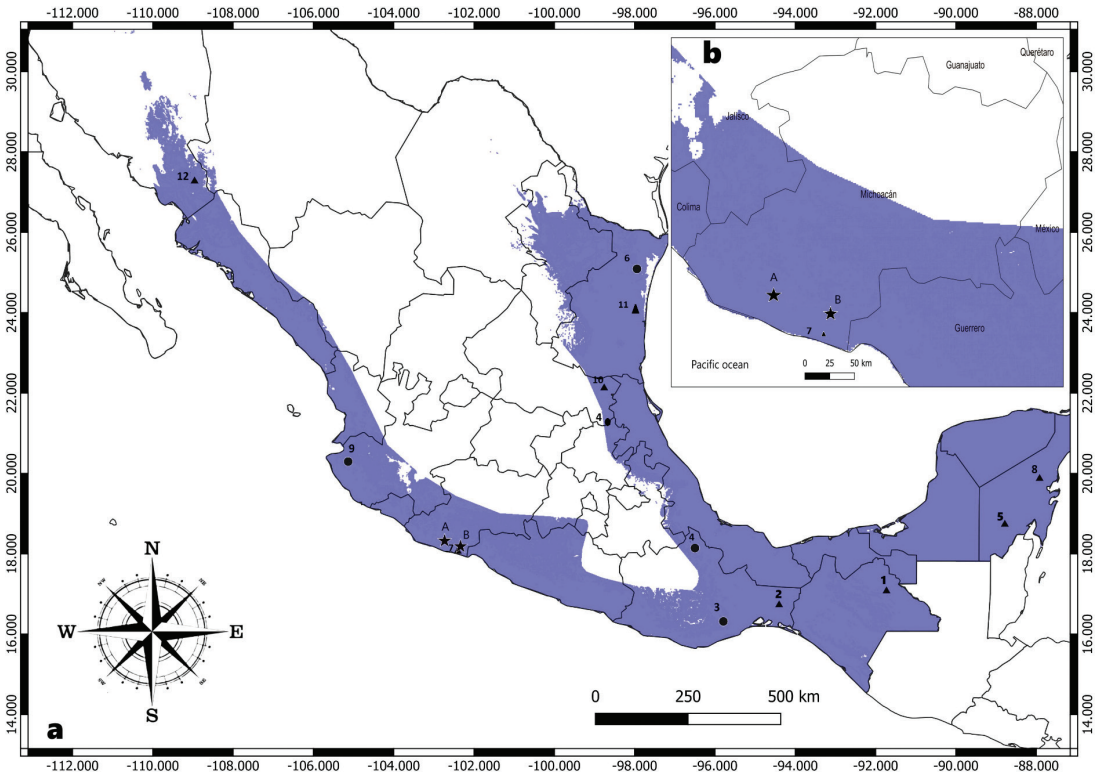

Figure 1. Triangles indicate study regions of camera trap ocelot studies in Mexico, and circles correspond to the areas with evidenced breeding. Numbering corresponds to Table 1. (a). Location of the two sampling sites of this study in central-western Pacific Mexico (stars) A) El Naranjal, Aquila, and B) San Jose de los Pinos, Arteaga (b). Blue-shaded areas represent the ocelot's potential distribution (Ceballos et al. 2006).

recovery time of five minutes after a detection event, obtaining three photographs per event (Wildview® Xtreme), and cameras programmed in video format produced 15-second video clips (Stealth Cam Skout 7MP Digital Scouting Cam; Grand Prairie, TX; and Bushnell 8MP Trophy Cam Trail 6.0 megapixels).

In both surveys, the camera-trap stations were placed between 1 and 3 km apart. Camera traps were revised every 30 days to replace batteries and memory cards. To ensure that only the natural movements of the animals were registered, no baits or olfactory attractants were used (Long et al. 2008).

Estimation of breeding activity and productivity

Ocelots were individually identified using their unique combination of rosettes, spots, stripes, scars, relative size (adult, juvenile, cub-kitten), sex (Moreno and Bustamante 2009; Palomo-Muñoz et al. 2014), and by examining camera location and date (Fig. 2). We determined the total number of males and females and the number and percentage of females accompanied by kittens or juveniles (Fig. 2).

We define the breeding effort parameter as the percentage of females evidenced rearing young (kittens or juveniles). Breeding efforts were estimated for each of the two surveys and for the overall study. In the absence of precise demographic analysis (cohort, life table, or productivity table analysis) for ocelots, we defined ocelot productivity as analogous to fecundity. Both terms constitute the same parameter in reproduction, but the term fecundity is also used for humans, whereas productivity is acceptable in wildlife (Monterrubio-Rico et al. 2002).

Figure 2. Adult female ocelots accompanied by kittens in the superior images and juveniles in the inferior section.

Ocelot productivity in this study was considered as the number of kittens/juveniles per reproductive female, defined as the females observed in the presence of offspring. The per capita rate (Smith and Smith 2007; Primack et al. 2001) was estimated using the number of kittens/juveniles divided by the overall sample of females in the survey, season, or entire study, which is a similar criterion to previous studies on the species (Satter et al. 2019). When a specific young ocelot (cubs or juveniles) was registered across different sampling seasons, productivity was accounted for only for the first season of appearance to avoid overestimations.

We examined breeding activity and productivity in combination with the sex ratio and densities obtained in previous studies (Monterrubio-Rico et al. 2017; Guzmán-Díaz 2019) to examine scenarios of female productivity and adult replacement times. To estimate female kittens' productivity, we considered the 50% sex ratio at birth (Murray and Gardner 1997). Densities of female ocelots and kittens were estimated in general by survey and season, adjusting the sex ratio for each specific season/survey/100 km^2, considering the Effective Sampled Area (ESA) of the two surveys (2010–2011 and 2014–2016).

Density models used in the previous studies (Monterrubio-Rico et al. 2017; Guzmán-Díaz 2019) include "Capture-Recapture" (Otis et al. 1978) with the CAPTURE software (Rexstad and Burnham 1991) and spatially explicit models (SCR; Royle et al. 2009a, b; Royle et al. 2014) in the nimble format code (R Core Team 2018).

Results

The cumulative survey effort analyzed was 11,356, averaging 1,622 camera traps/night of effort per sampling season (interval: 844–2,151 camera nights). Individual camera efforts averaged 85.6 ± 26.3 SD. The total number of ocelot records was 436 (186 from the first survey and 250 from the second survey). The overall capture rate was 4.3, in an interval from 2.4 to 6.8 ocelot records/100 camera-trap nights. Only 350 records were adequate for individual identification.

The total number of ocelots identified by combining the two surveys was 26 males and 46 females. Ten females (21%) were accompanied by 12 young (kittens, cubs, or juveniles) in an effective sample area (ESA) of 200 km^2. Breeding activity and productivity were registered every year but not for all the sampled seasons (Tables 2, 3). Photographic records of pregnant females were not registered.

Timing of breeding

Two juvenile ocelots were observed accompanied by an adult female in December and January, respectively, whereas the kittens/cubs captured (N= 5) and recaptured (N= 14) occurred in a relatively even distribution with 3–4 records from December to March.

Breeding activity

The percentage of females in the sample (the two surveys) accompanied by cubs or juveniles was 21.7% (n = 10; N 46), varying the percentage among seasons from 8.3 to 33%. During March–May 2014 and 2015, no cubs, kittens, or juveniles were registered. In the first survey, 13 male and 19 female ocelots were identified, including six females (31%) rearing seven young. During the second survey, the ocelots identified included 13 males and 27 females, with four females (14.8%) rearing five young (Table 2).

Productivity

The overall productivity estimation was 1.25 young per active breeding female, and the per capita rate was 0.26 for the study (12 young/46 females) (Table 2). The average per capita productivity by season was 0.152 ± 0.168 SD. The average seasonal productivity for survey 1 in "El Naranjal" (2010–2011; Fig. 1) was 0.218 ± 0.19, and for survey 2 in San José de Los Pinos (2014–2016; Fig. 1), the per capita productivity was 0.102 ± SD 0.156 (Table 3).

Female density ranged from 13.2 to 16.5 2 ind./100km^2 as adjusted by the observed sex ratio (Monterrubio-Rico et al. 2017; Guzmán-Díaz 2019), and cub-juvenile density was 2.4 to 3.4 /100 km^2 per survey, respectively. Assuming a 50:50 sex ratio at birth (Haines et al. 2006), the average female cub density is assumed to vary from 0.85 to 1.24/100 km^2 by season; pregnant females were not registered (Table 3). One female in two consecutive years was registered to rear cubs (March 2010 and March 2011). Breeding females were active from 19:00 to 05:00 h, without diurnal activity.

Discussion

The information generated in this analysis complements the knowledge of the ocelot population ecology for tropical dry forests and constitutes a basis for examining the viability of populations and related Protected Area requirements in the Pacific. The number of females rearing young in a population is a key influencing factor for recovery or viable populations in the wild (Shaffer 1981; Meffe and Carroll 1997; De la Torre et al. 2016).

Table 2. Ocelot population parameters in the central Pacific seasonal dry forests, (* when the statistic correspond to an average instead of a subtotal.

Surveyed season	First survey El Naranjal			Sub total/average*		Second survey San Jose de los Pinos			Sub total/average*	
	Feb-Jun 2010	Nov-2010-Feb 2011	Mar-May 2011	Feb 2010-Jun 2011	Mar-May 2014	Nov 2014-Feb 2015	Mar-May 2015	Nov 2015-Feb 2016	Nov 2014-Feb 2016	Total/ overall+
Survey effort	1,134	1,188	1,458	3,780	2,151	2,752	844	1,829	7,576	11,356
Average effort by camera	70.8	59.4	50.2	60.1*	86	105.8	105.5	121.9	104.8*	85.6+
Ocelot records	66	56	64	186	69	65	57	59	250	436
Ocelot records for id	52	47	64	163	41	49	43	54	187	350
Capture rate	5.8	4.7	4.4	5*	3.2	2.4	6.8	3.2	3.9*	4.3+
Male/ female records	21/31	12/36	10/54	43/121	16/25	22/27	11/32	32/20	81/104	124/225
Identified males/females	6/9	7/16	4/11	17/36	7/16	8/12	5/10	9/21	29/50	46/86
New-unique males/females	6/9	5/8	2/2	13/19	7/16	3/6	0/2	3/3	13/27	26/46
Females rearing young (cub-juvenile)	3	2	1	6	0	1	0	3	4	10
Percentage of females rearing young	33%	25%	0.9%	15.4*	0	8.3%	0	25%	16.5%*	21.7+
No. cubs-juvenile	4	2	1	7	0	1	0	4	5	12
No. female cub-juvenile (50%)	2	1	0.5	3.5	0	0.5	0	2	2.5	6
Percentage of female young raised (female recruitment)	0.22	0.125	0.045	0.13*	0	0.04	0	0.09	0.03*	0.07*

Table 3. Productivity, and densities (Monterrubio-Rico et al. 2017; Guzmán-Díaz 2019) in two surveys at western Pacific tropical dry forests.

	First survey					Second survey			
	Feb-Jun 2010	Nov-2010-Feb 2011	Mar-May 2011	Average-subtotal*	Mar-May 2014	Nov. 2014-Feb 2015	Mar.-May 2015	Nov 2015-Feb 2016	Average-subtotal*
Average number of records for identified female	3.4	3.75	4.9	4.0	2.27	2.16	3.2	1.6	2.3
Productivity by breeding female	1.3	1.0	1.0	1.16	0	1.0	0	2.0	1.25
Female per capita productivity	0.44	.125	.09	.218	0	0.08	0	0.33	0.102
Population density	13.8	28.0	14.8	18.8	22.0	22.0	27.8	27.6	24.8
Estimated female density	9.5	19.4	10.9	13.2	15.3	13.2	16.8	18.9	16.05
Density of females rearing young	2.6	4.7	1.0	2.7	0	1.1	0	2.7	1.9
Young productivity /100km^2	4.18	2.3	1.0	2.49	0	1.0	0	5.9	1.72
Female young density/100km^2	2.09	1.15	0.05	1.24	0	0.50	0	2.9	0.86

Most ocelot studies in general do not analyze breeding effort and productivity rates with camera traps; probably due to the limited number of identified ocelots and/or the design of the study (survey period's length and timing, etc.). Although the breeding effort is obtainable from camera trap data, it requires a large sample size of ocelots to obtain results with ecological significance (Appendix 1). After an extensive literature review, the number of studies with 10 or more females identified is low. The breeding effort could be determined due to the ocelot sample size, which was 72 adults (12 young). Our study analyzed one of the largest samples of identified ocelots in Mexico and the second in the Neotropics (Guzmán-Díaz 2019; Núñez-Landa 2023).

Before this analysis, the highest number of ocelots surveyed in Mexico corresponded to 51 ocelots, 19 males, 19 females, and two cubs for the protected wetlands of Tamaulipas (Ocañas-García 2019). Another assessment performed on the Sonoran Desert scrub registered 33 ocelots (16 males, eight females, and nine unidentified) without reporting recruitment or productivity (Gómez-Ramírez et al. 2017). The 12-year assessment published for Belize (Satter et al. 2019) still has the largest number of identified ocelots until now, with 322 ocelots in a 12-year analysis of five protected areas covered mostly by tropical humid forests.

Breeding effort in ocelot populations has been documented for humid tropical forests, varying from 10 to 26% (Di-Bitetti et al. 2006; Rodgers et al. 2014), whereas in our study it varied from 13% to 21% (10/46) (Table 2). Even though the region presents low annual rainfall (1300 mm) and severe droughts are common, the variation interval in population breeding effort is similar to intervals from populations in localities where higher rainfall regimes occur, implying that ocelot breeding effort is more influenced by local ecological interactions (i.e., competitors, prey) than climate, similar to other parameters previously reported such as local population density (Di Bitetti et al. 2008; Monterrubio-Rico et al. 2017).

The productivity observed was low and varied among survey periods and between areas; for instance, there was a slow potential population renewal. The ocelot population in this region exhibited a broad interval in productivity rates across years and between areas, from a high female annual per capita rate of 0.109 female cubs (10 females/100 adults) to as low as 0.034 (3.4 females/100 adults) female cubs. Considering the rate for the overall study, that constitutes a 0.13 for five years, and annually, a 0.026 rate implies a production of 5.6 female cubs for a hypothetical population of 100 adult female ocelots for a complete female renewal in 18.7 years. In contrast, the low rates of the second survey (0.034) would require 33 years for total female replacement. In comparison, annual recruitment rates for the ocelot populations of Belize ranged between 0.09 and 0.12 ocelots, for a female annual recruitment of 10 ocelots in a hypothetical population of 100 females (Satter et al. 2019).

Variation may be explained as a response to environmental variation and ecological interactions. Severe seasonal droughts may increase ocelot dispersal, hunger, and mortality caused by prey scarcity and predation by larger felines as local and regional habitat quality is affected (Núñez-Landa 2023). In addition to water availability and forest cover, ecological interactions like predation and intra- and inter-specific competition may influence productivity. It was evidenced by higher breeding effort in scenarios of low overall ocelot density and low breeding effort (low number of females active) when ocelot density was high (Table 3) (Monterrubio-Rico et al. 2017; Núñez-Landa 2023).

The presence of cougars and jaguars and prey abundance influenced the presence and abundance levels of ocelot males and females differently in the region, as female ocelot activity was negatively correlated with higher activity of large felines such as cougars and jaguars, whereas males were more associated with prey abundance (Núñez-Landa 2023). The specific responses of ocelot reproduction to environmental variation, local habitat quality, and how these relate to abundance and densities locally in Mesoamerica are still unclear (Núñez-Landa 2023). However, it is intuitive to consider that in the species' broad ecological and geographic range, from desert scrub lands to tropical rain forests, influencing factors may differ in intensity, and particularly important is to know the degree of influence of each factor or condition (Massara et al. 2018).

In general, it has been recognized that factors influencing ocelot abundance may be classified as environmental, ecological, and human impacts (Massara, Paschoal et al. 2018). For the seasonally dry forests in Michoacán, we hypothesize that an operating mechanism regulating the per capita recruitment level in the population is the percentage of local females breeding during a specific period, which fluctuates from reproduction suppression to 33% of females rearing cubs (Table 3).

No conclusive evidence of intraspecific competition was mentioned before, but in our data, indirect evidence is noticed by examining the breeding effort levels occurring at different density levels of adults (Table 3). Although ocelot intraspecific predation is unknown, the detrimental effect of intraspecific competition on mid-size feline populations and predation has been observed for the leopard (*Panthera pardus*), a species in which male leopards are responsible for 40% of cub mortality (Balme and Batchelor 2013).

The ocelot in the region is also sympatric with cougars (*Puma concolor*) and, to a lesser degree, jaguars (*Panthera onca*), which ecologically constitute competitors and predators (Caso et al. 2008). Predation by the competitors was not evidenced, but in the area, cougars exhibited a high frequency of activity (Monterrubio-Rico et al. 2017; Núñez-Landa 2023).

Notably, direct comparison between the reproductive parameters documented between both surveys is limited since they do not correspond to a balanced design, and some local factors such as waterhole availability may be influential. Water is a scarce resource in the region, limited during the 7-month dry season (Charre-Medellín 2012), and local water supply and spring availability may influence wildlife habitat use, territory size, and availability of prey (Charre-Medellín 2012). Local water availability in springs and other bodies of water during the drought period creates temporal heterogeneity that may assist in the explanation of the broad difference between surveys (Tables 2, 3). We hypothesize that springs and other water bodies may influence prey availability for all predators and sometimes favor ocelot per capita productivity at lower population densities (Table 3). The territory size of male ocelots is larger than that of females; during the dry season, male ocelots in territories with low water availability may modify or change their hunting areas, potentially explaining the low temporal number of male ocelots (Monterrubio-Rico et al. 2017).

Conservation perspectives

Although the studied region presents few human settlements and density, as mentioned earlier, the low and variable per capita productivity of the ocelot population increases its vulnerability to hunting by local villagers, which occurs in retribution for domestic cattle losses (personal observation). The poaching of one ocelot by each human settlement in the region may represent the total or a substantial proportion of the annual productivity in 100 km^2. Poaching control, habitat restoration, and population monitoring are required in the region to preserve all the feline populations and other endangered species (Shaffer 1981; Meffe and Carroll 1997; Monterrubio-Rico et al. 2017). Due to the ocelot's low reproduction rates, it is necessary to protect and maintain as many forest fragments as possible. The connection among the few protected areas of western Mexico, such as Chamela-Cuixmala Biosphere Reserve, Zicuirán-Infiernillo, and the Sierra de Nanchititla, should be reinforced with the establishment of complementary wildlife sanctuaries to guarantee the largest potential population possible under official protection. The studied region constitutes a representative portion of a larger wilderness landscape in western Mexico. Several studies recognize the region's strategic importance for the establishment of potential corridor networks to ensure jaguar mobility in the northern Neotropics (Rabinowitz and Zeller 2010; Rodríguez-Soto et al. 2011).

Future research needs

It is fundamental to the continuation of the monitoring effort for productivity in the region. Ideally, balanced designs measure the variation, consistency, and frequency of the results. Additional surveys in the landscape should extend into the Coahuayana and western Aquila municipalities to increase the sample of reproductive parameters, especially in areas of the region near Jalisco State. In Michoacan, the ocelot is also present in the Balsas basin, but the survey in the region that included the Zicuiran-Infiernillo Biosphere Reserve (ZIBR) revealed low abundance (Guido-Lemus 2015). Density estimations and productivity parameters are needed to assess the population status and viability of the reserve. It is also necessary to examine how local habitat quality, prey availability, and ecological interactions influence ocelot productivity. Ocelot survival rates and causes of mortality for kittens and juveniles under different levels of ecological scenarios should also be assessed.

The forest composition and topography of the studied region present similarities to the neighboring southern Guerrero and Oaxaca states along the Pacific slope mountain ranges, as these constitute the southern extension of the same ecoregion, the Sierra Madre del Sur (Olson et al. 2004). For instance, the productivity parameters from this study may be suitable when assessing ocelot viability for the entire ecoregion of the Sierra Madre del Sur.

Concluding remarks

This study provides the first estimation of ocelot population fecundity and productivity for the western seasonal dry tropical forests. The population parameters vary seasonally and between surveyed areas. The potential population renewal scenarios are low, confirming the species' vulnerability if drought, additional habitat loss, and poaching negatively affect the population size. The long-term viability of the species is uncertain, as drought and increasing forest fires experienced during the latest years are reducing habitat availability and quality, in addition to the ongoing human-caused fragmentation.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

During the study, ocelots were not captured, harmed or stressed, as all data was obtained by camera trapp surveys.

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Author contributions

Conceptualization: TCMR. Data curation: LNL. Formal analysis: TCMR. Funding acquisition: TCMR. Investigation: JFCM, LNL, TCMR. Methodology: LNL, TCMR. Resources: TCMR. Supervision: JFCM, TCMR. Writing - original draft: TCMR. Writing - review and editing: JFCM, TCMR.

Author ORCIDs

Tiberio C. Monterrubio-Rico https://orcid.org/0000-0001-5786-9696
Leticia Núñez-Landa https://orcid.org/0009-0002-2639-6253
Juan F. Charre-Medellín https://orcid.org/0000-0002-2192-1680

Data availability

All of the data that support the findings of this study are available in the main text.

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Appendix 1

Table A1. Characteristics of 35 ocelot population studies using camera traps. RF= Rainforest, TDF= Tropical Dry Forest, STF= Semideciduous Tropical Forest, TS= Tropical Scrub.

Study and Country	Vegetation (precipitation mm)-	Area status	No. camera stations	Trapping effort (camera-trap/days)	Individuals identified	Density	Juveniles and cubs	Source
1 Ecuador	RF (3200)	Protected	26	2340	35-36	31-34	–	Salvador and Espinoza 2015.
2 Peru	RF (3000)	Protected	23	983-2085	22-27	49-64	2	Kolowski and Alonso 2010.
3 Brasil	RF (2373)	Protected	50	7020	19	12-25	–	Gómez da Rocha et al. 2016.
3 Brasil	RF (2373)	Protected	50	7020	30	27-40	–	Gómez da Rocha et al. 2016.
3 Brasil	RF (2373)	Protected	50	7020	17	19-28	–	Gómez da Rocha et al. 2016.
4 Colombia	RF (2236)	Protected	21	1283	6	5-11	–	Diaz-Pulido and Payán-Garrido 2011.
5 Panama	RF (6000)	Protected	14	490	11	22-93	–	Moreno and Bustamante 2009.
6 Costa Rica	RF (4000)	Protected	10	600	5	8-11	–	González-Maya and Cardenal-Porras 2011.
7 Bolivia	RF (2440)	Protected	69	1018	17	40-66	–	Ayala et al. 2010.
8 Brasil	STF (1800)	Protected	52	504	9	9-30	–	Trolle and Kelly 2005
9 Mexico	RF (3000)	Protected	29	1920	14	12.9	–	De la Torre et al. 2016.
10 Belize	RF (1500)	Protected	7-19	239-1577	4-19	25.85	–	Dillon and Kelly 2007.
11 Belize	RF (2000)	Protected	7-17	238-1513	9	8-26	–	Dillon and Kelly 2008.
12 Guatemala	STF (1350)	Protected	33	1455	38	10	–	Moreira et al. 2007.
13 Mexico	RF (2500)	Unprotected	29	8529	9	22-38	–	Pérez-Irineo and Santos-Moreno 2014.
14 Guatemala	RF (1700)	Protected	25	1150	17	10.83	–	Palomo-Muñoz et al. 2014.
15 Mexico	STF (1200)	Protected	27	2160	12	13.98	–	Torres-Romero 2009.
16 Bolivia	TDF (1200)	Protected	16-31	960-2280	18-42	24-66	–	Maffei et al. 2005.
17 Brasil	STF (1300)	Protected	30	450	9	62.11	1	Trolle and Kéry 2003.
18 Mexico	TDF (1300)	Unprotected	9-9	2378-2270	6-11	23.7	–	Monterrubio-Rico et al. 2017.
19 Mexico	STF (1511)	Protected	22-27	1936-1755	9-10	2-26	–	Avíla-Nájera et al. 2015.
20 Mexico	TDF (1017)	Protected	34-45	7786	15	4-46	–	Martínez-Hernández et al. 2014.
21 Brasil	STF (3014)	Protected	14-19	585	6	21	–	Fusco-Costa et al. 2010.
22 Argentina	RF (2200)	Protected	34-39	1409-1631	17-34	7-20	2	Di Bitetti et al. 2006.
23 USA	TS (680)	Protected	18	658	3	14.8	A pregnant female	Haines et al. 2006.
24 Argentina	RF (1919)	Protected	42-47	1871-2059	10-33	4-9	–	Di Bitetti et al. 2008.
25 México	RF (2500)	Protected	44	12800	5	7.82	1	Pérez-Irineo et al. 2017.
26 México	TDF (1441)	Protected	34	5168	51	131.2	2	Ocañas García, 2019.
27 Guatemala	RF (2252)	Protected	40	784	8	-	–	Hermes, 2004.
28 México	TDF (1800)	Protected	63	2381	13	-	2	Cacelin Castillo, L. A. 2015.
29 Panamá	RF (2600)	Protected	-	1824	-	163-181	4	Rodgers 2014.
30 Belize	RF (3000)	Protected	20-50	29137	-	6-22.5	–	Satter 2017.
31 Belize	RF (3000)	Protected	20-50	74854	51	6-14	–	Satter et al. 2019.
32 Ecuador	TDF (2800)	Protected	22-36	7000-1700	45	102-149	–	Mosquera 2011.
33 Colombia	TDF (2176)	Protected	9	360	2	1.5-1.8	–	Garrote et al. 2019.
34 Colombia	TDF (-)	Unprotected	41	1502	2	-	–	Valderrama-Vásquez 2013.
35 México	TS (400)	Unprotected	270	88508	33	1.53	–	Gómez-Ramírez et al. 2017.