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Article

Cambio de uso de suelo, fragmentación del paisaje y la conservación de *Leopardus pardalis* Linnaeus, 1758

Land-use change, landscape fragmentation and the conservation of *Leopardus pardalis* Linnaeus, 1758

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Resumen:

En México la selva alta perennifolia y el bosque mesófilo de montaña han sido eliminados y fragmentados, en estos ecosistemas habita el ocelote (*Leopardus pardalis*), una especie considerada en peligro de extinción en México. El objetivo del presente trabajo fue determinar los cambios de uso del suelo, fragmentación de la vegetación primaria y sus efectos sobre el ocelote, en una zona clave para la conectividad de sus poblaciones. Para llevar a cabo el trabajo, se calcularon las tasas de cambio de vegetación y uso del suelo, además se realizó un análisis de fragmentación. Para el registro de ocelotes, se colocaron cámaras trampa en un área de 110 km^2. Los resultados mostraron una tasa de cambio de -2.63 y -2.29 para la selva alta perennifolia y el bosque mesófilo de montaña, respectivamente. Las observaciones de ocelote ocurrieron en el interior o muy cercanas (1.6 km) a zonas con valor de conectividad mayor a 10 %. El tamaño de los fragmentos de hábitat fue pequeño: 0.85 ha para bosque mesófilo de montaña y 1.04 ha en selva alta perennifolia; y la conectividad entre ellos fue de <30 %. Estos resultados reflejan la necesidad de mantener la conectividad del paisaje para la conservación de las poblaciones de *L. pardalis*.

Palabras clave: Bosque mesófilo de montaña, carnívoros, conectividad, mamíferos, selva alta perennifolia, tasas de cambio.

Abstract:

In Mexico, the tropical rain forest and the mesophilic mountain forest have been eliminated and fragmented, and in these ecosystems is where the ocelot (*Leopardus pardalis*), a species considered in danger of extinction in Mexico, lives. The objective of this work was to determine the changes in land use, fragmentation of primary vegetation and its effects on the ocelot, in a key area for the connectivity of their populations. To carry out this work, the rates of change in vegetation and land use were calculated, and a fragmentation analysis was carried out. For the registration of ocelots, trap cameras were placed in an area of 110 km^2. The results showed a change rate of -2.63 and -2.29 for the tropical rain forest and the mountain mesophilic forest, respectively. Ocelot observations occurred inside or very close (1.6 km) to areas with a connectivity value > 10 %. The size of the habitat fragments was small: 0.85 ha for mountain mesophilic forest and 1.04 ha for tropical rain forest; and the connectivity between them was <30 %. These results reflect the need to keep landscape connectivity for the conservation of *L. pardalis* populations.

Key words: Mountain mesophilic forest, carnivores, connectivity, mammals, tropical rain forest, exchange rates.

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Introduction

Change in land use and the fragmentation of the landscape have led to the elimination and transformation of primary vegetation in more than 50 % of terrestrial ecosystems; these changes are associated with the growth of the human population, agriculture, livestock and the increase of industry (Mendenhall *et al.,* 2012).

In 2015, FAO cited for Mexico a primary vegetation change rate of -0.6 %, for the 2000-2010 period; and of -0.7 % from 1990 to 2015 (FAO, 2015). The analysis carried out by Mas *et al.* (2009) shows deforestation rates of -4.2 to -8.15 % for tropical rain forest and -10.1 % for mountain mesophilic forest.

This accelerated transformation has led to areas such as the northern and southeastern portions of the state of *Puebla* and the *Sierra Mazateca* of *Oaxaca* State, originally covered by high evergreen forest and mountain mesophilic forest, currently located in fragments and in a secondary state, surrounded by agriculture and induced grasslands for livestock (Guevara, 2011; Velasco *et al*., 2014).

Changes in the landscape cause changes in the spatial distribution of the species and even their elimination, which causes a chain effect of biodiversity loss (Fischer and Lindenmayer, 2007). The disappearance of a secondary predator, such as *Leopardus pardalis* (Linnaeus, 1758), affects the ecological balance of ecosystems (Terborgh *et al*., 2001).

The ocelot is distributed in both coastal plains of Mexico and in the *Yucatán* peninsula, it inhabits mainly densely covered areas such as: the high evergreen forest and the mountain mesophilic forest, thorny forests and the xerophytic scrub (Aranda, 2005). It also tolerates fragmented environments, but in places bordering large mountain ranges of protected natural areas (Torres-Romero, 2009; Michalski *et al*., 2010; Ramírez-Bravo *et al*., 2010; Cruz-Rodríguez *et al*., 2015). Therefore, it is necessary, not only to study the net reduction of the surface of its habitat, but the loss of connectivity of the patches of primary vegetation in very fragmented landscapes outside protected natural areas.

The ocelot in Mexico is classified in danger of extinction (Semarnat, 2010); at the international level, the Convention on International Trade in Endangered Species of Wild Fauna and Flora it is listed in Appendix I (CITES, 2015). On the other hand, the International Union for the Conservation of Nature and Natural Resources only classifies it as LC ("least concern"); that is, in "minor concern" (IUCN, 2015). The greatest threats to this mesopredator are human activities, such as the destruction and fragmentation of its habitat and hunting (Caso *et al*., 2008). In this context, the objective of this study was to assess the effects of land use change and landscape fragmentation on the spatial distribution of the ocelot in the *Sierra Negra de Puebla* and *Sierra Mazateca de Oaxaca*.

Materials and Methods

Study area

The study was developed in two adjoining mountain ranges: the *Sierra Negra de Puebla* and the *Sierra Mazateca de Oaxaca* (Figure 1). In the region the humid warm climate prevails with rains all the year, the temperature oscillates between 16 and 26 °C; rainfall varies from 3 000 to 4 500 mm (Inegi, 2009).

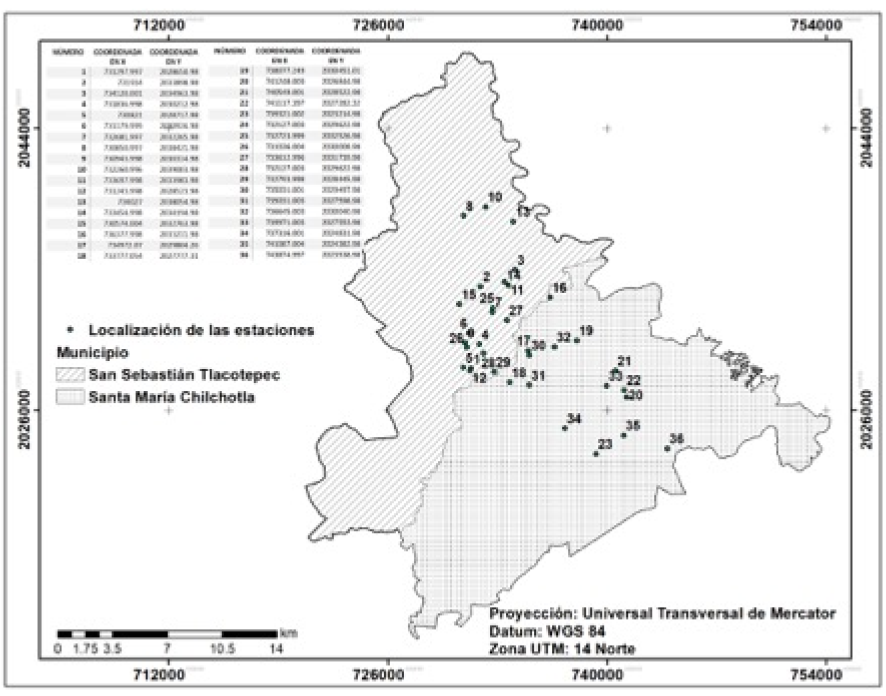


Figure 1. Location of the area of interest and phototramping stations in *San Sebastián Tlacotepec*, *Puebla* and *Santa María Chilchotla*, *Oaxaca*.

Field work was made in one municipality of each mountain range: *San Sebastián Tlacotepec* (SST), located in the southeast of the state of *Puebla*, between 18°14' and 18°32' N and 96°43 'and 96°55' W, with an altitudinal interval of 60 to 1 580 m (Inegi, 2010). SST has a total population of 13 534 inhabitants distributed in 61 towns, with an average population density of 56.99 km^{-2} inhabitants (CDI, 2010; Sedesol, 2013). Agricultural activities such as the cultivation of seasonal maize, sugar cane, coffee and the breeding of cattle and pigs in 40 % of their territory (Inegi, 2010).

The other municipality under study was *Santa María Chilchotla* (SMCH), located north of the state of *Oaxaca*, between 18°10 'and 18°24' N and 96°35' and 96°52' W, with an altitude of 0 to 2 100 m (Inegi, 2010). Its total population is 20 584 inhabitants distributed in 110 localities, with an average population density of 72.36 km^{-2} inhabitants (CDI, 2010; Sedesol, 2013). Agricultural activities occupy 60 % of its territory (Inegi, 2010). Within agriculture, coffee cultivation is the most important, followed by corn and beans. Regarding livestock, the low (tropical) zone is mainly dedicated to cattle, and in the middle (temperate) and high (cold) areas, to goats and sheep (García, 2008).

Land use and vegetation

The cartography of land use and vegetation (USV) was generated for two dates: 2000 and 2016. For the year 2000, Landsat 7 (ETM +) was used on July 13th, and for 2016, Landsat 8 (OLI-TIRS) was used on April 28th, both of path 24 / Row 47.

The effects of fog and cloudiness were reduced by the atmospheric correction of the images with the COST model (Chávez, 1996) incorporated to the Idrisi Selva program.

Due to the intensity of the fragmentation of the natural vegetation of the zones, it was necessary to improve the spatial resolution of the images with the sharpening tool and the Gram-Schmidt Spectral Sharpening algorithm of ENVI 4.7^{TM}, which allowed to increase the resolution of 30 to 15 m.

With the high resolution images, a supervised classification with the maximum likelihood algorithm was carried out. Spectral bands 4, 3, and 2 of Landsat 7 and 5, 4, 3 of Landsat 8 were used, since they are the best for vegetation analysis (Chuvieco *et al.,* 1995). To the resulting image of the classification, a majority filter was applied with a window size of 5 * 5, with which those isolated pixels were reclassified. The accuracy of the classification was determined with the value of the general precision and the Kappa coefficient (Lesschen *et al.,* 2005).

Sampling design

Based on the map of land use and vegetation of the year 2000, as well as the phototraping criteria described by Chávez *et al*. (2013) and Hernández-SaintMartín *et al.* (2013), a polygon of 110 km^2 was delimited, within which three lines separated by 3 km were drawn; in each one there were six phototraping stations (trap cameras: *StealthCam*® Delta8 model STC-Q8X/STC-D8BZ; *Cuddeback*® *Ambush Black Flash* model 1194; *Bushnell*® *Trophy Cam HD Essential y Covert*®) spaced 1 to 3 km apart. The 18 stations placed were georeferenced (Figure 1).

The cameras were installed on paths used by mammals, to maximize the probability of detection (Medellín *et al.,* 2006). These were programmed to take three photographs every 5 minutes, after the last photo capture. The equipment was placed at a height of 40 - 50 cm from the ground, at a distance of 2 m from the path. Six double stations were implemented, in which Obssesion® perfume was used as an attractant for felines.

Three sampling periods were carried out. The first was one month (December 2013 to January 2014), with 18 stations at a distance of 1 km between them. The second was conducted during one month (April 2014), with 11 stations spaced every 3 km. The third comprised 3 months (July-September 2014), with 18 stations, the distance between the cameras was 3 km (Hernández-Saint Martín *et al.,* 2013). The sum of the three sampling periods generated information from 36 different points, since eight cameras were damaged and three repeated locations during two seasons; 18 photographic equipment was placed in *acahuales* and 18 in primary vegetation, however the sampling effort was greater in primary vegetation: 943 trap days and in *acahual*: 702 days, for a total of 1 645 trap days.

Rate of vegetation change and land use

In order to know the dynamics of vegetation change and the speed at which these transformations occurred at a local scale, the vegetation change rate was estimated, for which, equation 1 was used (Palacio-Prieto *et al*., 2000):

$$C = \left[(T2/T1)^{(1/n)} - 1\right] * 100 \qquad \text{(Equation 1)}$$

Where:

C = Rate of change

T1 = Surface area covered by vegetation/land use *i* in the initial year

T2 = Surface area covered by vegetation/land use *i* in the most recent year

n = number of years of the analysis period

Landscape fragmentation

In order to describe the condition of the landscape and typify its occupation by the ocelot, landscape metrics considered relevant were estimated, according to what was referred by various authors: size, number and patch connectivity (Michalski *et al*., 2010; Ramírez-Bravo *et al*., 2010; Cruz-Rodríguez *et al*., 2015); thus, the Patch Analyst 5.1 (PA51) and Conefor Sensinode 2.2 (CS22) programs were used.

PA51 allowed to calculate the average patch size (MPS) and the number of patches (NumP) (Rempel *et al.,* 2012). Ocelot habitat coverings included high evergreen forest and mountain mesophilic forest. A buffer size (or edge) of 100 m was used.

The Integral Index of Connectivity (IIC) was calculated through CS22, which estimates the degree of connectivity of vegetation relicts considered as habitat (Saura and Pascual-Horta, 2007). Equation 2 shows the variables used:

$$IIC= \frac{\sum_{j=1}^{n}\sum_{j=1}^{n}\frac{ai*aj}{1+nl_{ij}}}{A_L^2} \qquad \text{(Equation 2)}$$

Where:

IIC = Integral Index of Connectivity

n = Total number of nodes in the landscape

ai, aj = Attributes of the nodes i and j

nl_{ij} = Number of links of the shortest route (topological distance) between the i and j patches

AL = Maximum attribute of landscape (it is the value of the attribute that that would correspond to a patch that covers all the landscape with the best possible habitat)

A search threshold of 1 800 m was determined, a distance that was established according to the home range of the ocelot; in literature, values of 1 800 to 4 500 m are recorded (Torres-Romero, 2009).

The importance of the patches was calculated based on what was obtained in IIC, and consisted of assigning a value to each node in terms of its level of importance to maintain connectivity within the landscape; it was calculated as a percentage and was estimated by applying equation 3.

$$dIIC(\%) = 100 * \frac{I-I\ removed}{I} \qquad \text{(Equation 3)}$$

Where:

dIIC = Importance of nodes calculated by the Integral Index of Connectivity

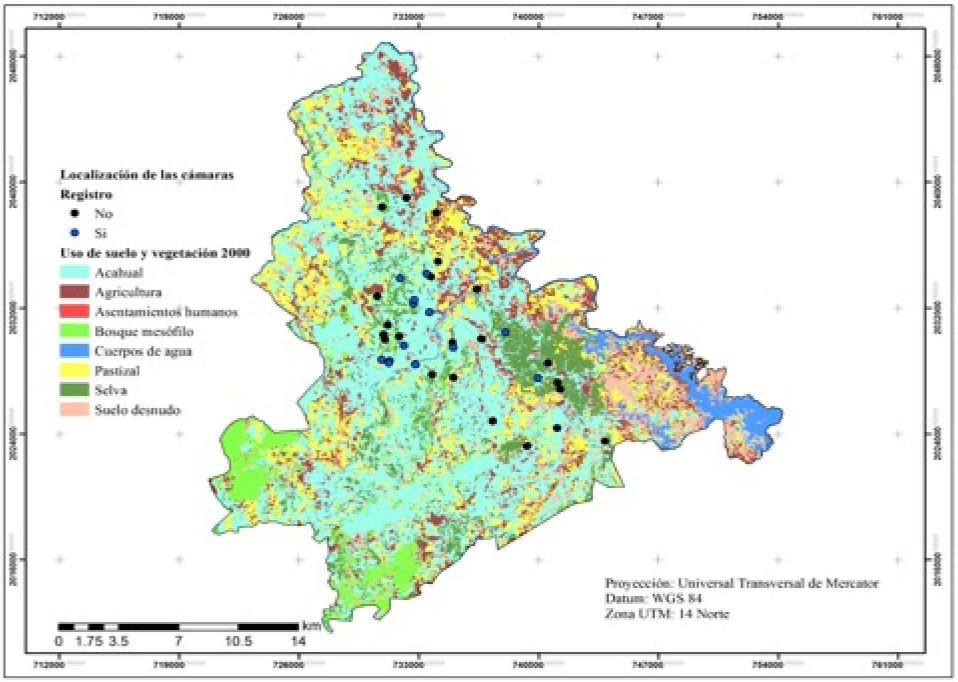
I = Value of the global index when all the initially existent nodes are present in the landscape.

I removed= Value of the general index after the elimination of a unique node of the landsape

Results and Discussion

The general accuracy obtained for the USV mapping of the year 2000 was 88 % and a Kappa coefficient of 0.86; for 2016, an accuracy of 91.9 and a Kappa coefficient of 0.90 was obtained. According to Lesschen *et al.* (2005) the values of general precision obtained for both dates are acceptable and reliable for post-classification studies.

The identified land and vegetation uses are shown in figures 2 and 3. The acahual occupied the highest percentage of surface area with 44.3 % (2000) and 48.6 % (2016); the mountain mesophile forest and the high evergreen forest represented 9.6 % of the study area. These results differ from what was indicated by the Inegi in the V and V land use mapping, where the area corresponding to the two covers totals 5.8 %. As indicated by Mas *et al.* (2009), these contrasts are mainly due to the spatial scale and the methodology used in the elaboration of both cartographies, which does not denote the superiority of one or the other method, but rather the condition and dynamics of the vegetation coverage of the area under study.



Localización de las cámaras = Location of cameras; *Registro* = Register; *No* = No; *Si* = Yes; *Uso de suelo y vegetación* = Land use and vegetation; *Agricultura* = Agriculture; Asentamientos humanos = Human settlements; *Bosque mesófilo* = Mesophilic forest; *Cuerpos de agua* = Water bodies; *Pastizal* = Grasslands; *Selva* = Tropical rain forest; *Suelo desnudo* = Bare soil.

Figure 2. Land use and vegetation year 2000.

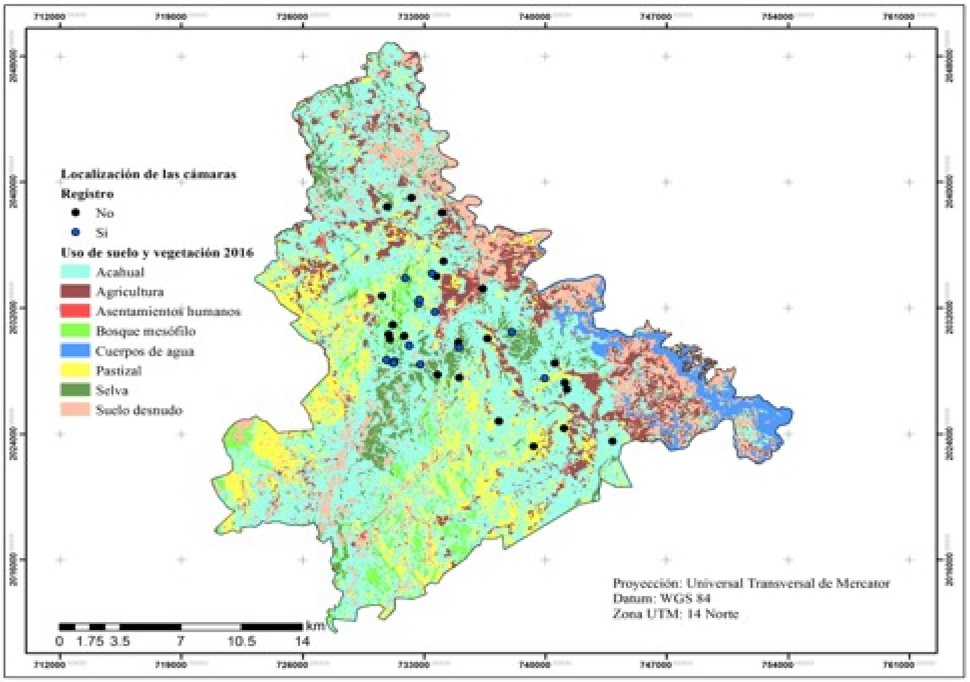


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Figure 3. Land use and vegetation year 2016.

The ocelot was observed in 13 stations, 23 % of the records were in *acahuales* and 77 % in primary vegetation (high evergreen forest and mountain mesophilic forest). Results that indicate a greater presence of *Leopardus pardalis* in conserved environments, compared with disturbed ones. In contrast, in the Mexican southeast, Gil-Fernández *et al.* (2017) determined that it is one of the felines most tolerant to fragmentation; and Cruz-Rodríguez *et al.* (2015) in the Colombian Caribbean, recorded 55 % sighting vegetation with disturbance (agriculture, pasture, scrub and secondary vegetation). It is possible that the contrast is due to the fact that the sampling effort in the study area was higher in the primary vegetation than in the *acahuales (*secondary vegetation*)*.

The rates of change for high evergreen forest and mountain mesophilic forest were -2.63 and -2.29, respectively (Table 1), which exceeds that documented by Díaz-Gallegos *et al.* (2010) for the Mexican southeast in the period 1978-2000, whose average rates varied from - 0.8 to -1.0 %.

Table 1. Area and rate of change for the period 2000-2016 in the *Sierra Negra de Puebla* and *Sierra Mazateca de Oaxaca*.

Terrestrial coveers	**Year 2000** **Surface area (ha)**	**Año 2016** **Surface area(ha)**	**Change rate** **%**
Acahual	23 058.8	25 298.3	0.58
Agriculture	6 561.8	5 349.6	-1.27
Human settlements	27.7	148.1	11.04
Mesophilic forest	3 040.5	2 099.0	-2.29
Water bodies	2 021.2	2 006.7	-0.05
Grasslands	8 292.6	7 411.7	-0.70
Tropical rain forest	4 448.8	2 904.9	-2.63
Bare soil	4 608.3	6 841.2	2.50
Total area	52 059.7 ha		

[1] = Positive values indicate surface area gain and negative values, loss.

The primary vegetation lost in a period of 16 years became areas destined for agriculture and livestock, these changes occurred mainly in areas near water bodies and population centers; therefore, the growth of human settlements is the main cause of deforestation and fragmentation of the landscape in *Sierra Negra* and *Sierra Mazateca*. This agrees with the research carried out by other authors in similar sites (Velasco *et al*., 2014; Reynoso *et al.*, 2016). If this trend of change keeps without changes, the habitat of the ocelot will be reduced and there will be an increase in encounters with the inhabitants, who perceive them as a threat to their domestic animals, which leads to an increase in hunting (Velasco *et al*., 2014; Galindo-Aguilar *et al*., 2016).

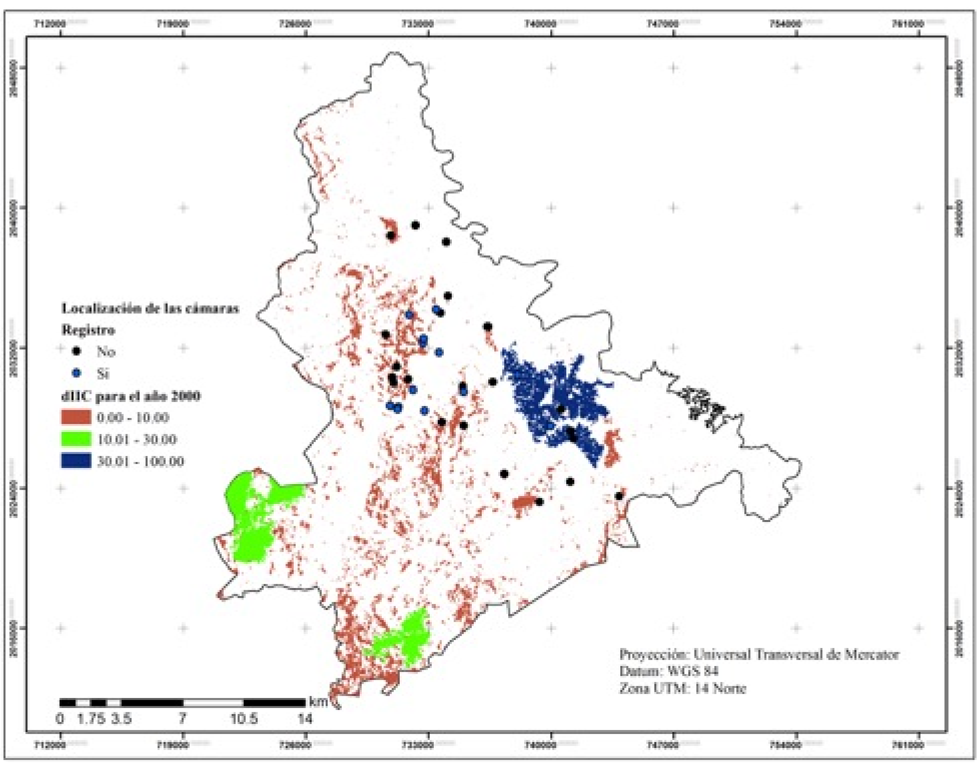
The results of the landscape metrics, calculated using PA51, showed an accelerated process of fragmentation of the native vegetation. For the mesophilic mountain forest an increase in the number of patches and the decrease in the size of the same was observed, which indicates that the compact areas that were in 2000, for the year 2016 were fragmented and resulted small patches isolated to the interior from the landscape. The same dynamic was presented for the high evergreen forest. Currently, the average size of the tropical forest patch is 1.04 ha and that of the mountain mesophile forest is 0.85 ha (Table 2); areas insufficient to maintain an ocelot population in the study area, if we consider that Benchimol and Peres (2015) calculated that the critical area required for this feline is 20 ha.

Table 2. Landscape metrics calculated by PA51 for the *Sierra Negra de Puebla* and *Sierra Mazateca de Oaxaca*.

Cover	**MPS 2000 (ha)**	**MPS 2016 (ha)**	**NumP 2000**	**NumP 2016**
Acahual	4.61	3.08	789.00	963.00
Agriculture	1.11	1.96	123.00	140.00
Mesophilic forest	21.55	0.85	37.00	53.00
Water bodies	13.93	12.27	32.00	37.00
Grassland	0.85	1.50	252.00	248.00
Tropical rain forest	3.98	1.04	103.00	82.00
Bare soil	1.20	1.97	74.00	189.00

[2] = Average value of the surface area of all the patches in the landscape; [3] = Number of patches per class.

The Index of Connectivity showed dynamic changes. In the *Sierra Mazateca*, in the year 2000, the areas where connectivity existed exceeded 30 %, but in 2016 they decreased to less than 30 %. However, it was observed that in *Sierra Negra* that some areas with connectivity of less than 10 % increased to 30 % (figures 4 and 5). It is possible that these changes are due to the system of slash-and-burn agriculture used by rural communities in the tropics (Conklin, 1961). This system is imade-up by by crop areas, *acahuales* and primary vegetation that are rotated; once the sowing season ends, they let the area repopulate with vegetation, which leads to the formation of the *acahuales*, and later to the mature forests. *Acahuales* are strategic for the conservation of tropical mammals (Naughton-Treves *et al*., 2003; Gonzáles-Marín *et al*., 2008; Guzmán-Aguirre, 2008); as long as their age is greater than seven years (Ochoa *et al*., 2007).



Figue 4. Index of Comnectivity for the year 2000.

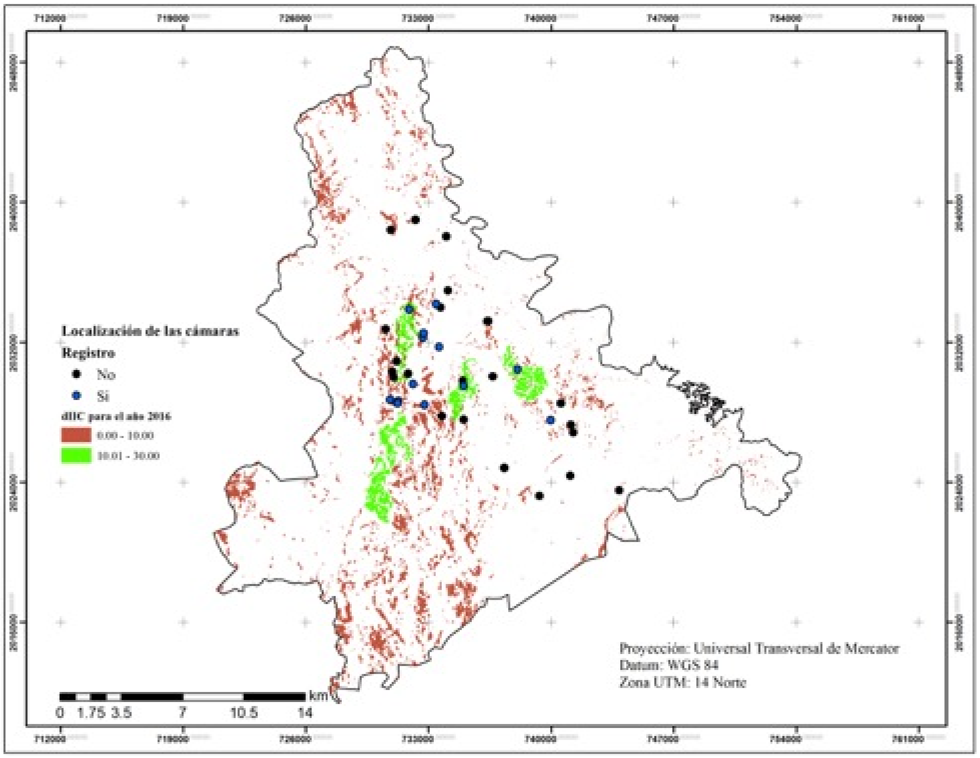


Figure 5. Index of Connectivity for the year 2016.

The cameras that filmed ocelots were located inside or very close (1.6 km) to areas with a connectivity value higher than 10 %. These results support the need to maintain vegetation remnants with dense cover and high connectivity, a fact that other authors have pointed out (Martínez-Calderas *et al.,* 2011).

Conclusions

The ocelot shows preference for areas covered by primary vegetation and with greater connectivity; therefore, if the accelerated loss and fragmentation of habitat in the *Negra* and *Mazateca* mountain ranges continues, the conservation of *Leopardus pardalis* is at risk.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Rosa Elena Galindo Aguilar and María Jesús Hernández Pérez: design of the study, methodology planning, field data recollection, data analysis and writing of the manuscript; Roberto Reynoso Santos: review and correction of the manuscript; Octavio Rosas-Rosas: design of the study, methodology planning, review and correction of the manuscript; Catalina González Gevacio: review and correction of the manuscript.

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