UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
POSGRADO EN CIENCIAS BIOLÓGICAS

INSTITUTO DE BIOLOGÍA

ECOLOGÍA

LOS CARNÍVOROS EN MÉXICO Y SU IMPACTO EN LOS PUEBLOS MESOAMERICANOS

TESIS

(**POR ARTÍCULO CIENTÍFICO**)

Connecting worlds: indigenous territories, habitat suitability and conservation of three large carnivores (Mammalia: Carnivora) in southern Mexico

QUE PARA OPTAR POR EL GRADO DE:

MAESTRA EN CIENCIAS BIOLÓGICAS

PRESENTA:

Biól. Emilia Fernanda Guerrero Montes de Oca

TUTOR PRINCIPAL DE TESIS: Dr. Víctor Manuel Guillermo Sánchez Cordero Dávila

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Centro Regional de Investigaciones Multidisciplinarias

Ciudad Universitaria, CD. MX., Julio, 2021

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COORDINACIÓN DEL POSGRADO EN CIENCIAS BIOLÓGICAS
INSTITUTO DE BIOLOGÍA
OFICIO CPCB/596/2021
ASUNTO: Oficio de Jurado

M. en C Ivonne Ramírez Wence
Directora General de Administración Escolar, UNAM

P r e s e n t e

Me permito informar a usted que en la reunión ordinaria del Subcomité de Ecología, Manejo Integral de Ecosistemas, Biología Evolutiva y Sistemática del Comité Académico del Posgrado en Ciencias Biológicas, celebrada el 26 de abril del 2021, se aprobó el siguiente jurado para el examen de grado de **MAESTRA EN CIENCIAS BIOLÓGICAS** en el campo de conocimiento de **ECOLOGÍA** de la alumna **GUERRERO MONTES DE OCA EMILIA FERNANDA** con número de cuenta **308010257** por la modalidad de graduación de **tesis por artículo científico** titulado: **"Connecting worlds: indigenous territories, habitat suitability and conservation of three large carnivores (Mammalia: Carnivora) in southern Mexico",** que es producto del proyecto realizado en la maestría que lleva por título: **"Los carnívoros en México y su impacto en los pueblos mesoamericanos",** ambos realizados bajo la dirección del **DR. VÍCTOR MANUEL GUILLERMO SÁNCHEZ CORDERO DÁVILA,** quedando integrado de la siguiente manera:

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Vocal:	**DR. FRANCISCO ROBERTO VERGARA SILVA**
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Sin otro particular, me es grato enviarle un cordial saludo.

A T E N T A M E N T E
"POR MI RAZA HABLARÁ EL ESPÍRITU"
Ciudad Universitaria, Cd. Mx., a 17 de junio de 2021

COORDINADOR DEL PROGRAMA

DR. ADOLFO GERARDO NAVARRO SIGÜENZA

POSGRADO EN CIENCIAS BIOLOGICAS
COORDINACIÓN

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VII

"Que nada te asuste sobre la tierra
pues contigo nació
el que acompaña tus pasos
alma de tu ser
al que para guardarte mandaron
tigres
árboles
y peñascos[1]*"*

Irma Pineda Santiago[2]

[1] Santiago, P. (2008). Irma. Doo yoo ne ga'bia': De la casa del ombligo a las nueve cuartas. *Zapoteca del Istmo/Español. Comisión Nacional para el Desarrollo de los Pueblos Indígenas (CDI), Serie Literatura Indígena Contemporánea*, México. 37 p.

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Índice

Resumen

En la historia de México han aparecido diferentes percepciones hacia la vida silvestre y entre esas percepciones, hay evidencias que los grandes carnívoros habían sido considerados en la época prehispánica como símbolos sagrados y mensajeros de los dioses. Pero entonces, ¿qué sucedió a través de la historia que, de ser considerados animales sagrados, hoy en día es uno de los grupos más afectados ante la gran amenaza ambiental y antrópica? El primer objetivo de este trabajo fue analizar la relación entre humanos y carnívoros y analizar los componentes históricos y actuales que han influenciado en la percepción de la relación humanos-carnívoros en Oaxaca. Se inició con investigación documental de gabinete sobre las evidencias de interacción entre carnívoros y humanos, en el Pleistoceno, examinando los procesos de domesticación animal, migración de los humanos y migración de los carnívoros a través del Estrecho de Bering. Así mismo, se investigó sobre la representación de los carnívoros dentro de la cosmovisión de los pueblos mixtecos, zapotecos y nahuas en Oaxaca. Posteriormente, se analizó la percepción de los carnívoros en la Península Ibérica durante el siglo XV y durante el proceso de colonización de la Nueva España. Por último, se analizaron reportes recientes de casos de conflictos entre humanos y carnívoros en Oaxaca dentro de publicaciones científicas. Demostramos la importancia de las alianzas históricas entre pueblos indígenas y carnívoros. En su mayoría estas alianzas históricas fueron positivas, pero actualmente fluctúan debido a intereses económicos y sociales. Por lo que se propone que la percepción actual de estas comunidades indígenas hacia los carnívoros tiene un vínculo histórico con fines utilitarios, pero además se basan fuertemente en los componentes naturales que los carnívoros ofrecen hacia la localidad. De esta forma, esta percepción basada en la naturaleza, podría facilitar las iniciativas de conservación hacia los carnívoros. El segundo objetivo de este trabajo de investigación fue analizar la relación geográfica que tienen pueblos de alta autoadscripción indígena (mixteca y zapoteca) con la idoneidad de hábitat del jaguar, puma y coyote. Para ello, se realizó un análisis multicriterio multitemporal y se realizaron modelos espaciales de idoneidad, para obtener la disponibilidad de hábitat y su idoneidad para tres especies de carnívoros (jaguar, puma y coyote) y su relación con dos de los principales pueblos indígenas (Mixtecos y Zapotecos) en el estado de Oaxaca, México. Encontramos una relación positiva entre la alta autoadscripción indígena y el alto índice de idoneidad del hábitat para la conservación de estas 3 especies de carnívoros en las regiones de Sierra Norte, sierra Sur, Costa y región mixteca. Al estar la mayoría de estas zonas fuera de las áreas protegidas, la inclusión de los pueblos indígenas en el manejo y la planificación del territorio

es de gran importancia para salvaguardar la memoria biocultural y asegurar la permanencia de especies de carnívoros y sus ecosistemas en Oaxaca.

Abstract

In the history of Mexico different perceptions of wildlife have appeared and among these perceptions, there is evidence that great carnivores had been considered in pre-Hispanic times as sacred symbols and messengers of the gods. But then, what happened throughout history than being considered sacred animals, today it is one of the groups most affected by the great environmental and anthropic threat? The first objective of this work was to analyze the relationship between human and carnivores and analyze the historical and current components, which have influenced the perception of humans to carnivores, specifically in Oaxaca. It began with a literature research on archaeological evidence of interaction between carnivores and humans, from the Pleistocene, focus on the subject of animal domestication and the process of migration of humans and carnivores through the Bering Strait, then, we described punctually the presence of carnivores in America. Second, we analyzed the representations of carnivores within the cosmovision of the Zapotecs, Mixtecs and Nahuas of Oaxaca. Third, we explored the perception about the carnivores in a European context at the end of the fifteenth century and during the colonization process of New Spain. Finally, we analyzed recent human–carnivores conflicts conducted by literature research based on scientific publications. We demonstrate the importance of the human history alliances, especially in the indigenous peoples of Oaxaca, are mostly positive but which today have fluctuated according to economic and social practices. We propose that the current perception of these indigenous communities on human–carnivores conflicts has an historical utilitarian–based component from the Colonial period, but also includes a nature–based component on the carnivore species occurring in their region. This nature–based perception of indigenous cosmovision has strongly facilitated community–based conservation initiatives of carnivore species in Oaxaca. The second objective of this research work was to analyze the geographical relationship of population with high indigenous self-description (Mixtecs and Zapotecs) with the suitability of habitat of the jaguar, cougar and coyote. To do this, we used multi-temporal and multi-criteria analyses to assess species habitat suitability of the jaguar (*Panthera onca*), puma (*Puma concolor*), and coyote (*Canis latrans*), and quantified the overlap with the Mixtec and Zapotec indigenous territories in Oaxaca. We observed a positive and proactive relationship between indigenous communities' self-identification and a high species habitat suitability for the conservation of these large carnivores in the Sierra Norte, Sierra Sur, Coastal, and Mixtec regions. Given that most of these areas occur outside natural protected areas, the inclusion of indigenous communities in the management of their

territory is crucial for preserving their ethnocentric vision and ensuring long-term conservation of these charismatic top predator species and their habitat in Oaxaca.

Introducción general

A través de la historia de México, se ha observado el vaivén en las relaciones entre poblaciones humanas y vida silvestre. Específicamente desde hace más de 200 años la fauna silvestre ha estado en una constante amenaza debido a la gran influencia que tuvieron los mitos impuestos por la conquista europea. Parte de la fauna silvestre mexicana que alguna vez fue considerada sagrada hoy está considerada en peligro de extinción. Este trabajo desarrolla 2 estrategias metodológicas que conforman 2 capítulos, uno de investigación bibliográfica y otro experimental, centrándonos en el estado de Oaxaca (uno de los estados de más amplia multiculturalidad en México). La elaboración de este proyecto nos otorga un seguimiento histórico y un seguimiento geográfico actual que desarrolla importantes relaciones entre la biodiversidad y la diversidad étnica y, por último, realzamos la importancia de estrategias de conservación a partir de las relaciones humano-vida silvestre.

La vida silvestre ha sido parte de los conflictos e intereses de actores que han ido apareciendo en los procesos de urbanización e industrialización. Actores como ganaderos, campesinos y comunidades indígenas originarias compiten entre ellos y defienden sus propios intereses económicos y políticos, lo cual los perjudica a ellos mismos y al hábitat natural circundante, específicamente a los carnívoros. La conceptualización de éstos como depredadores, es parte de una ideología y una percepción originada por experiencias, emociones y creencias que se reproducen mediante acciones ligadas a relaciones de poder que por lo general son asimétricas entre los humanos y los carnívoros. La posición en la que el humano se ha mantenido ha causado modificaciones importantes en los procesos ecológicos con implicaciones importantes en la conservación de la biodiversidad. Esto ha generado como resultado la aparición de interacciones negativas hacia las especies que son consideradas depredadores, que identifica a los mamíferos carnívoros, principalmente por una competencia por espacio y recursos (Crooks, 2002; Arias-Alzate, 2013). Este conflicto se aborda principalmente desde una perspectiva científica, pero también los ámbitos político, económico y social están sumamente involucrados. Por ello, para poder entender la problemática, y poder generar estrategias que mejoren las dinámicas ecológicas y sociales, es importante conocer el origen de las interacciones negativas humano-fauna silvestre, que se pueden agrupar principalmente en dos tipos: a) competencia o b) conflicto por depredación. La competencia se genera cuando la fauna silvestre, por ejemplo, los carnívoros y los

humanos entran en disputa indirectamente por un recurso y/o espacio limitado. Esto causa una relación horizontal entre ambos competidores, ya que actúan como rivales por recursos y/o por territorio (Knight, 2000). Por otro lado, el conflicto por depredación puede ser una relación vertical, ya que, en este caso, los animales carnívoros interactúan atacando al ser humano o a los animales domésticos, causando así una interacción antagonista entre ambas partes. Esta relación generalmente trae como resultado la persecución y muerte de los animales carnívoros depredadores (Knight, 2000).

Sin embargo, la visión descrita anteriormente no necesariamente es la misma que la que tenían los pueblos originarios o pueblos indígenas que son considerados los herederos de un largo linaje cultural que conoce y maneja la biodiversidad del territorio que comparten (Toledo y Barrera, 2008). Este dato en particular, es necesario tomarlo en consideración debido a que entre el 70% y 80% de los bosques y selvas en México son propiedad de dueños de ejidos y de comunidades indígenas (Galindo, 2010). Todo esto en conjunto, conforma un complejo biológico-cultural producto de los miles de años de interacción entre las culturas y sus ambientes naturales (Toledo y Barrera, 2008). Las diversas representaciones de carnívoros, de aproximadamente 2,500 años de antigüedad, demuestran que alguna vez existió una cosmovisión distinta que estaba fuertemente relacionada con la naturaleza, incluyendo a los carnívoros (Capítulo I, Tabla 1).

En este contexto, uno de los estados en México que cuenta con más número de grupos o pueblos indígenas es el de Oaxaca. Cuenta con 1,205,886 personas de 18 grupos indígenas de los 65 grupos existentes en México, haciendo de este estado uno de los más multiculturales del país ("Dirección General de Población de Oaxaca: Oaxaca población Siglo XXI", 2018). El 72% del territorio oaxaqueño es de pertenencia colectiva dentro de las comunidades indígenas (Galindo, 2010). Es el estado con el mayor porcentaje de población indígena, aproximadamente 7 de cada 10 personas se consideran indígenas y las lenguas indígenas que sobresalen son el zapoteco y mixteco, que juntas concentran más del cincuenta por ciento de los hablantes de alguna lengua indígena en la entidad (INEGI, 2015).

Oaxaca, siendo un territorio con elevada biodiversidad, la alta correspondencia entre las áreas de mayor biodiversidad y territorios indígenas da lugar a un término llamado “axioma biocultural”. Este “axioma” propuesto por B. Nietschmann (1992) habla de una relación geográfica dependiente entre la diversidad biológica y la cultural (Toledo y Barrera, 2008). De esa forma, esta relación constituye un principio clave para la conservación y sus aplicaciones interdisciplinarias.

Considerando lo anterior, el primer objetivo principal de este trabajo fue analizar las

relaciones entre humanos y carnívoros a partir de componentes históricos, y analizar cómo estos elementos han influenciado en la percepción y en la relación actual de las poblaciones humanas y los carnívoros distribuídos en Oaxaca. Como segundo objetivo principal fue analizar la relación geográfica que tienen pueblos de alta autoadscripción indígena con la idoneidad de hábitat de jaguar, puma y coyote, con el fin de integrar una estrategia de manejo y conservación hacia los carnívoros que realze la inclusión, percepción y simbolismo de los pueblos índigenas.

Para llevar a cabo los objetivos principales se dividió el trabajo en dos capítulos, en el capítulo I (ver Anexo) analizamos las interacciones humano-carnívoro desde un enfoque interdisciplinario, específicamente histórico, antropológico, etnológico y biológico. En la sección inicial, se realizó un análisis bibliográfico que describe el tipo de interacción que tuvo lugar entre humanos y carnívoros, enfocando el análisis hacia las relaciones establecidas a partir de los procesos de domesticación. En la sección siguiente, examinamos la cosmovisión de pueblos originarios de Mesoamérica que tienen hacia numerosas especies de carnívoros mediante documentos históricos del siglo quince y dieciséis (periodo pre-Colonial). En la tercera sección se analizaron las ideas que se tenían hacia los animales y hacia ciertos carnívoros, en particular en la Península Ibérica a finales del siglo quince y posteriormente poder enfocarnos en las relaciones y perspectivas de los carnívoros que se trasladan y establecen al Nuevo Mundo. En la cuarta y última sección nos enfocamos en los conflictos que involucran a los pueblos indígenas y a los carnívoros en la actualidad en Oaxaca. Con la finalidad de realzar la relevancia que estas percepciones fuertemente influyen en las acciones de conservación locales.

Al conocer la gran relevancia que tienen los pueblos indígenas y sus percepciones hacia los carnívoros, en el capítulo II (artículo científico presentado en sobretiro de la versión publicada), evaluamos la relación geográfica de dos grupos indígenas principales (mixtecas y zapotecas) y la idoneidad del hábitat del jaguar (*P. onca*), puma (*P. concolor*) y coyote (*C. latrans*), tres especies carismáticas carnívoras presentes en Oaxaca. Dado que la autoadscripción de estas comunidades indígenas involucra una alianza con la biodiversidad (Capítulo I), asumimos que la superposición de hábitats idóneos con un alto valor etnocultural y biológico en la región proporciona un escenario positivo para la conservación de estas grandes especies de carnívoros. Esto es de particular importancia no sólo para la conservación a largo plazo, sino también teniendo en cuenta que en esta región la toma de

decisiones sobre planeación y regulación territorial implica más del 70% de bosques y selvas, que entran en las demarcaciones de ejidos y comunidades indígenas (Galindo 2010). De esta forma realzamos la importancia que tiene la inclusión de los pueblos indígenas en el manejo y la planificación del territorio para salvaguardar la memoria biocultural y asegurar la permanencia de especies de carnívoros y sus ecosistemas en Oaxaca.

NOTA: El presente artículo científico deriva de los resultados obtenidos en la investigación correspondiente en el Anexo de esta Tesis. Por lo que cronológicamente se realizó primero la investigación del Anexo y posteriormente el artículo científico.

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Connecting worlds: indigenous territories, habitat suitability and conservation of three large carnivores (Mammalia: Carnivora) in southern Mexico

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ABSTRACT

Human and wildlife conflicts pose conservation challenges for several charismatic species worldwide. Given their close and long-standing interactions with wildlife, indigenous communities set an interesting framework to identify factors establishing these relationships. The first step is to account the perceptions and symbolisms of indigenous communities to define and complement conservation efforts. We used multi-temporal and multi-criteria analyses to assess species habitat suitability of the jaguar (*Panthera onca*), puma (*Puma concolor*), and coyote (*Canis latrans*), and quantified the overlap with the Mixtec and Zapotec indigenous territories in Oaxaca, located in southern Mexico. We observed a positive and proactive relationship between indigenous communities' self-identification and a high species habitat suitability for the conservation of these large carnivores in the Sierra Norte, Sierra Sur, Coastal, and Mixtec regions. Given that most of these areas occur outside natural protected areas, the inclusion of indigenous communities in the management of their territory is crucial for preserving their ethnocentric vision and ensuring long-term conservation of these charismatic top predator species and their habitat.

Keywords: Human-Wildlife Conflict; Jaguar; Puma; Coyote; Indigenous Communities.

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SIGNIFICANCE STATEMENT

This study assessed from a spatial ecology perspective, the relationship between indigenous communities and the conservation of large carnivore species. We used a multitemporal and a multicriteria habitat suitability analyses to infer the habitat suitability of the jaguar (*Panthera onca*), puma (*Puma concolor*), and coyote (*Canis latrans*), and its association with two indigenous territories in southern Mexico. The findings showed a high geographic overlap of a positive and proactive relationship between indigenous communities' self-identification and a high species habitat suitability for the conservation of these large carnivores. The inclusion of the indigenous communities in conservation actions is a crucial step to ensure the preservation of their ethnocentric vision, and long-term protections of these charismatic top predator species.

INTRODUCTION

The human population has been significantly increasing in the last 200 years along with an exponential demand for natural resources (FAO 2017). Rapid human population increase entailed overexploitation of natural resources, drastically degrading the landscapes and ecosystems. This has resulted in significant detrimental impacts on local indigenous communities, and the provision of environmental services and biodiversity conservation essential for their well-being (González-Maya et al. 2013; Ellis 2011; Ripple et al. 2014; Easter et al. 2020). The overexploitation of natural resources has increased human and wildlife conflicts worldwide, posing conservation challenges on several charismatic species. Further, the loss of large areas of ecosystems has reduced several environmental services of which indigenous communities are highly dependent (Redford 1992; Crooks 2002; Brooks et al. 2006; González-Maya et al. 2013; Williams et al. 2018). The consequences due to rampant natural habitat degradation have raised international concerns urging to establish conservation strategies that incorporate local inhabitants involved in programs of sustained use of natural resources and biodiversity conservation (United Nations 2019). However, some approaches to conservation were not adequately oriented so as to afford integral protection to biodiversity, it is necessary to include local inhabitants and their relationship with the environment (González-Maya et al. 2013; Williams et al. 2018).

In Mexico, the indigenous communities cosmovision linked to biodiversity is in many cases preserved, and this includes charismatic species as large carnivores (Saunders 1994; Seller 2004; López Austin 2012, 2013; Sánchez and Durán 2018). However, regional conservation of biodiversity sets some challenges as local indigenous communities face cultural distortions, given the vision of some stakeholders to apply a strict economic use of natural resources and the expansion of areas for agriculture and livestock (Toledo 2001; Toledo and Barrera 2008; Descola 2001). For this reason, conflicts between the local indigenous communities and wildlife arise, particularly in areas where livestock losses occur due to large carnivores' predation (Guerrero-Montes de Oca et al. in preparation). Hence, conservation actions need to incorporate an integrated and participatory vision for preserving the biodiversity perceptions and historical symbolism of the indigenous communities. An integrated strategy needs to include the preservation of indigenous identity, sustainable use of natural resources, and conservation of biodiversity and ecosystems that provide critical environmental services to local inhabitants (Stevens 1997; Carabias et al. 2010; González-Maya et al. 2013).

The Mexican State of Oaxaca has been identified with a high diversity of multiculturality holding a high percentage of the indigenous population in Mexico. It is estimated that approximately 70 - 80% of its territory shows a collective self-attribution to one or another indigenous community (Galindo 2010), including two of the main ethnolinguistic groups, the Mixtecs (*Ñuu savi*) and the Zapotecs (*Binnizá, Bene Xon, or Ben'zaa*) (INEGI 2015; INALI e INPI 2019). The Mixtecs and Zapotecs are among the most ancient groups in Oaxaca, where their presence has been recorded over the last 3,500 years. The Mixtecs are located in the Mixteca Alta, Mixteca Baja, and the Coastal Zone regions, and have been characterized by the depth and continuity of its beliefs (INALI e INPI 2019). The Zapotecs are the dominant group—in political, economic, and cultural spheres—in extensive regions of Oaxaca, including the Central Valleys and the Isthmus of Tehuantepec (Vela 2010; INALI and INPI 2019). For over 2,500 years, diverse records (e.g., sculptures and other artistic products, and narrative and mythical traditions) have been found documenting the positive and proactive vision of these ethnic groups on biodiversity and a close and long-standing interaction with large carnivore species occurring in Oaxaca (Guerrero-Montes de Oca et al. in preparation).

Oaxaca also holds an exceptional species richness and endemicity of flora and fauna, ranking top in terrestrial vertebrate species nationwide (García-Mendoza et al. 2004). It is considered a Mesoamerican biodiversity hotspot, although human-induced activities such as deforestation, livestock and urbanization expansion threaten its conservation (Monroy-Gamboa et al. 2019). However, Oaxaca includes few protected areas covering a small fraction of less than 5% of its territory and more recently a high number of conservation initiatives involving governmental agencies, non-governmental organizations, and local communities have established areas with specific objectives related to biodiversity conservation (Monroy-Gamboa et al. 2019).

We assessed the geographic overlap of two main indigenous groups (Mixtecs and Zapotecs) and the habitat suitability of jaguar (*Panthera onca*), puma (*Puma concolor*) and coyote (*Canis latrans*), three large top predators and charismatic carnivore species occurring in Oaxaca. Given that self-identification of these indigenous communities entails a proactive appreciation of biodiversity, we assumed that the overlap of suitable habitats with a high ethnocultural and biological value in the region provides a proactive scenario for the conservation of these large carnivore species. This is of particular importance not only for the long-term conservation, but also given that

in this region decision-making on territorial planning and regulation involves over 70% of woodlands and tropical forests, which enter into the demarcations of *ejidos* and indigenous communities (Galindo 2010).

MATERIAL AND METHODS

Study Area

The study area is located in the State of Oaxaca in southern Mexico (17.0732° N, 96.7266° W) with an area of 93,757 km^2 (4.85% of Mexico) (Figure 1). It is divided into 570 municipalities that are grouped into eight regions and 30 districts (INEGI 2017a). Oaxaca has a complex topographic and climatic composition, where the Sierra Madre del Sur and the Sierra Madre Oriental converge. Almost 70% of the area of Oaxaca shows a tropical humid climate mostly located in northern, eastern, and coastal regions; 15% of the area shows a temperate humid climate located in the highlands of the Sierras (> 2000); 11% of the area shows a dry climate in the center and northwest regions. Annual mean temperature is 22°C (range 12-3°C); annual mean precipitation is 1550 mm. The complexity of topographic and climatic conditions has favored the existence of a high ecosystem diversity. For example, it is estimated that close to 80% of the 32 main vegetation types occurring in Mexico are represented in Oaxaca, including temperate humid montane forest, pine, pine-oak, and oak forests, tropical dry and humid forests, and xeric vegetation (García-Mendoza et al. 2004). Main anthropogenic activities include increasing agriculture, livestock, and urbanization threatening biodiversity conservation statewide (Monroy-Gamboa et al. 2019).

Multi-temporal analysis of habitat suitability

To evaluate the habitats' conservation status for jaguar, puma, and coyote and their relation with the Mixtec and Zapotec territories, we conducted a multi-temporal analysis of habitat suitability using a multi-criteria inferential analysis. Then, we overlap these areas with the decreed protected areas and with the distribution of the Mixtec and Zapotec ethnic groups, and their respective spatial pattern of self-identification. This allowed us to identify the areas showing a biological and cultural interaction, and therefore the priority areas of biocultural conservation (Toledo and Barrera 2008; Granados-Peña et al. 2014).

Specifically, we evaluated the suitable habitats availability for these large carnivore species using a multi-criteria inferential analysis performed with the overlay geoprocessing spatial analyst tool via map algebra expression in the ArcGis 10.5 program (ESRI 2011). This technique facilitates decision-making processes that integrate two or more variables, such as those that emerge in conflicts of environmental management, where many attributes and relations are considered, occurring at a particular time-space or different times-spaces (Tecle and Duckstein 1993; Martinez-Alier et al. 1998; Munda 2005). This analysis was conducted based on variables and values ranges, starting with landscape and land cover (urban areas, agricultural areas, natural forest, woods and natural forest, shrubland, wetlands, natural pasture, permanent cultivated pasture, low secondary shrub vegetation, secondary high arboreal vegetation, without apparent vegetation, and degraded areas), distance from water bodies and main roads, elevation and terrain inclination, distance from human populations, and population densities in Oaxaca (Table 1). We used the data layers for Land Use and Land Cover maps (LULC) at 1:250,000 scale (modified by CONABIO) for three time periods: LULC 2009, LULC 2013, and LULC 2016 (INEGI 2009, 2013 and 2016). We chose these time periods because these data layers are closely linked to the INEGI's 2015 Inter-Censal Survey and are the current official data layers available. Afterward, a significance assessment was conducted to these group of variables, where a range and a weight values were assigned to each group according to the information previously published for the species and based on expert knowledge (González-Maya et al. 2010; Benítez et al. 2013, and Granados-Peña et al. 2014). These ranges were classified as not significant (1), little significant (2), neutral (3), significant (4), and very significant (5) (Table 1). The weight value was related to the importance of each group of variables according to the ecology and natural history of jaguar, puma, and coyote, respectively. This metric indicates the relative importance of each variable related to habitat use for each focal species. These weight values range from 0 to 100%, and the sum of the total variables' percentage should reach 100% for each species (see Penrod et al. 2010) (Table 1). Subsequently, all these variables were rasterized and projected to World Mercator Datum WGS 1984 with a resolution of 500 m^2. Then the resulting values were reclassified into three categories: high, medium, and low suitability values following published protocols (Rondinini et al. 2011; Crooks et al. 2017). This classification provides better understanding and criteria to select areas with suitable or unsuitable habitat conditions for a long-term occurrence and conservation of jaguar, puma, and coyote in Oaxaca. All these analyses were performed using the software ArcGis 10.5 (ESRI 2011).

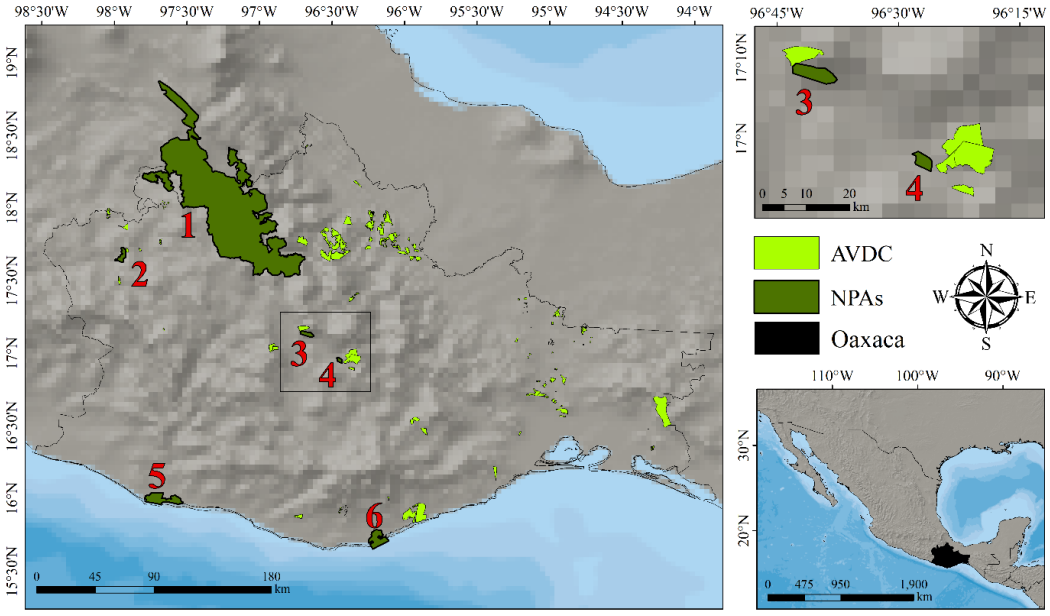

Figure 1. Study area depicting the State of Oaxaca in southern Mexico. The natural protected areas (NPAs, dark green) are: (1) Tehuacán-Cuicatlán Biosphere Reserve, (2) Boquerón de Tonalá Flora and Fauna Protection Area, (3) Benito Juárez National Park, (4) Yagul Natural Monument, (5) Lagunas de Chacahua National Park, (6) Huatulco National Park Areas. The areas voluntarily designated for conservation (AVDC, light green) are landed property (*predios*) donated for the conservation of biodiversity.

Table 1. List of variables and ranges, and habitat types included in the multi-criteria inferential analysis and used for the multi-temporal species habitat suitability for jaguar (*Panthera onca*), puma (*Puma concolor*), and coyote (*Canis latrans*). An assessment of significance was assigned to each group of variables and ranges, ranked as not significant (1), little significance (2), neutral (3), significant (4), and very significant (5). The weight values were related to the importance of each group of variables according to the ecology and natural history of jaguar, puma and coyote (see Materials and Methods section for details).

Variable	Ranges	Jaguar	Puma	Coyote	Jaguar Weight (%)	Puma Weight (%)	Coyote Weight (%)
Land use and land cover times series (INEGI 2009, 2013, and 2016)	Urban areas	1	2	3	35%	35%	30%
	Agricultural areas	2	3	4			
	Natural forests	5	5	5			
	Woods and semi-natural areas	3	4	4			
	Shrubland	3	4	4			
	Wetlands	5	3	2			
	Natural pasture	3	4	4			
	Permanent cultivated pasture	2	3	3			
	Low secondary shrub vegetation	2	3	4			
	Secondary high arboreal vegetation	4	4	4			
	Without apparent vegetation	1	2	2			
	Degraded areas	1	2	3			
Distance from water bodies (INEGI 2006)	1 km	5	5	5	11%	10%	10%
	3 km	5	5	5			
	6 km	5	4	4			
	10 km	2	3	3			
	50 km	1	2	2			
Inclination (CONABIO 2016)	<15%	5	5	5	10%	13%	12%
	15% - 30%	3	3	3			
	30% - 45%	3	3	2			
	45% - 60%	2	2	2			
	>60%	1	1	1			
Elevation (Worldclim 2019)	<500 masl	5	5	5	11%	12%	15%
	500 - 1000 masl	5	5	4			
	1000 - 1500 masl	4	5	3			
	1500 - 2000 masl	3	5	2			
	2000 - 3000 masl	2	4	2			
	>3000 masl	1	3	1			
Distances from main roads (INEGI 2017b)	<1 km	1	2	2	12%	10%	8,%
	1 - 3 km	3	3	3			
	3 - 6 km	3	4	4			

6 - 10 km	4	4	4			
>10 km	5	5	5			
Distance from human populations (CONABIO 2014)	1 km	1	2	2	11%	10%	10%
	3 km	2	3	3			
	6 km	3	4	4			
	10 km	4	5	5			
	50 km	5	5	5			
Population Density in Oaxaca (ind/km^2)	1.80 - 40.53	5	5	5	10%	10%	15%
	40.53 - 136.39	4	4	4			
	136.39 - 582.40	3	4	4			
	582.4 - 1,784.5	2	3	3			
	1,784.5 - 15,506.8	1	2	2			

Indigenous territory and species habitat suitability

Our initial assumption was that indigenous communities maintain proactive attitudes toward environmental conservation, and hence, higher species habitat suitability for wildlife (Durán et al. 2007). To establish whether such relationship exists between large carnivores' habitat suitability and the indigenous communities, we first determined the self-identification spatial distribution in Oaxaca. The degree of self-identification for each municipality was based on the "Estimators of the total population and its percentage distribution according to the database of municipalities indigenous self-identification and large age groups", in the Tabulated Data of the INEGI's 2015 Inter-Censal Survey (INEGI 2015). This information was spatially related to the municipalities layer and rasterized using the self-identification value, with a resolution level of 500 m^2. Then, this layer was reclassified ranging from 0% to 40% as low, 40% to 60% as medium, and > 60% as high indigenous self-identification level, respectively.

Afterward, we recompiled the punctual localities corresponding to these indigenous communities obtained from the INPI-INALI Atlas of indigenous populations belonging to Oaxaca (CARTO 2019) and related them with the corresponding habitat suitability value of jaguar, puma, and coyote for each LULC time series and the corresponding self-identification value using the extraction function of the spatial analysis tool (ArcGis 10.5). After that, a Pearson correlation analysis ($p < 0.05$) was performed between indigenous self-identification and large carnivores' habitat suitability for each LULC time series. The correlation index (r) ranges from −1 to 1, if $0 < r < 1$indicates a positive and direct correlation and if $-1 < r < 0$ indicates a negative and inverse correlation. Specifically, two analyses were conducted: one with species habitat suitability ranges > 3.0and indigenous self-identification values > 60%, and two with species habitat suitability ranges > 3.0 and indigenous self-identification values > 75%. These indigenous self-identification values were set at 60% and 75%, since we were interested in determining the municipalities with a preponderance of indigenous self-identification communities; that is, where > 60% of the communities regarded themselves as indigenous.

These values enabled a better visualization of each scenario of LULC for the correlations between species habitat suitability and indigenous self-identification. If the correlation was positive, we expected points occurrences with a high degree of indigenous communities' self-identification and a high species habitat suitability. These were areas with high potential for conservation. If the relation was negative, we expected no geographical concordance between indigenous communities' self-identification and species habitat suitability. Under this scenario, it is likely that other factors existed (environmental, social or economic) affecting indigenous communities' self-identification and/or species habitat suitability. Likewise, correlations were identified between the areas of medium and high species habitat suitability with the current geo-economic regions of Oaxaca (Istmo, Papaloapan, Cañada, Sierra Norte, Valles Centrales, Sierra Madre del Sur, Sierra Mixteca, and Costa) (Irazoque and Barbosa 1962). For this purpose, we performed a density analysis using correlation graphs for visualizing changes affecting species habitat suitability in the Zapotec and Mixtec territories, using the R Studio platform version 3.5.3 (R Core Team 2015).

Finally, we compared areas of species habitat suitability models, with jaguar, puma, and coyote records in natural protected areas (NPAs) and areas voluntarily designated for conservation (AVDC), between 2000 and 2019 (Table 2). The aim was to analyze whether the species habitat suitability models matched the large carnivores' occurrences (these occurrences were not used to estimate the habitat suitability models for each species). These records were searched from commonly used sources as GBIF Backbone Taxonomy (https://doi.org/10.15468/39omei), SNIB (http://enciclovida.mx), VertNet (http://portal.vertnet.org/search), the digitized Collection of Biological Photo-Specimens (Colección de Fotocolectas Biológicas, http://ibdata.ib.unam.mx/web/colecciones.php) of the Institute of Biology UNAM, and the database of Biological Monitoring of the Protected Natural Areas of the CONANP (https://simec.conanp.gob.mx/monitoreo.php). This process was conducted using the R Studio platform version 3.5.3 (R Core Team 2015).

Table 2. Number of occurrence records from 2000 to 2018 for jaguar, puma, and coyote in natural protected areas (NPAs) and areas voluntarily designated for conservation (AVDC) in Oaxaca, Mexico.

Conservation areas	Name of NPAs and AVDC	Species	Number of records	Year
NPAs	Tehuacán-Cuicatlán Biosphere Reserve	Puma	4	2004
			1	2005
			5	2007
			3	2008
			12	2010
			6	2011
			10	2012
			7	2013
		Coyote	10	2003
			13	2004
			5	2005
			2	2007
			1	2010
			7	2011
			11	2012
			6	2013
	Boquerón de Tonalá Flora and Fauna Protection Area	Puma	50	2012
			16	2013
			9	2014
			5	2015
		Coyote	1	2013
			3	2014
	Benito Juárez National Park	Puma	1	2014
			1	2015
		Coyote	1	2014
	Huatulco National Park	Coyote	1	2018
	Yagul Natural Monument	Coyote	1	2012
			4	2014
			25	2015
			2	2016
AVDC	Barranca del Epazote	Coyote	1	2014
	Camino a la Calavera	Jaguar	1	2012
		Puma	2	2012
		Coyote	2	2012
	Corral de Piedra	Coyote	1	2015
	El Baño	Puma	7	2013
	El Huerto	Puma	2	2012
			4	2013
			1	2014
	El paredón	Puma	5	2016
		Coyote	5	2016
	El Pie de la Peña	Puma	1	2013
			5	2014
			1	2015
		Coyote	1	2013
			1	2014
	El Portillo	Coyote	7	2013
	El Sauz 1	Puma	1	2012
	El Sauz 2	Puma	5	2012
	El Tular	Coyote	1	2014
			2	2015

AVDC	Hermenegildo	Coyote	5	2016
	La 2000	Puma	2	2013
			4	2014
			3	2015
			3	2016
		Coyote	2	2013
			1	2014
			5	2016
	La Cañada de Gregorio	Puma	1	2015
			11	2016
	La Cruz	Puma	4	2014
			3	2015
	La Cuevita	Puma	2	2014
			1	2015
	La Peña del Corral	Puma	6	2015
	La Rosa de Gacha	Coyote	9	2013
	La Ventana	Puma	2	2014
	Las Cuevas	Puma	1	2014
	Los Cajetes	Coyote	3	2015
	Los Lavaderos	Puma	1	2012
	Los Tepetates	Puma	1	2014
	Mogote del Pozo	Puma	18	2014
			1	2015
			19	2016
		Coyote	5	2016
	Paredones 2	Puma	2	2013
			11	2014
		Coyote	1	2014
	Río Concha	Coyote	2	2013
	Río del Jaguar	Jaguar	1	2013
	Río del Jaguar 2	Puma	1	2015
	Río Vaquero	Puma	1	2014
			2	2015
		Coyote	1	2014
	La Lima	Jaguar	2	2014
			3	2015
	La Manzanita	Jaguar	3	2014
	Xhachue	Jaguar	1	2015
	Arroyo del Aguacatal	Puma	5	2014
	Camino a Yelagago	Puma	3	2015
	Camino de Conducción de Agua Potable	Puma	2	2015
	Guia Dhao	Puma	1	2015
	La Lima	Puma	1	2014
	La Manzanita	Puma	1	2014
			1	2015
	Nhiza Yoya	Puma	1	2015
	Piedra Flor 2	Puma	2	2014
	Pozo del Aguacatal	Puma	3	2014
			1	2015
	Río de la Palma	Puma	2	2014
	Roa Gulabexho	Puma	1	2015
	Xhachue	Puma	1	2015
	Rancho Cajón	Coyote	1	2014

RESULTS

Multi-temporal analysis of species habitat suitability

In general, the suitable habitats (medium and high) for the three large carnivore species consisted mainly of areas covering natural and semi-natural forest, as well as secondary vegetation, wetlands and natural shrubland. Likewise, these areas included water bodies in the vicinity and showed a low or medium anthropic and agricultural and livestock impact (Figure 2). For the jaguar, there were fewer areas with a medium and high habitat suitability values than for the puma and coyote, respectively. These areas were found mainly in eastern and southern Oaxaca, and to a lesser extent in northern and western portions of the State. The areas of low habitat suitability included larger villages or towns and main cities, and areas crossed by major roads and highways (Figure 2).

With respect to the three time periods, the high habitat suitability areas showed a decrease for jaguar and coyote from LULC 2009 to LULC 2013, but an increase from LULC 2013 to LULC 2016. For example, high habitat suitability areas decreased 0.28% for coyote and 3.21% for jaguar from 2009 to 2013 and increased 0.93% for coyote and 6.51% for jaguar from 2013 to 2016. In contrast, for puma, high habitat suitability areas decreased 0.30% from 2009 to 2013, and 0.77% from 2013 to 2016. These high suitability differences between species may result from high elevational habitat preferences of puma (> 1500 masl; Table 1) compared to low and medium elevation habitat preferences of coyote and jaguar (Figure 2).

We observed a high number of records of the puma (130 and 159) and coyote (93 and 55) in both NPAs and AVDC, respectively. For example, the Tehuacán-Cuicatlán Biosphere Reserve, the Boquerón de Tonalá Flora and Fauna Protection Area, the Yagul Natural Monument, and the Benito Juárez National Park ranked top in the number of records, as well as some AVDC (Table 2). Only 11 records of jaguars were observed for AVDC, and no records were observed for NPAs. These conservation areas showed a medium-to-high habitat suitability for the three large carnivore species (Figure 2; Add file 1, 2, 3). However, the Boquerón de Tonalá Flora and Fauna Protection Area, the Yagul Natural Monument and the Benito Juárez National Park showed low-to-medium habitat suitability areas for these species (Figures 1 and 2).

Indigenous territories and species habitat suitability

The areas of higher overlap between indigenous territories and species habitat suitability were found in western, southern, and eastern portions of Oaxaca. These areas included local inhabitants that described themselves as indigenous communities, with self-identification values of over 60% (Figure 3). The high rates of indigenous self-identification and high values of species suitability models overlapped in six of the eight geo-economic regions of Oaxaca: Sierra Norte, southeastern and western parts of the Sierra Sur, the Coastal Region, and some municipalities of the Mixtec region (Figures 2 and 3).

The correlation analyses comparing > 60% of species habitat suitability with indigenous communities' self-identification showed the following trends (Figure 4A). The Zapotec areas showed a significant positive correlation with medium-to-high habitat suitability values (CI = 95% for all correlations) for jaguar (LULC 2009, r = 0.063; LULC 2013, r = 0.099; LULC 2016, r = 0.108, $p < 0.05$), and puma (LULC 2009, r = 0.058; LULC 2013, r = 0.097; LULC 2016, r = 0.107, $p < 0.05$). For coyote, a negative significant correlation was observed (LULC 2009, r = -0.177; LULC 2013, r = -0.166; LULC 2016, r = -0.201, $p < 0.05$). The Mixtec territories showed a negative significant correlation with the coyote (LULC 2009, r = -0.210; LULC 2013, r = -0.188; LULC 2016, r = -0.205, $p < 0.05$), but not with the puma (LULC 2009, r = -0.386; LULC 2013, r = -0.028; LULC 2016, r = -0.019, $p > 0.1$), nor the jaguar (LULC 2009, r = 0.003; LULC 2013, r = 0.013; LULC 2016, r = 0.017, $p > 0.1$) (Figure 4A).

Moreover, the correlation analyses comparing the species habitat suitability values > 75% with indigenous communities' self-identification showed a more pronounced trend (Figure 4B). The Zapotec territories showed a significant positive correlation with the puma and a significant negative correlation with coyote ($p < 0.05$). The Mixtec areas showed a significant negative correlation with the coyote, and a negative tendency for the puma. For the jaguar, the Mixtec self-identification showed a positive tendency (except for 2013) and a significant positive correlation with Zapotec communities in the LULC 2009 ($p < 0.05$), LULC 2013 ($p < 0.05$) and LULC 2016 ($p < 0.05$), respectively (Figure 4).

DISCUSSION

The perceptions and the cultural heritage of indigenous communities are key components to establish strategies for ecosystem and biodiversity conservation, including these large carnivore species. In

Meso-American indigenous cultures, for instance, the jaguar plays an important role within their communities cosmovision (Saunders 1994; Seller 2004; Sahagún 2005; López Austin 2012; Olivier 2016; Sugiyama 2016). Thus, according to their inclination and perceptions, this cosmovision may have important implications for ecosystems and resources maintenance in the long-term (Conforti and de Azevedo 2003; Treves and Karanth 2003; Campbell and Torres Alvarado 2011; Fita 2018). This is the result of nature ancestral perception and the large carnivore species awareness, referred as their "bio-cultural memory" (Toledo and Barrera 2008). For example, in Zapotec culture, jaguar, puma, and coyote are present in their common language (Seller 2004) and there are jaguar and puma clay figures representation from Monte Albán (i.e. a pre-Columbian archaeological site) (López Austin 2013). There are also stories and legends about the Zapotec origins involving the jaguar as an animal associated with gods, stories that remain until today (Henestrosa 2003). In Mixtec culture, the jaguar and coyote are represented in the Nutall Codex as an important species for their history and cosmovision (Zouche-Nutall 1987; Seller 2004).

The close and long-standing interactions of Mesoamerican indigenous communities with these large carnivore species have been gradually changing over time, because of the European influence (i.e. perceptions and land used dynamics) brought to America (Seller 2004; López-Austin 2013; Sánchez and Durán 2018). This result in some changes of the indigenous collective imaginary that generates a distortion towards a more utilitarian vision of natural resources, as seen in part of our results, in terms of communities' self-identification distribution and habitat suitability trends, so directly impacting the ecosystems where these large carnivores occur. This emphasizes the importance of empowering the collective and bio-cultural memory of these indigenous communities with the ecosystems and biodiversity conservation, which in turn play an important role

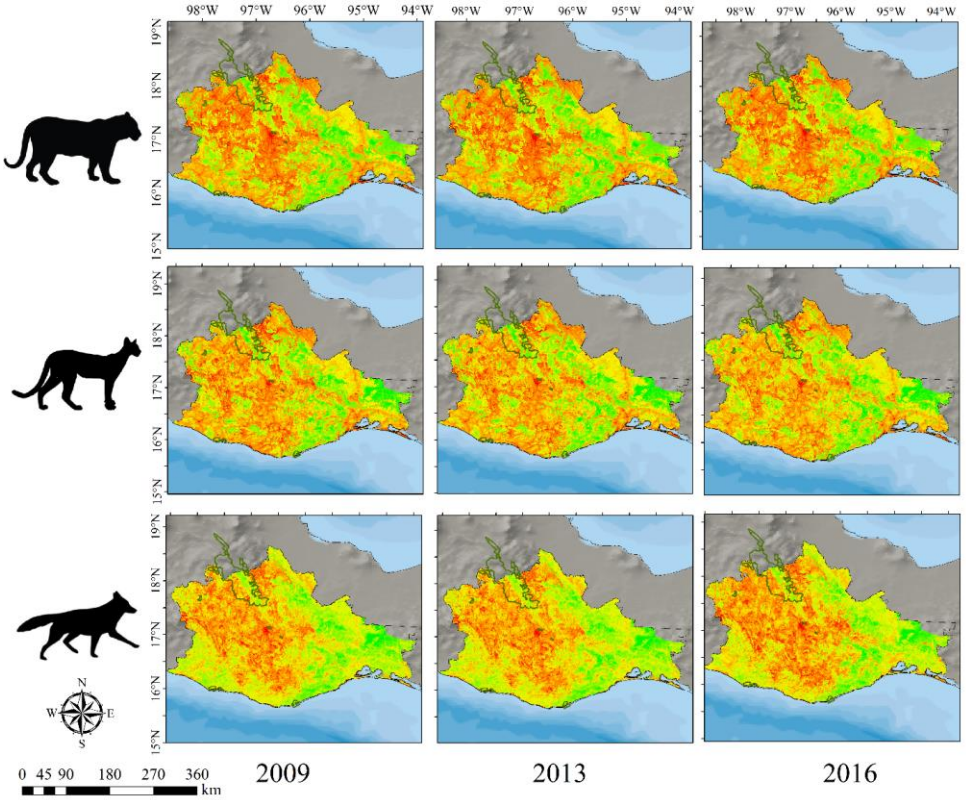

Figure 2. Distribution of high (green), medium (yellow), and low (red) habitat suitability for jaguar, puma, and coyote, in the INEGI land use and land cover map of LULC 2009, LULC 2013, and LULC 2016 of Oaxaca, respectively.

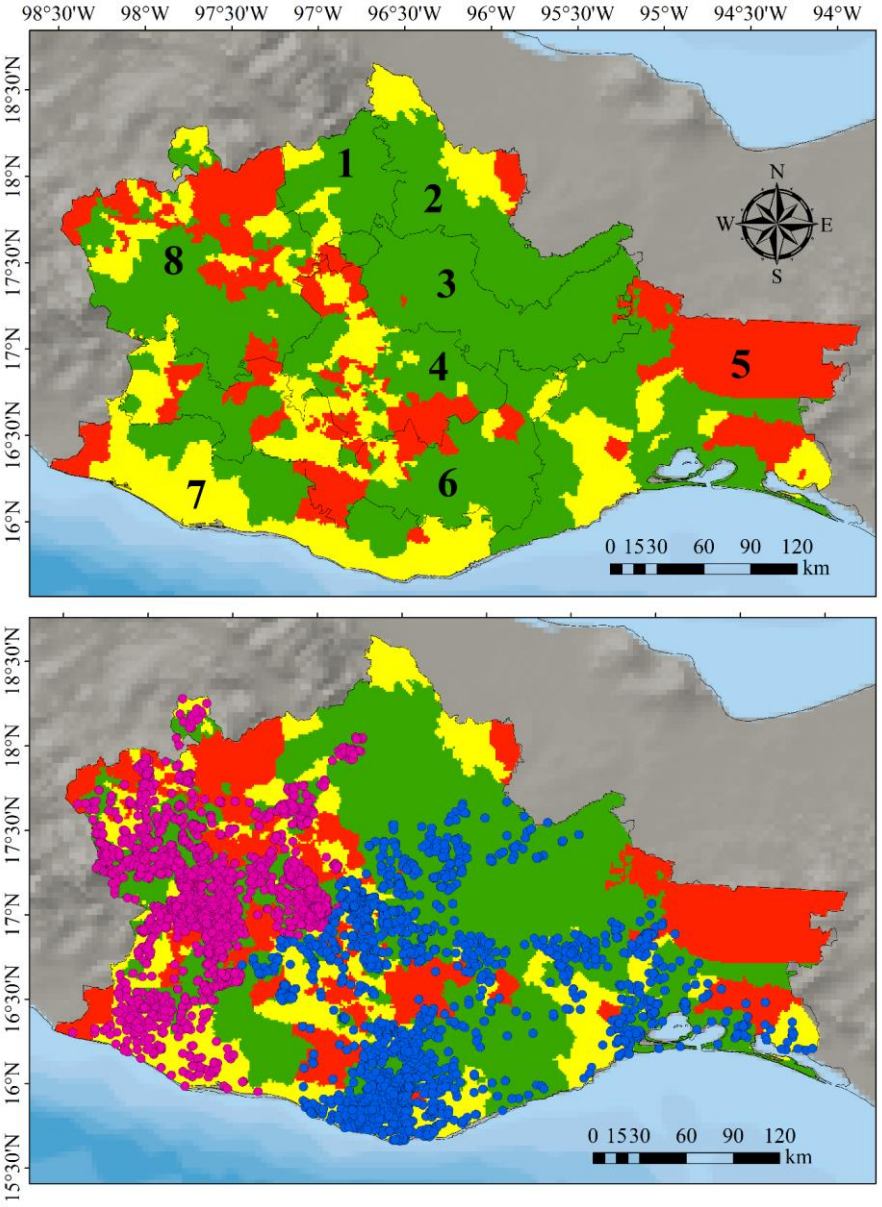

Figure 3. Spatial distribution of high (green), medium (yellow), and low (red) indigenous self-identification communities by geo-economic regions (top panel), and by indigenous Zapotec (blue points) and Mixtec (magenta points) villages (bottom panel). The geo-economic regions are: Cañada (1), Papaloapan (2), Sierra Norte (3), Valles Centrales (4), Istmo (5), Sierra Sur (6), Costa (7), and Mixteca (8).

for the environmental services availability and well-being of local indigenous communities (Buenrostro-Silva et al. 2015; Espinoza-Ramírez et al. 2017).

Our study also documented an important influence of the Zapotec and Mixtec indigenous communities on the ecosystems maintenance to support the

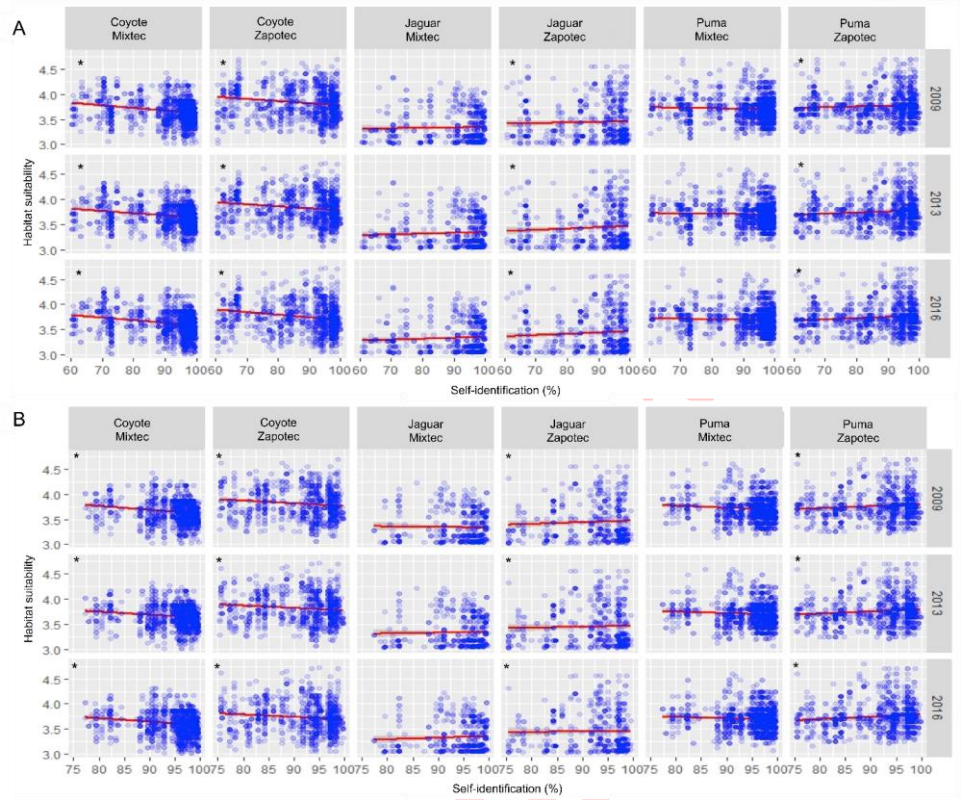

Figure 4. Pearson correlation ranks between jaguar, puma, and coyote habitat suitability (> 3.0) and areas holding indigenous self-identification communities. Indigenous self-identification with > 60% (A), and > 75% (B) are depicted for the Zapotec and Mixtec communities, respectively. Correlations are indicated for the LULC 2009 (upper panel), LULC 2013 (central panel), and LULC 2016 (bottom panel) time periods, respectively. *Significant correlation ($p < 0.05$).

populations of these large carnivore species in the long-term. We showed that the areas with medium-to-high species habitat suitability overlapped meanly with the Zapotec territories and to a lesser extent with Mixtec territories. Despite no positive correlation was observed for the coyote, it is likely that coyotes also actually occur in these areas as well (Botello et al. 2008). These areas should be prioritized for the conservation of these large carnivore species, given the proactive attitude of these indigenous communities toward nature. However, it is possible, that the potential of these large carnivore species as key top predator has been largely overlooked (Sanderson et al. 2002; Hunter 2005; Ray 2005; Granados-Peña et al. 2014). Additionally, coyotes did not show a positive correlation in areas of Zapotec and Mixtec high self-identification, possibly due to their high ecological plasticity and adaptability to disperse into anthropized habitats, as urban and peri-urban areas (Hidalgo-Mihart et al. 2004; Gehrt and Riley 2010; Hody et al. 2019). Moreover, some areas outside the NPAs and AVDCs showed high ecosystem degradation due to external factors of these indigenous communities (e.g., extensive expansion of the agricultural and livestock, development of infrastructure, human demographic growth), that negatively affect this correlation result, but shows a real perspective about biodiversity conservation of the region (Botello et al. 2008; Buenrostro-Silva et al. 2015).

We observed that six of the eight geo-economic regions in Oaxaca included areas with high species habitat suitability that coincided with the highest values of indigenous self-identification. Nonetheless, not all the AVDC areas show medium-high habitat suitability values for these large carnivore species in the region. The AVDC areas with low-medium habitat suitability values were highly degraded until they were incorporated recently into governmental conser-

vation programs in 2008 (LGEEPA 2008). It is likely that some of these AVDC areas should need more time to reach a medium or high suitable habitat recover (Monroy et al. 2019). Thus, it is necessary to include additional areas or corridors of high suitable habitats for these species overlapping with areas holding a high indigenous self-identification to ensure the conservation of these ecosystems in the long term. For example, additional areas and corridors with high suitable habitats could be connected with large protected areas as the Tehuacán-Cuicatlán Biosphere Reserve, the Huatulco National Park, the Lagunas de Chacahua National Park, the Benito Juárez National Park, and small protected areas as Yagul Natural Monument, Playa Escobilla Sanctuary, Playa de la Bahía de Chacahua Sanctuary and Boquerón de Tonalá Flora and Fauna Protection Area (Monroy-Gamboa et al. 2015, 2019; Wilson et al. 2011).

It is important to involve the indigenous communities in the environmental conservation planning and actions in local and regional resolution processes, since 40% of the priority terrestrial regions of Oaxaca belong to indigenous territories (Boege 2008). Oaxaca holds a high diversity of conservation initiatives, including areas of payments for biodiversity conservation and ecosystem services, voluntary areas for conservation, and forestry management, which have been recognize at international level as successful examples of local community participation in conservation efforts (Monroy-Gamboa et al. 2015, 2019). For example, there are over one hundred conservation areas that have been voluntarily proposed by local communities such as the *Unión de Comunidades Zapotecas-Chinantecas* located north of Oaxaca, and the *Sistema Comunitario para la Biodiversidad* in the coast that have established very successful conservation programs protecting biodiversity hotspots (Monroy-Gamboa et al. 2015, 2019). In addition, some governmental agencies as the National Commission of Forestry have established reforestation areas (CONAFOR 2010). There are also programs of payment for conserving areas for their importance to biodiversity and provision of environmental services (Martin et al. 2011).

This scenario, in turns, may generate not only a higher economic independence by developing activities contributing to biodiversity conservation as their main objective, but also could support and adjust other activities to decrease negative environmental impacts (e.g., deforestation, expansion of agriculture and livestock, etc.). In all this process considering these large carnivore species as important pieces not only for the ecosystem and ecological processes conservation, but also for the protection and safeguarding of the ancient cosmovision of local communities. When a specie is appreciated and regarded as a symbol of nature, a proactive attitude permeates the areas where indigenous communities and these carnivore species coexist (Mech 1970; Toledo and Barrera-Bassols 2008) (Figures 1-4). Therefore, a sustainable use of natural resources and the proportion of habitat connectivity with other conservation areas actively fostered by the indigenous communities could establish an integrated regional strategy of biodiversity conservation. This strategy should involve indigenous communities, stakeholders, and federal and local governmental and non-governmental organizations (Gadgil et al. 1993; Conforti and de Azevedo 2003) in order to generate a change in the negative perception towards these carnivore species, turning them as beneficial rather than threatening species (Millar et al. 2016) and then achieve a peaceful coexistence in all these territories.

CONCLUSION

Our study assessed species habitat suitability of the jaguar (*P. onca*), puma (*P. concolor*), and coyote (*C. latrans*), and quantified the overlap with the Mixtec and Zapotec indigenous territories in a biodiversity hotspot in southern Mexico. We found a positive and proactive relationship between indigenous communities' self-identification and a high species habitat suitability for the conservation of these large carnivores in the Sierra Norte, Sierra Sur, Coastal, and Mixtec regions. Given that most of these areas occur outside natural protected areas, the inclusion of indigenous communities in the management and planning of their territory is crucial for preserving their ethnocentric vision, and ensuring the conservation of these charismatic large carnivores and their habitat. The long-term conservation of ecosystems and their provision of environmental services will ultimately benefit the well-being of the indigenous communities in this biodiversity hotspot.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

CONTRIBUTION STATEMENT

Conceived of the presented idea: EG-M, AA-A. Carried out the experiment: EG-M, CGH, FMF, AA-A. Carried out the data analysis: EG-M, AA-A. Wrote the first draft of the manuscript: EG-M, AA-A, FB, VS-C. Review and final write of the manuscript: EG-M, FB, VS-C, AA-A. Supervision: FB, VS-C, AA-A.

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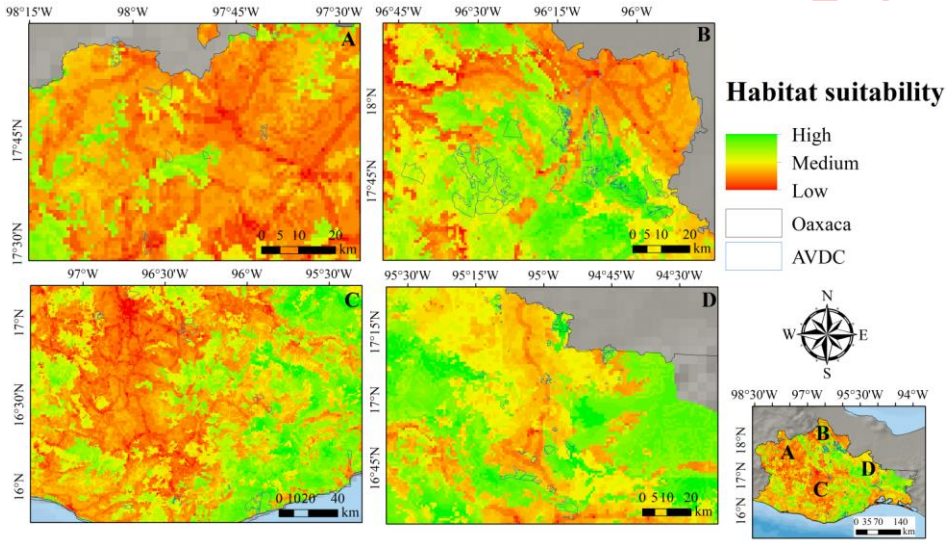
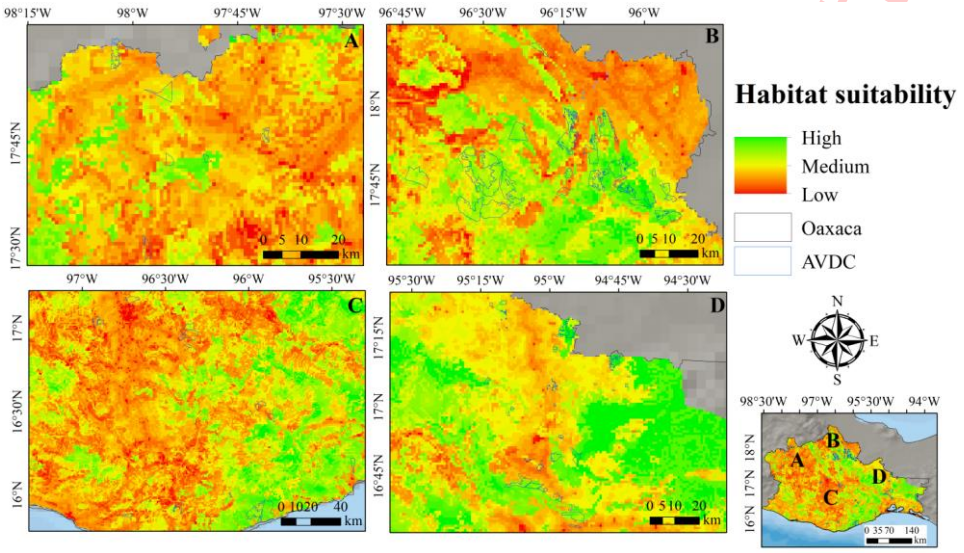
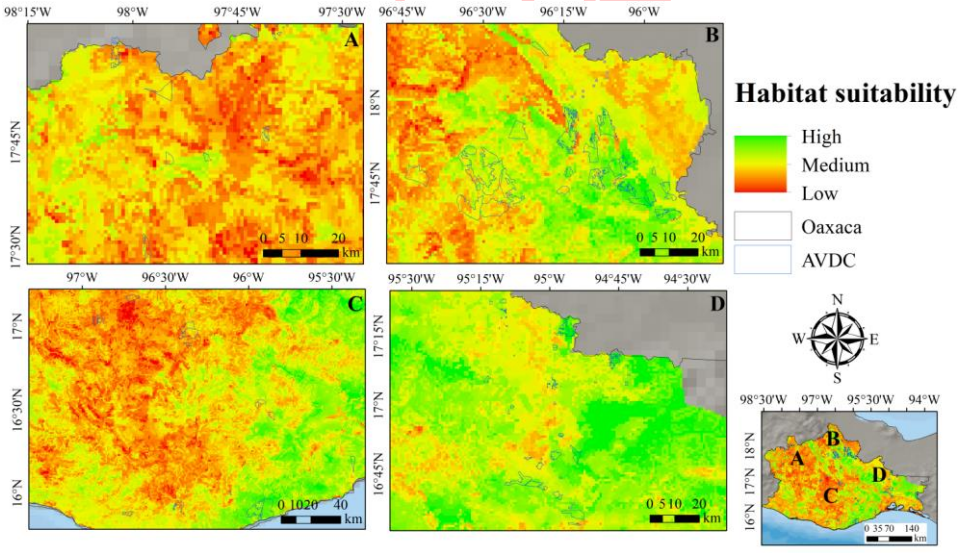
Additional Files



Add File 1. A closer view of high, medium, and low jaguar habitat suitability trend for the LULC 2009 and its relationship with the Areas Voluntarily Designated for Conservation (AVDC in blue).



Add File 2. A closer view of high, medium, and low puma habitat suitability trend for the LULC 2009 and its relationship with the Areas Voluntarily Designated for Conservation (AVDC in blue).



Add File 3. A closer view of high, medium, and low coyote habitat suitability trend for the LULC 2009 and its relationship with the Areas Voluntarily Designated for Conservation (AVDC in blue).

Discusión general

Exploramos las interacciones a largo plazo entre humanos y carnívoros, que se pueden establecer desde el comienzo de la humanidad. Estas interacciones dieron lugar a interacciones complejas entre los seres humanos y diferentes especies de carnívoros, que van desde depredadores-presas, caza y comportamientos antagónicos. Por ejemplo, las distribuciones traslapadas de humanos y lobos (*C. lupus*) en Eurasia dieron lugar a diferentes interacciones, que van desde antagónicas hasta mutualistas (Arroyo-Cabrales y Castañeda, 2009). La caza de presas comunes inicialmente resultó en una interacción competitiva entre humanos y lobos. Sin embargo, la domesticación de lobos resultó beneficiosa para ambas especies en el aumento de la eficiencia cinegética (Arroyo-Cabrales y Castañeda, 2009; Barras, 2020). De hecho, esta interacción específica fechada en el año 30.000 a.C. es una de las primeras interacciones entre especies humanas y silvestres (Barras, 2020), que finalmente dio lugar a la alianza y la domesticación de perros. Más tarde, otras especies de vida silvestre fueron domesticadas para el ganado, y los perros desempeñaron un papel crucial en las actividades de la vida cotidiana humana. Sin embargo, lobos y humanos mantuvieron una interacción antagónica debido a la competencia por las presas comunes, y la depredación al ganado. Estas secuencias de eventos muestran de una manera simplista, la compleja interacción entre los seres humanos y la vida silvestre y las especies domesticadas en Eurasia. No obstante, estas interacciones fuertemente competitivas no se produjeron en Mesoamérica hasta después del siglo XV dado que el ganado fue traído de Europa. Los viajes de Cristóbal Colón introdujeron diferentes especies de ganado como caballos, vacas, ovejas, cabras y cerdos a América, que se establecieron en amplias regiones del continente (Beja-Pereira et al. 2006; Ajmone–Marsan et al. 2010; Pitt, 2019). Por supuesto, la introducción del ganado en América tuvo un impacto significativo en la interacción entre las culturas locales, la vida silvestre y las especies domesticadas recién introducidas (Martínez et al. 2012).

En Mesoamérica, ha habido una larga relación entre las culturas regionales y las especies de vida silvestre, incluidos los carnívoros. Por ejemplo, en las culturas mixteca, zapoteca y nahua, grandes especies carnívoras como jaguar, puma, lobos, linces, entre otros, fueron frecuentemente incluidos en el arte prehispánico, pinturas, esculturas, leyendas, así como la incorporación de estos con fines alimenticios y medicinales (Capítulo I, Tabla 1). La cosmovisión que refleja la interacción entre estas culturas y la vida silvestre era altamente valorada y reconocida. Además, las especies de vida silvestre eran consideradas y respetadas

como equivalentes a nuestra especie e inclusive, mensajeros de los dioses (López Austin, 2012, 2013). Sin embargo, el impacto de la introducción de especies domesticadas como ganado tuvo un impacto significativo en las culturas regionales en Mesoamérica. Durante los 300 años de interacciones socioeconómicas cercanas a la ganadería con el Viejo Mundo, las culturas regionales estaban cambiando gradualmente la cosmovisión de su entorno, desde una percepción basada en la naturaleza hasta una percepción antropogénica de la vida silvestre. Este último se centró predominantemente en una percepción económica y utilitaria de la vida silvestre, incluyendo una visión de especies consideradas como competidoras y antagónicas al modo de vida. Múltiples consecuencias negativas resultaron de este cambio en la percepción del entorno natural, particularmente en el siglo XX. Una expansión desenfrenada del ganado vacuno y ovino en zonas tropicales con altas tasas de deforestación y, en consecuencia, pérdida de biodiversidad (Martínez et al. 2012), y pérdida de poblaciones carnívoras como el lobo mexicano (*C. lupus baileyi*) (Servin, 1993). Otros grandes carnívoros distribuidos en regiones tropicales también sufrieron fuertes cambios en los hábitats y fueron incluidos en una categoría de conservación de alto riesgo a nivel nacional (Currier, 1983; Hidalgo–Mihart et al. 2004).

Entre 2003 y 2013 (Capítulo I; Tabla 2), la ganadería tenía un área potencial de 2.8 millones de ha, lo que representaba el 25% del uso de la tierra rural en Oaxaca. Actualmente, el 70% de la producción ganadera en Oaxaca es extensiva y estos datos aumentan anualmente (Gobierno del Estado de Oaxaca y Banco de México, 2012; INEGI, 2020). Actualmente, las interacciones humanas con la vida silvestre fluctúan en sus percepciones históricas, de actitud positiva a negativa y de negativa a positiva, proactiva para su conservación (i.e Capítulo I; Tabla 2; Caso #1). Este complejo cambio de interacciones de positivas a negativas entre humanos y vida silvestre, es el resultado de diversos factores y circunstancias históricas negativas, por ejemplo, la pérdida de ganado, ataques consecutivos de animales silvestres a pobladores o animales domésticos, etc. Por el contrario, nos enfocamos en recuperar y realzar algunas tradiciones y percepciones hacia las singulares especies del género Carnívora que ayudan a intensificar una actitud positiva hacia su conservación. La primera parte de nuestro estudio mostró que, para estas comunidades indígenas, los seres humanos que permanecen con una visión complementaria en el ecosistema, retomando la visión histórica de su cultura, facilitan la idea de que los seres humanos y la vida silvestre son complementarios y no antagónicos. Por lo tanto, las interacciones humanas y de vida silvestre se volvieron proactivas en lugar de una visión utilitaria. De los ocho casos reportados (Capítulo I; Tabla 2)

en Oaxaca, tres pertenecen a la comunidad indígena zapoteca, que ha estado históricamente relacionada estrechamente con su medio ambiente y vida silvestre, incluyendo a los grandes carnívoros (Capítulo I; Tabla 1). Los zapotecas y los mixtecas son poblaciones ampliamente distribuidas en Oaxaca; por lo tanto, se esperaba que ambas comunidades representaran más casos proactivos, sin embargo, sólo la comunidad zapoteca fue altamente mencionada en los casos con una actitud de conservación hacia la vida silvestre. En este sentido, se propone aumentar nuestro conocimiento de cómo otros grupos étnicos como, mixteco, chinanteco, cuicateco, zoque y mixe se relacionan proactivamente con la vida silvestre. Ya que la cosmogonía de las tradiciones, rituales y creencias históricas y actuales desempeñan un papel sustancial en la interacción humana con la vida silvestre de estas localidades.

En general, los casos reportados son limitados debido a la profundidad y especificación de la investigación de ciertas especies principalmente carnívoras como jaguar, puma y coyote. Además, el estudio de las interacciones y percepciones entre humanos y vida silvestre implica y requiere criterios históricos, biológicos y sociales. La rara literatura confirma la importancia de profundizar en la percepción y relación de los pueblos humanos sobre los carnívoros para llevar a cabo una gestión completa en la resolución de conflictos entre humanos y carnívoros.

Proponemos que para lograr llegar a una solución con conflictos entre humanos y carnívoros debe apoyarse de manera integral y multidisciplinar que involucre tanto a la administración estatal como al conocimiento científico y empírico, para encontrar soluciones en diversos aspectos de carácter ambiental. Los conflictos entre humanos y carnívoros pueden ser una oportunidad para construir modelos de intervención etnobiológico y social, en el entendimiento de que las poblaciones indígenas y las comunidades rurales son una parte necesaria e integral de los esfuerzos de conservación.

En el segundo capítulo analizamos la influencia de las comunidades indígenas zapotecas y mixtecas en el mantenimiento de los ecosistemas para apoyar a largo plazo las poblaciones de grandes especies de carnívoros. Dado que la historia (Capítulo I) y la alta autoadscripción indígena de estas comunidades implica una apreciación proactiva de la biodiversidad, asumimos que la superposición de hábitats idóneos con un alto valor etnocultural y biológico en la región, proporciona un escenario positivo para la conservación de estas grandes especies carnívoras. Demostramos que las áreas con idoneidad de hábitat de nivel medio y alto de jaguar y puma se correlacionaron positivamente con los territorios zapotecos y en menor

medida con los territorios mixtecos. A pesar de que no se observó una correlación positiva para el coyote, es probable que los coyotes se distribuyan en estas áreas también (Botello et al. 2008).

Además, los coyotes no mostraron una correlación positiva en áreas de alta autoadscripción zapoteca y mixteca, posiblemente debido a su alta plasticidad ecológica y adaptabilidad para dispersarse en hábitats antropológicos, como áreas urbanas y periurbanas (Hidalgo-Mihart et al.2004; Gehrt y Riley 2010; Hody et al. 2019).

Observamos que seis de las ocho regiones geoeconómicas de Oaxaca incluían zonas con alta idoneidad de hábitat de especies que coincidían con los valores más altos de autoadscripción indígena e inclusive con áreas AVDC. Sin embargo, no todas las áreas AVDC muestran valores de idoneidad de hábitat medio-alto para estas grandes especies carnívoras en la región. Esas zonas AVDC con valores de idoneidad bajos y medianos están en plena recuperación, ya que se incorporaron recientemente a programas gubernamentales de conservación en 2008 (LGEEPA 2008). Es probable que algunas de estas áreas AVDC necesiten más tiempo para alcanzar un hábitat medio o alto adecuado para recuperarse (Monroy et al. 2019). Por tanto, es de alta importancia que estas áreas deban priorizarse para la conservación de estas grandes especies carnívoras, dada la actitud positiva y proactiva de estas comunidades indígenas hacia la naturaleza.

Por lo tanto, es necesario incluir áreas adicionales o corredores de hábitats de alta idoneidad para estas especies superpuestas con áreas que poseen una alta autoadscripción indígena para asegurar la conservación de estos ecosistemas a largo plazo. Por ejemplo, más áreas AVDC y corredores con hábitats de alta idoneidad podrían estar conectados con grandes áreas protegidas como la Reserva de la Biosfera Tehuacán-Cuicatlán, el Parque Nacional Huatulco, el Parque Nacional Lagunas de Chacahua, el Parque Nacional Benito Juárez y pequeñas áreas protegidas como el Monumento Natural Yagul, el Santuario playa Escobilla, el Santuario playa de la Bahía de Chacahua y el Área de Protección de Flora y Fauna boquerón de Tonalá (Monroy-Gamboa et al. 2019; Wilson et al. 2011).

Los resultados de este capítulo representan una propuesta para la identificación de áreas prioritarias bioculturales a partir de atributos de paisaje, información cartográfica, información etnológica, análisis de actores, que permite una aproximación a la priorización de

áreas claves para la conservación de la fauna silvestre (González-Maya et al. 2013). La mayor parte de las amenazas sobre la biodiversidad requieren de acciones de conservación urgentes con información suficiente a tiempo (Knight et al. 2008), por ello este tipo de estudios etnobiológicos y espaciales nos permite enfocarnos en las zonas prioritarias para conservar el conocimiento indígena y la riqueza natural en México. Por lo tanto, un uso sostenible de los recursos naturales y la proporción de conectividad del hábitat con otras áreas de conservación fomentadas activamente por las comunidades indígenas podrían establecer una estrategia regional integrada de conservación de la biodiversidad.

Finalmente, involucrar a las comunidades indígenas en la planificación y acciones de conservación ambiental en los procesos de resolución locales y regionales es sumamente importante, ya que el 40% de las regiones terrestres prioritarias de Oaxaca pertenecen a territorios indígenas (Boege, 2008). Oaxaca tiene una alta diversidad de iniciativas de conservación, incluyendo áreas de pagos para la conservación de la biodiversidad y servicios ecosistémicos, áreas voluntarias para la conservación y manejo forestal, que han sido reconocidos a nivel internacional como ejemplos exitosos de participación de la comunidad local en los esfuerzos de conservación (Monroy-Gamboa et al. 2015, 2019). Este escenario, a su vez, puede generar no sólo una mayor independencia económica mediante el desarrollo de actividades que contribuyan a la conservación de la biodiversidad como su principal objetivo, sino que también podría apoyar y ajustar otras actividades para disminuir los impactos ambientales negativos (i.e. deforestación, expansión de la agricultura y la ganadería, etc.). En todo este proceso se deben considerar estas grandes especies carnívoras como piezas importantes no sólo para la conservación de procesos ecosistémicos y ecológicos, sino también para la protección y salvaguardia de la antigua cosmovisión de las comunidades locales.

Cuando una especie es apreciada y considerada como un símbolo de la naturaleza, una actitud proactiva impregna las áreas donde conviven las comunidades indígenas y estas especies carnívoras (Mech 1970; Toledo y Barrera-Bassols, 2008) (Capítulo II; Figuras 1-4). De esta manera, al considerarlos como parte del mismo entorno reduce el sentido de dicotomía y otredad y promueve la vinculación positiva hacia ellos (Descola, 2001; 2002) y aporta bienestar humano. Para los grandes carnívoros es particularmente importante dado el papel ecológico clave como principales depredadores que estas especies juegan en sus ecosistemas (Sillero-Zubiri y Laurenson, 2001; Ray et al. 2013).

Conclusiones generales

En Mesoamérica, las grandes especies de carnívoros como los, jaguares, pumas y coyotes tienen un papel predominante en la cosmogonía de los indígenas relacionados con las creencias y tradiciones. La interacción proactiva entre grandes carnívoros y grupos éticos se basa en la percepción de una alta apreciación y respeto hacia la naturaleza, y la ausencia de acciones antropogénicas meramente utilitarias. Sin embargo, a partir de la colonización, las percepciones de los carnívoros han cambiado, pero se pueden reanudar desde el punto de vista de la alianza. En México y específicamente en Oaxaca, es de gran importancia crear consultorías en cada localidad para recomendar cuáles serían las mejores actividades económicas que podrían ser utilizadas en esa área, de acuerdo con los factores históricos, etnológicos y ambientales de la zona. Las comunidades indígenas involucradas pueden mejorar sus condiciones económicas modificando las actividades productivas para que se generen menos impactos ambientales y el deterioro de los ecosistemas. Por supuesto, es forzosamente necesaria una plataforma de actividades y acciones, incluida la educación ambiental, para incorporar estas actitudes proactivas a programas de conservación concretos.

Además, la administración de bienes comunes (Ostrom 2000) dentro de las comunidades pueden contribuir a la conservación social y de la vida silvestre. Esto es sustancial, porque la conectividad y el flujo de individuos con otras áreas preservadas por los pueblos indígenas podría ser la base de una estrategia regional de conservación entre las importantes comunidades nativas y la apreciación y conservación de la vida silvestre circundante (Gadgil et al. 1993; Conforti y de Azevedo 2003).

Encontramos una relación positiva y proactiva entre la autoidentificación de las comunidades indígenas y una alta adecuación de hábitat de especies para la conservación de estos grandes carnívoros en las regiones Sierra Norte, Sierra Sur, Costera y Mixteca. Dado que la mayoría de estas áreas se producen fuera de las áreas naturales protegidas, la inclusión de las comunidades indígenas en la gestión y planificación de su territorio es crucial para preservar su historia y su visión etnocéntrica y al mismo tiempo garantizar la conservación de estos grandes carnívoros carismáticos y su hábitat. La conservación a largo plazo de los ecosistemas y su prestación de servicios ambientales beneficiarán en última instancia al bienestar de las comunidades indígenas en este punto crítico de la diversidad biológica.

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Anexo

Between veneration and rejection: An historical journey of the interaction among humans and some carnivores' species in Oaxaca, Mexico

Abstract

Interactions between humans and wildlife pose a threat for the conservation of species, including carnivores. We focus on the relationship between human and carnivores to analyze the historical and current components, which have influenced the perception of humans to carnivores, specifically in Oaxaca state. This is a desk–based documentary research project using a fourth–stages protocol. First, we conducted a literature research on archaeological evidence of interactions among humans and carnivores, from the Pleistocene, focus on the subject of animal domestication and the process of migration of humans and carnivores through the Bering Strait. Afterwards we described punctually the presence of carnivores (Family: Canidae) in America. Second, we analyzed the representations of carnivores within the cosmovision of the Zapotecs, Mixtecs and Nahuas of Oaxaca, a state of considerable bio–cultural importance in Mexico. Third, we explored the perception about the carnivores in a European context at the end of the fifteenth century and during the colonization process of New Spain. Finally, we analyzed recent human–carnivores conflicts conducted by literature research based on scientific publications. We demonstrate the importance of the alliances in human history and especially the alliances between indigenous peoples and carnivores. Based on the fact that in the past of the indigenous peoples (Zapotec, Mixtec and Nahua) of Oaxaca are mostly positive but which today have fluctuated according to economic and social practices. We propose that the current perception of these indigenous communities on human–carnivores conflicts has an historical utilitarian–based component from the Colonial period, but also includes a nature–based component on the carnivore species occurring in their region.

This nature–based perception of indigenous cosmovision has strongly facilitated community–based conservation initiatives of carnivore species in Oaxaca.

Introduction

Humanity has interacted with animals in different ways. These interactions have facilitated significant advances in agriculture and livestock, social and cultural developments throughout the history of humankind (Kruuk 2005; Carabias et al. 2010). Human—wildlife interactions have been historically complex ranging from a nature–based cosmovision where humans are inherently part of wildlife, equivalent to any species, to a utilitarian–based vision, where wildlife is considered for serving exclusively for a socioeconomic benefit habitat, a world characterized by biodiversity (Conover 2001; Toledo and Barrera 2008). The latter hypothesis has partially resulted from an increasing demand in natural resources worldwide. The expansion of agriculture and livestock and an increasing demand for wildlife species has exacerbated human–wildlife conflicts worldwide (WWF 2019; IUCN and SSC 2020). The impact on wildlife has been severely affecting species distributions; the local population has been extirpated, and in some cases, species have gone extinct (FAO 2019; WWF 2019).

Human–wildlife conflicts, specifically in carnivores (Mammalia, order: Carnivora), are particularly problematic as humans and species of carnivores overlap in large areas worldwide and in a high diversity of ecosystems. Furthermore, local communities frequently face socioeconomic challenges of poverty and inequalities. These multiple reasons have generated considering the appearance of negative human–carnivores interactions, especially as regards medium and large–sized species with a meat diet, principally as a result of competition for space and natural resources (Crooks 2002; Arias–Alzate et al. 2013; Arroyo–Cabrales et al. 2016).

This phenomenon occurs with even greater frequency in terrestrial and marine environments, rural, urban and peri–urban zones. Therefore, in view of the loss of biodiversity

facing the planet (WWF 2019), this is a matter of considerable importance for the biology of conservation, above all when what is involved is conflict over the appropriation of shared resources, which in most cases are limited (Graham et al. 2005). This context is also of importance in other aspects, not only from a scientific perspective, but also in political, economic and social areas. Hence, in order to understand the problems involved and to generate strategies for improving ecological and social dynamics it is important to be aware of the origins of negative interactions between humans and wild fauna, which can be grouped mainly into two types: a) competition or b) conflict by depredation. Competition is generated when the wild fauna (e.g. predators at the top of the food chain) and humans enter indirectly into dispute for a limited resource and/or space. This causes a horizontal relation between both competitors, since they act as rivals for resources and territory (Knight 2000). On the other hand, conflict over prey may be a vertical relation when, in such cases, fauna preys upon human beings or domestic animals, thus causing antagonism between the parties. This relation generally results in the persecution, assassination and in some cases, extinction of the predators (Knight 2000).

In the present work we analyzed the human–carnivore interactions from an interdisciplinary approach, specifically anthropologic, historic, ethnologic and biologic point of view. In an initial section, documents have been analyzed that describe the kind of interaction that took place between humans and carnivores, paying attention to the relationships established from the domestication processes. At the second section we examined, through documents of the fifteenth and sixteenth centuries (prior to contact with Europeans), the cosmovision of numerous carnivore's species present in indigenous peoples of the Oaxaca state. In the third section, ideas about animals will be discussed and of certain carnivores, in particular in the Iberian Peninsula at the end of the fifteenth century, to later analyze the relations and perspective with carnivores established in the "New World". In the

fourth section, we are in the actuality to focus on the approach of different conflicts that occurred in Oaxaca state and to analyze the relevance of carnivore's perceptions in scientific conservation actions.

Methodology

Bibliographic and ethnographic compilation of human–carnivorous interactions since the Pleistocene to the colonization of New Spain. First stage, and third stage.

We started reviewing academic papers and book chapters that talk about human–carnivorous interactions from the most antique evidence to the end of the fifteenth century. We used the Google Scholar search engine and National Autonomous University of Mexico (UNAM) digital library (mainly editorials: SpringerLink, Librisite, Scopus, Alfaomega Grupo Editor, Nature Publishing Group, Elsevier). The fields of search were by title, abstract, or keywords. Afterwards, the bases for the search were the following archives: specialized research library Yvonne Oddon of the Musée de l'Homme; specialized library of the Musée du Quai Branly–Jacques Chirac; central library of the Musée National d'Histoire Naturelle; and the specialist library on mammals of the Musée National d'Histoire Naturelle, all located in Paris, France. A search for bibliographic reference was carried out on the basis of the following keywords: "carnivore", "animal interaction", "domestication", "conflict", "wildlife", "human–carnivore", "wildlife conflicts", "carnivore conflicts", "human–carnivore relationship".

Bibliographical compilation of the different representations of species of carnivores in the Oaxaca region of Mesoamerica. Second stage.

For the reports encountered on the existence of carnivores of medium or large size related with indigenous peoples in Oaxaca, the following keywords were used: "Mesoamerica", "Oaxaca", "tiger", "tigre"[1], "jaguar", "lion", "león", "cougar", "puma",

"wild beasts" "fauna", "animals", "indigenous peoples", "indígenas", "myths", "chronicles". Databases were consulted of the Juan Comas Library of the Instituto de Investigaciones Antropológicas, the UNAM Central Library, the Miguel Othón de Mendizábal library of the Dirección de Etnología y Antropología Social and the Doctor Eusebio Dávalos Hurtado Library of the Museo Nacional de Antropología e Historia, the two latter belonging to the Instituto Nacional de Antropología e Historia (INAH). The appraisal the indigenous peoples had of the carnivores was described, taking into account the information compiled by means of pictorial, sculptural and literary allusions. A table was then drawn up (Table 1) showing the number of times and the sources of the documents in which the species of carnivores were mentioned for different indigenous peoples of Oaxaca. The variables in the table were: the species of carnivores, the type of representation in which they were mentioned, and the name of the indigenous people. The predominant sources of information regarding species of carnivores concerned the Mixtec, Zapotec and Nahua population, for which reason it was decided to concentrate the analysis on these three ethnic groups.

Bibliographical compilation of human–carnivores interaction cases in Oaxaca in the twenty–first century. Fourth stage.

For the fourth stage, we used the Google Scholar search engine and UNAM digital library. We compiled literature research (scientific publications, book chapters and thesis) that talk about human–carnivorous interactions since the year 2000, exclusively in the Oaxaca state. At first, we try to search in advanced search of Google Scholar like the following: Oaxaca AND "carnivores" OR "*fieras*" OR "*dañeros*"[2], "*beedxe'"* OR "*bedxe' yaga*" OR "*gueu*"[3] AND "*kuììn*" OR "*ntìkà'a*" OR "*ntiva'u*"[4], "*ocelotl*" OR "*tequani*" OR "*miztli*" OR "*miztl*" OR "*coyotl*"[5], "interaction" OR "conflict" OR "cattle" OR "livestock" OR "tradition" AND "distribution" OR "relationship" OR "conservation" OR "protection". But we didn't find results because it was too specific, so we opted to search with fewer keywords in the

setting of Google Scholar set up as “important words”. We search with the following keywords according to the advanced search, the “important words” is established (with the next setting: a space between the keywords, anytime, any language, any region, any format and showing the most relevant results). So we search with the following keywords with a space between them: “Oaxaca”, “carnivores”, “interaction”, “conflict” “cattle”, “tradition”. Exact repeats have been removed from the results, being a total of 356 cases reviewed. Afterwards, we searched in the advanced search tool of UNAM digital library including scientific base dates in: Scopus, SpringerLink, Librisite, Nature Publishing Group, Elsevier, and others. We wrote the following keywords in spanish: “Oaxaca”, “*zapotec*”, “*mixtec*”, “*nahua*”, “*carnívoros*”, “*fieras*”, “*dañeros*”, “*interacción*”, “*conflicto*”, “*ganadería*”, “*ganado*”, “*tradición*”, “*puma*”, “*coyote*”, “*jaguar*” Exact repeats have been removed from the results, being a total of 450 cases reviewed. And we made a second research in UNAM digital library with the following english keywords: “Oaxaca”, “zapotec”, “mixtec”, “nahua”, “carnivores”, “meat–eating”,“flesh–eating”, “interaction”, “conflict”, “cattle”, “livestock”, “tradition”, “mountain lion”, “coyote”, “jaguar”. Exact repeats have been removed from the results, being a total of 350 cases reviewed too. The total cases (1156) were selected according to the following criteria: a) that cases is reported since the year 2000, but we consider that the fact starts years before; b) that the author’s documentation was merely descriptive and objective; c) that the wildlife reported dealt with interactions positive or negative with indigenous populations. Being a total of 8 specific cases that we selected (Table 2). Within these cases, the following were taken into account: a) the type of investigation: biologic or ethnological or both; b) Date; c) Geoeconomic Region; d) Regional ethnic group; e) Locality; f) Language reference to a human groups; g) Main ecological treats; h) Animal species involved; i) Uses for wildlife fauna (Phillips et al., 2001; León–Martínez, 2006; Sánchez, 2006; Monroy–Vilchis et al., 2008; Osbahr y Morales, 2012; Gil and Guiascón

2012); j) the anthropic activities associated (Table 2).

Results

Stage 1. An approach to human–carnivore relations through Pleistocene and Holocene

The documentary evidence shows that during the Pleistocene, competition for the same resources between humans and wild fauna was an everyday matter; hunting and collecting were frequently practiced activities (Clutton–Brock 1994; Milner and Smith 1989; Knight 2000; Liebenberg 2013; Arroyo–Cabrales et al. 2016). There was a vertical relationship with animals (in particular with carnivores), which competed for the same resources; on the other hand, there were also alliances for consumption of resources, as is the case of the alliance between man and wolf (*Canis lupus).*

One of the oldest documented interactions between humans and other non–primate animals is the sustained one with the wolf (*C. lupus*), which has been sympathetic to humans since Homo sapiens is considered as such. During the later Pleistocene (13,000 BC) in Eurasia the human–wolf relation was intense due to the hunting of ungulates. This cooperation grew even closer when wolves began to be bred, improving the success of the hunt (Milner and Smith 1989). Not only was this a form of cooperation for hunting, but it was also the common practice for humans (according to archaeological evidence) to adopt young individuals of other species, to breed, play, and even as a prestige symbol. We know that this alliance remained and still exists, since over the millennia the wolf was domesticated until becoming the domestic dog (*C. lupus familiaris*) (see details in Wang et al. 2004; Arroyo–Cabrales and Carranza–Castañeda 2009).

According to work carried out with nuclear and mitochondrial genetics, specifically the European subspecies (*Canis lupus lupus*) is the one that, in interaction with the human, gave rise to the first species of domestic wolf or primitive dogs, long before the human arrived in America (Valadéz et al. 2003).

From the above, and according to mitochondrial DNA analyses, among dogs of different origins, including analysis of archaeozoological samples, it is now considered that all dogs that came to America before the sixteenth century are originated from the Eurasiatic wolf (Valadéz et al. 2003; Arroyo–Cabrales and Carranza–Castañeda 2009), in a coordinated association that probably allowed both species to localize and obtain food at a time when the main activities of the human were related to hunting and harvest (Lee and DeVore 2017; Heberlein et al. 2016).

At the beginning of the Holocene (8,000 BC), human beings changed their hunting and collecting habits for agriculture[6] and animal husbandry (Diamond 2002; Beja–Pereira et al. 2006; Pitt et al. 2019). The most widely accepted hypothesis for explaining the origin of farming activities refers to environmental changes that caused human populations to adopt new techniques for obtaining food by means of domestication of animals and food plants (Clutton–Brock 1994; Diamond 2002). Domestication was based on the observation of patterns in the behavior of certain species that had been hunted in the past. The first animals hunted were: deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*), boar (*Sus scrofa*) and horse (*Equus ferus*); in western Asia were gazelle (*Gazella sp*.), wild sheep (*Ovis orientalis*) and goats (*Capra aegagrus*), aurochs (*Bos primigenius*), boar (*Sus scrofa*) and wild ass (*Equus hemionus* or *Equus hydruntinus †)*; later, these animals were primordial species for the establishment of livestock activities. The first animals domesticated for provision of food were sheep and goats, followed by cattle and wild pigs. The domestication of the horse came later, 5,000 yrs ago in Ukraine (Clutton–Brock 1987, 1992). These animals satisfy certain conditions for easy maintenance: they can feed on a large variety of plants, they are easy to look after, they can be moved from place to place and reproduce rapidly (Hale 1962; Garrard 1984; Clutton–Brock 1987; Diamond 2002; Ajmone–Marsan et al. 2010). Meanwhile, interactions between wolf and human may have changed due to the predation of livestock by

the former, which subsequently resulted in the removal of some wolf populations in large areas of Eurasiatic continent (Boitani and Linnell 2015).

On the other hand, when humans migrate to North America, 30,000 yrs ago (Barras 2020), the wolves were already established in the continent (Arroyo–Cabrales and Carranza–Castañeda 2009). Initially 19 subespecies were recognized (*Canis lupus alces, C. l. beothucus, C. l. bernardi, C. l. columbianus, C. l. crassodon, C. l. floridanus, C. l. fuscus, C. l. griseoalbus, C. l. hudsonicus, C. l. irremotus, C. l. labradorius, C. l. ligoni, C. l. mackenzii, C. l. manningi, C. l. mogollonensis, C. l. monstrabilis, C. l. orion, C. l. pambasileus, C. l. tundrarum, C. l. youngi*), but in the recent sources (Wang et al. 2004), five subespecies are distinguished (*C. lupus arctos, C. l. baileyi, C. l. lycaon, C. l. nubilus, C. l. occidentalis*). Particularly, the subespecie *C. l. baileyi* was distributed in Mexico. Along with humans came the dogs, domesticated in Siberia and Northeast of Asia ≈23, 000 yrs ago (Perri et al. 2021), all of them descendants of primitive lineages of the Eurasian wolf (Valadéz et al. 2003).

In America, activities like hunting and collection persisted for thousands of years, and agriculture was subsequently established. There wasn't livestock species at that time, just domesticated animals like dog, turkey, guinea pig and two Andean camelids (Martínez et al. 2012) so human populations may not have significant conflicts with the American wolves (Koblmuller et al. 2016), and the human–dog–wolf interaction was probably minimal, as genetic data shows no relation of dogs and North American wolves (Valadéz et al. 2003; Arroyo–Cabrales and Carranza–Castañeda 2009). The first livestock species arrived with the second trip of Colombus in fifteenth century (1493), they came from Iberian Peninsula to America (Martínez et al. 2012) (as described in higher detail below).

The development of the cattle ranch gave a function to the dog, like shepherds. Simultaneously, the absence of wolves began to be stronger in the country. Although we cannot access the representations of these two animals in the beginnings of livestock, in the

subsequent centuries the definitions of one and the other will be related to each other.

On the other hand, the other canid present in North America, the coyote (*Canis latrans*), had an origin in North America. During the Pleistocene, fossils indicate that coyotes roamed in extensive areas in northern, central (Young and Jackson, 1951) and southern Mexico and Central America during the Pleistocene–Early Holocene in the Pre–Columbian period. So, on the arrival of human populations in America and in the arrival of European settlers, the coyotes were probably in the south of Mexico due to the livestock introduction (Hidalgo–Mihart et al. 2004).

This shows how human and carnivorous interactions can change depending on the context and evolution of the former's activities and livelihood. The case of the wolf and its domestication that gave rise to the dog in Asia (Wang et al. 2004; Arroyo–Cabrales and Carranza–Castañeda 2009), its joint journey to the American continent, and the little interaction that these two species (human and dog) could initially have with the American wolves that had previously reached the continent (1.8 Ma [Irvingtonian period]). It is until other domestic species arrive from Europe with humans that the interaction intensifies negatively, leading the wolf practically to extinction in several regions of America, similar luck, though not so drastic, that other species of larger predators would have on the continent. This highlights the importance of evaluating the context, especially the material, when analyzing interactions with wildlife.

Stage. 2 Main aspects of the relationships between humans and carnivores in the Mesoamerican worldview.

In a context free of larger domestic species in Mesoamerica, where the negative interaction of livestock predation was absent, large carnivores were species that were otherwise integrated into cultures. While the most similar activity was the livestock keepers of

turkeys and dogs (Martínez et al. 2012). In this area, the most practiced agricultural activity was the cultivation of maize (*Zea mays* L.), bean (*Phaseolus* spp.), chili (*Capsicum* spp.) and squash (*Cucurbita* spp.) (Zizumbo–Villarreal and Colunga–GarcíaMarín 2010), a substantial activity that did not involve carnivores as a negative interaction, on the contrary, domestic and wild carnivores, were considered as symbols for rituals, food use and were appreciated as social actors (Sugiyama, Somerville and Schoeninger 2015; Corona–Martínez 2017b).

Some documentary sources tend to stress their hunting habits, associating them with the night. There are records of their presence through iconography, sculpture and mythical narrative. Some carnivores such as the jaguar (*Panthera onca*), the cougar (*Puma concolor*) and the coyote (*Canis latrans*) were the principal actors in rituals of war, tales, dances; they were even regarded as deities or messengers of the gods (Sahagún 1577, 2005; Seller 2004; López Austin 2012, 2013; Olivier 2016b; Sugiyama 2014; Sugiyama 2016). In many native cultures the jaguar, the cougar, coyote, wolves and dogs were represented in the ceremonial centers themselves (Blanco et al. 2007; Sugiyama 2014; Sugiyama 2016). It highlights the case of Teotihuacan, where there are not only mural paintings with representations of carnivores, but also archeophaunistic remains that have allowed their identification at the species level (and race, in some cases). Traditionally, the canids of paintings were interpreted as coyotes, but recent research have identified coyote, wolf, dog and also wolf–dogs hybrids in ritual and day life contexts (Valadez et al. 2002; Sugiyama 2014; Valadez 2016; Corona–Martínez 2017a). The presence of hybrids demonstrates the existence of biological knowledge of each of these species and ways of handling for the production of crosses (Valadez et al. 2002, Valadez 2016), as shown by the hybrid canid protagonist of the offering 125 of the Templo Mayor of Tenochtitlan (López Lujan et al. 2012). There is an extensive representation and evidence of the presence of these carnivorous species for Zapotec, Mixtec and Nahuas cultures, some with more types of representation than others (i.e the gray fox

(*Urocyon cinereoargenteus*), the bobcat (*Lynx rufus*) and the ocelot (*Leopardus pardalis*)) (Table 1).

Table 1. Pre-Columbian Representations of different carnivores in the Zapotec, Mixtec and Nahua cultures.

Species of carnivore	**Type of representation**	**Mixtecs (1500BC - the present)**	**Zapotecs (1400BC - the present)**	**Nahuas (500AD - the present)**
Jaguar (*Panthera onca*)	**Language / Writing**		Zapotec language: *Pèche-táo* "the large animal".	Nahua language: *ocelotl*, *tequani* "wild beast".
	Present in codices (as animal form)	Bodley Codex 15. Cospi Codex 8. Selden Codex 11, 61. Zouche-Nuttall Codex 11, 24, 40, 46, 50, 58, 59, 79, 80.		Florentine Codex, Book 1, 2, 6, 11. Telleriano-Remensis Codex 4, 9. Borgia codex 8, 27. Vaticanus B Codex 8, 18, 19, 42, 45, 87. Azcatitlan Codex 13. Azoyú Codex II 80. Laud codex 2.

	Sculpture		Clay figures at *Monte Albán*. Mask-pectoral from *Monte Albán*. (Postclassic, Monte Albán II, 100 BC-100 AD). Present in hall: South Wing: Cultures of Oaxaca (1500BC – 1521AD) of the *Museo de Antropología e Historia*, Mexico City.	Representations as glyphs in ceramic.
	Artistic production			Pictorial representations in murals at *Teotihuacán*, represented as *nahual* of the god *Tezcatlipoca* and *Tepeyóllotl*, the form of the god as jaguar. Present as a calendar god.
	Mythic narrative		Zapotec tale: *Los hombres que dispersó la danza*. The case of the Jaguar of Light, derived from a legend at Comotlán, Oaxaca.	Legend of the suns: Jaguars finished off the mankind of the era. The jaguar could be found as one of the chosen animals for the nahualism of the nobility. The jaguar was taken as an animal that transcended the "anecumenical" threshold. If one possessed part of its skin it passed on its faculties of a strong, bold and terrifying killer. Representation as the "nightly sun", stars and

				constellations (e.g. Ursa Mayor).
	Ceremonies		Found in an offering in *Monte Albán* (in a burial of 5 individuals, one of them possessed a jade pectoral giving the form of two faces: one with human characteristics and the other a jaguar. The representation is associated with the transformation of a man into a jaguar or of a jaguar becoming human).	Used in rituals for war and the skin is used in ornamental parts of the battle dress and helmets of the warriors of the Jaguar elite order.
	Medicinal use			Its blood was used to restore the vigor of one who had lost it in the exercise of public office.

Puma / Mountain Lion / Cougar (*Puma concolor*)	**Language / Writing**		Zapotec language: *Pèche-piáha, pèche-yàche* o *pequeça* “the golden animal”.	Nahua language: *miztli, miztl.*
	Present in codices	Zouche-Nuttall Codex 59 (but there is doubt among authors in this respect).		
	Sculpture		Ceramic sculpture of a Mountain Lion found at *Monte Albán*. Present in the South Hall (Cultures of Oaxaca, 1500BC –1521AD) of *Museo de Antropología e Historia*.	Ceramic sculpture of a Mountain Lion found at *Xochicalco,* Morelos.

	Artistic production			Pictorial representation on a vertical wall surface at the *Calzada de los Muertos* in *Teotihuacán*. Pictorial representation of a Mountain Lion with a feather headdress and solar halo at *Tetitla.*
	Mythic narrative			The feline associated with the Sun on account of its golden fur; the mountain lion was seen as an animal that transcended the anecumenical threshold.
	Ceremonies			Part of rituals for war.
	Medicinal use			Its blood was used to restore the vigor to one who had lost it in the exercise of public office.
Coyote (*Canis*	**Language / Writing**		Zapotec language: *peeza*, *peeza-yache* "the yellow coyote"	Nahua language: *coyotl* "howling wolf"

latrans)	**Present in codices**	Zouche-Nuttall Codex 26, 27 and 64.		Mendoza Codex 2, 49. Vaticanus B Codex 29, 31, 88, 90. Borgia Codex 10, 11, 57, 59, 64. Borbonicus Codex 4, Fejérváry-Mayer Codex 32. Florentine Codex Book 6.
	Sculpture			Stone figure: "Fleshless animals"; a jaguar and a coyote are depicted showing the back stripped of flesh.
	Mythical narrative			For the ancient Mexicans, the coyote was the thieving animal, the savage beast, a cousin of the jaguar. With a highly developed sexual appetite, it was related to the cult of *Tezcatlipoca*, and was one of the manifestations of the god music and dance called *Huehuecóyotl*. In myths: coyotes were the guards de *El Dueño* in the Sacred Mountain. The coyote was regarded as an animal that transcended the anecumenical threshold.
	Ceremonies			Present in war rituals.

	Medicinal use			Its blood was used to restore the vigor to one who had lost it in the exercise of public office.
Wolf / *Cuetlachtli* (*Canis lupus*)	**Language / Writing**			Present in the Nahua language: *Cuetlachtli* "wolf".
	Present in codices			Present in Florentine Codex, Books 2, 8, 9, 10, 11, 12.
	Mythical narrative			A messenger of the gods on account of its howls. It was believed that there was a monstrous wolf with wooden legs, this mythical creature menaced a *Tepanec* captain of the time of *Nezahualcóyotl*. It was believed to be a companion on the journey to the underworld.
	Ceremonies			Present in an offering dedicate to death, sacrifice and war in the *Templo Mayor, Tenochtitlán*.
	Medicinal use			Its blood was used to restore the vigor to one who had lost it in the exercise of public office.

Gray fox (*Urocyon cinereoar-genteus*)	**Language / Writing**		Zapotec language: *paate*	Nahua language: *tlalcoyotl* "The coyote of the land"
Red lynx (*Lynx rufus*)	**Language / Writing**			Nahua language: *Ocotochtli*
	Present in codices			Florentine Codex, Book 10.
	Medicinal use			Its blood was used to restore the vigor to one who had lost it in the exercise of public office.
Ocelot (*Leopardus pardalis*)	**Language / Writing**			Nahua language: *Tlacomiztli.* (but there is doubt among authors in this respect).
	Medicinal use			Its blood was used to restore the vigor to one who had lost it in the exercise of public office.

For Zapotec culture, the jaguar, the cougar, the coyote and the fox were present in the common language of the inhabitants (Seller 2004); likewise, there are figures of jaguar and cougar from Monte Albán (López Austin 2013). There are stories and legends of Zapotec origin about the jaguar that still resonate today (Henestrosa 2003), such as the case of the Jaguar of Light (see in Case 1, Table 2). As for Mixtec culture, the jaguar is represented in the *Codex Nutall 11, 24, 40, 46, 50, 58, 59, 79, 80*, and the coyote likewise, *Codex Nutall 26, 27, 64* (Zouche–Nutall 1987; Seller 2004). The Nahuas represented the jaguar as a being related to Tezcatlipoca, god of darkness and, therefore, "sorcerer". In the *Codex Fejérváry–Meyer 15* he appears represented as the wild beast that devours the hearts of people (Fejérvary–Mayer 1971; Seller 2004). When Tezcatlipoca manifested himself in the form of a jaguar he was given the name Tepeyóllotli and he was shown with horizontal black stripes on the face, personifying the image of the feline, as recorded in *Codex Borgia 10* and in *Codex Vaticanus B 3773* (Vaticano B Codex 1972; Borgia Codex 1976; Seller 2004).

Without a doubt, large carnivores have a prominent place in the worldview and are associated with ritual, offerings and commonly context. They are loaded with a strong symbolic and mithycal values (Dehouve 2013; Sugiyama 2014; Valadez 2016, González and Corona–Martínez, 2017, Sánchez–Herrera et al. 2020).

Stage 3. Changes in concepts of nature from Iberian Peninsula to México.

Iberian Peninsula

The attitude towards the natural world changed with Christianity, which encouraged people to exploit the natural world, understanding it as available resources (Kalof 2007). During that period, the "will of God", was a marked support for actions: for instance, the first book of the Bible tells how mankind has permission to use and kill animals in accordance with his natural satisfaction and needs:

And God said, let us make man in our image, after our likeness: and let them have

> *dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth. […] And the fear of you and the dread of you shall be upon every beast of the earth, and upon every fowl of the air, upon all that moveth upon the earth, and upon all the fishes of the sea; into your hand are they delivered* (Holy Bible, Authorized Version, 1960, Genesis 1:26 and 9:2).

In the Middle Ages (401–1500 cal yrs AD) domesticated animals were a constant presence in society and in the Christian cosmovision, generating a strong comparison between their characteristics and human behavior. It was believed that animals reflected aspects of human nature; in other words, they symbolized sins, virtues, emotions, the hierarchies of power, the social classes, etc. From that moment the idea of "otherness" was developed, emphasizing human conditions and behaviors materialized in animals (Careta 2001). An example of this, at the arrival of the eighteenth century, was the habitual practice of carrying out trials and sacrifices of animals in the town squares of Europe, with which the animal was humanized and the community was cleansed of its sins or guilt (Campion–Vincent 2005; Cohen 1994; Careta 2001).

As has been described above, the way of appreciating nature changed; a strongly anthropocentric vision of animals was established, supported to a great extent by the ecclesiastical doctrine that presented human beings as the center in the story of creation (Maehle 2002). These ideas were firmly established at the moment when the Spanish explorers decided to search for the territory of the "Indies" (Wolloch 2017; Careta 2001); however, on discovering the American continent in their voyages of discovery, their interest in resources stimulated them to explore these new territories and consequently to colonize them, which entailed the subjection of the indigenous peoples by means of military conquest and religious domination. For the colonizers the idea of the "other" which made them see animals as different and inferior was projected onto both native animals and native peoples

(Krotz 2002). These interactions caused the native people, as they assimilated “western” attitudes, to modify the vision they had of nature into one of human superiority and subjection of the fauna (Clutton–Brock 1994).

How did Europeans understand the fauna of the "New World"? Contact with the American peoples brought with it the knowledge of a new nature. Thinking of it as a process of knowledge (production of knowledge and distribution of it) implies putting into play a set of tools, namely: the interpretation of the new, communication (intercultural [and with languages] and within the same group), the nomination of animals. A hierarchy of the ways of knowing was also developed that legitimized and reproduced the inequality established with the conquest.

A feature of sixteenth century descriptions of animals is comparison with animals already known, sometimes incompletely, and sometimes as a statement. Contact with the American fauna was also a nomination process. A good example of the way of naming animals is offered by Hernán Cortés in the second letter of Relationship (1520), when describing the Houses with animals that Moctezuma had:

> *There were in the same palace several large halls on the ground floor, filled with immense cages built of heavy pieces of timber, well put together, in all or most of which were kept lions, tigers, wolves, foxes, and a variety of animals of the cat kind, in great numbers, which were fed also on fowls* (Tatcher, 1907. Vol 5, p. 325).

It is not just a language problem to name the jaguar as a tiger, the puma as a lion, etc., but also processes of "cultural translation", a way of linking two imaginary. An interesting case to deepen this is that of the translation into Nahuatl of Aesop's fables that is carried out in the San José de los Naturales and Santa Cruz de Tlatelolco Schools. Not only the words are translated, but also the animals. Thus, the coyote takes the place of the fox ("The goat and the coyote", "The coyote and the puma", "The coyotes"), not only because of a physical

resemblance, but also because of common characteristics attributed to them (Sanchis Amat 2019).

Perceptions interchange through colonization in Mexico

With the beginning of Spanish domination, a process of colonization began, which had economic, social and also worldview implications. This last aspect, which Serge Gruzinski (2001) has called the "colonization of the imaginary", is of central importance, since it was about practices and ideas that crossed the most diverse aspects of daily life. The vision the indigenous people had of carnivores and the natural environment in general, was modified due to a series of ideas and practices that evangelization brought with it, that contrasted with the perceptions of the Pre–hispanic groups related to their 'ecumenic' medium (visible and invisible creatures in the earthly world) and with their anecumenic medium (beings free of the material, manifested as invisible deities) (López Austin 2012) and which were essential elements of their cosmovision. In particular, practices associated with *nahualismo* were regarded by the invaders as acts of witchcraft, and the sacrificial or warring rituals were closely watched over on account of their pagan nature. These ideas modified the perception of certain carnivores and other animals, which became seen as "diabolic" or as personifications of "the Devil himself" (López Austin 2013). For example in the case of the jaguar, the Spanish friar Tomás de Coto translated the word *balam* (jaguar) as *hechicero* (sorcerer) and in the seventeenth century, due to this notion, the Spaniards represented the jaguar as an animal to be despised (Olivier 2016a); at the same time, the introduction of cattle, pigs, and sheep into the "New World" turned carnivores into undesirable animals and enemies. The chronicler and historian Gonzalo Fernández de Oviedo (1950:146) relates:

> *In the year 1522, I and other councilors of the city of Santa María del Antigua del Darien made in our municipality and council an ordinance in which we promised four or five gold pesos to anyone who killed one of those tigers. And for that prize many of them were killed*

in a brief time, as has been said, and with traps likewise.

The arrival of cattle in Mexico territory marks the beginning of "an all–out war" against the Mexican wolf that causes the decline of its populations while increasing livestock (Servín 1993), having recorded that meat supply was regulated by the viceroyalty authorities since the sixteenth century (Quiroz 2017). By the seventeenth century there was a marked relationship between mining and livestock activity, both constantly growing, and by the eighteenth century there was a growing trend towards livestock rearing over agriculture (Van Young 1989), with data on the existence of 800,000 head of cattle spread over only ten farms in a single province (New Kingdom of Leon), with cattle movements of 700 km at different times of the year (Martínez et al. 2012). This numerical and spatial expansion of livestock continued to increase to the demand for 50,000 head of cattle per year for cities such as Oaxaca by the early nineteenth century and standing livestock became Mexico's most important industry by the end of that century (De S. Lopes 2008). At the beginning of the twentieth century this growth trend was stopped by the Mexican Revolution war, however, by 1920 there are already coordinated efforts in the United States of America to exterminate the wolf for its livestock impact (Servin 1993), the same policy that the Mexican government pursued in subsequent years declaring itself to the mexican wolf (*C. lupus baileyi*) extinct in the early 1970s (Servín 1993). Luckily, actually exist multiple efforts to recover areas of the Mexican wolf (Servín et al. 2007; Siminski 2016; Servín et al. 2018; Martínez–Meyer et al. 2021).

It is impossible to know how many carnivores were annihilated during that period, but it is clear that some species once held to be sacred now came to be considered a threat that must be dealt with; in other words, there was an “ontological turn” (Descola 2001) in the way in which Amerindians perceived themselves in relation to their natural environment.

The history of science, and of biology in particular, has its turning point in the mid–eighteenth century. The moralizing vision of animals changes with the development of natural

history. The natural history develops under the idea of a system of nature. In the eyes of the scientists of the time, this system should be able to express itself in the form of a classification that integrated all living beings. The idea of objectivity and observation as a method of production and validation of knowledge is developed. Along with observation, scientific illustration takes independence as a differentiated practice of art.

A major milestone is the publication of the Carl Linnaeus Nature System (1735). Scientific expeditions, specimen collection and collection training are also carried out as part of a global project to classify nature (Pratt 1997). In this context, the Natural History of Georges–Louis Leclerc, Comte de Buffon, was of outstanding importance. It describes the fauna of the "Old World" and "New World" (it maintains these names), had a wide diffusion and served as a reference for all subsequent works on the subject. In a general way, it classifies animals by their form of movement. Within the quadruped groups it includes the division "domestic animals", "butcher animals" and "wild animals" (Buffon 1802; 1803). This classification, based on the relationship of animals to humans, is relevant to the animals we are studying here.

He refers to butcher animals as harmful, but clarifies: *These are not harmful but because they are rivals of man, because they have the same appetites, the same fondness for meat* (Vol. 4 p. 185). Subsequently, he defines the wolf as *one of those animals that have a more passionate interest in meat* (Vol. 8, p. 11). He compares it to the dog because of its physical resemblance, although he says that *it does not present the same characters but under an entirely opposite aspect* and *if the shape is similar, its result is quite the opposite: its nature is so different that they are not only incompatible, but unfriendly by nature, and enemies by instinct* (Vol. 8, p. 13). Interestingly, he doesn't mention the coyote.

It makes an extensive description of the mountain lion or cougar or puma (*Puma concolor*) in terms of its physical, behavioral and distribution characteristics, which it locates

from Pennsylvania (and the land of the Iroquois) to Peru. He mentions the jaguar as a species among cats, and describes it based on a dead specimen that was brought to him (in editions of the nineteenth century, the description of Felix de Azara is added). He says: *This is the most formidable animal, the cruelest, in a word, the tiger of the new world, where nature seems to have reduced all genders of quadruped animals* (Vol. 8, p. 129). Buffon still maintains the interpretation of the American nature by the comparison between the Old and the New World.

In later years the effort to differentiate species will be clear. The Methodical Encyclopedia: Natural History of Animals, published by Daubenton in 1788, says that the cougar is an *animal of America, named after the natives of Peru and to whom the Europeans have given the name of Leon, but without foundation* (Vol. 1, p. 220). Keeps the cougar like a different animal.

Describe the coyote, noting that Buffon and Linneo do not mention it:

> *Coyote (Mexican coyote) is, according to Clavigero, from whom this description has been derived, a beast similar in voracity to the wolf, in instinct to the fox, and in the figure to the dog, and in other properties to the adive, and to the jackal, which is why the historians of Mexico have already attributed it to one, and to another of these quadruped species, but it is undoubtedly diverse from all of them* (Vol. 1, p. 84).

In this context, the establishment of Christianity as a religion in New Spain, adds to the integration of livestock as a productive activity, thereby reinforcing the change in social perception towards large carnivores as problematic species that have negative connotations in the religious plane (in particular, jaguar, puma, wolf and coyote). It is not only a negative perception from the moral and religious, but it implies the conception of nature and animals as resources for humans.

Stage 4. The human–carnivore relationship from the twentieth century to a new outlook

assisted by the cosmovision of indigenous people.

The eight selected works are scientific writings that have a value in the context of the conservation of the species of interest in this work (Table 2). All cases were reported between 2003 and 2013. The first characteristic that we differentiate in the reports is that six out of eight cases the type of investigation is ethnobiology; the other two reports have a biological perspective. We analyzed the type of reference to the human groups to emphasize the approaching of the scientific reports to the social component, including the regional ethnicity group. It is interesting to report that three cases out of eight are Zapotec ethnic group, follow by Zoque, Chinantec, Ciucatec and Mixe in that order.

Table 2. Bibliographical compilation of human-carnivores interaction cases in Oaxaca between 2003 and 2013.

Case number		1[a]	2[b]	3[c]	4[d]	5[e]	6[f]	7[g]	8[h]
Research category	Biologic	X	X	X	X		X	X	X
	Ethnologic	X	X		X	X		X	X
Date		2004	2007-2008	2003-2004	2005	2013	2009-2010	N/D	2016
Geoeconomic region		Papaloapan	Papaloapan	Istmo	Sierra norte	Sierra norte	Istmo	Cuicatlán	Istmo
Regional ethnic group		Zapoteco	Chinanteco	Zoque	Zapoteco	Zapoteco	Zoque	Cuicateco	Mixe
Location		Municipality of Santiago Camotlán. Village: Asunción Lachixila	Municipality of San Felipe Usila. Villages: Santa Cruz Tepetotutla, San Antonio del Barrio, San Pedro Tlatepusco and Santiago Tlatepusco	Municipality of Santa María Chimalapa and Municipality of San Miguel Chimalapa	Municipality of Santiago Camotlán	Municipality of Capulálpan de Méndez, Ixtlán district.	Municipality of Santa María Chimalapa. Villages of Congregación de la fortaleza, San Francisco La Paz, Ejido La Esmeralda and Municipio San Miguel Chimalapa	Municipality of San Lorenzo Pápalo	Villages of San José El paraíso and Santo Domingo Tehuantepec

Mention to human groups		Community member, community leader, zapotec community	Indigenous community, Chinantec indigenous peoples, farmers, legal community members.	Local people, residents, local authorities, informants, inhabitants,	Zapotec settlers, settlers, Zapotec ethnic group, inhabitants.	Residents, community members, community residents, native groups, farmers and indigenous communities, farmers, Zapotec community of ancient origin, Zapotecs.	Inhabitants of the Zoque forest, producer, owner, ranchers, hunters.	Persons, community, indigenous people, cuicatec persons.	The Ayuuk Ja'ay (mixes), collaborators, participants, the population.
Main problem situation	Cattle attacks or livestock predation	X	X	X	X		X		
	Practice of extensive production methods						X		
	Indiscriminate hunt of potential preys for own consumption			X	X		X		
	Habitat loss and fragmentation		X	X	X		X		
	Deforestation	X		X			X		
	Wildlife traffic			X			X		

	Other (specify)			Stages of secondary succession	Disease transmission from domestic animals to potential preys		Gradual loss of traditional knowledge		Regulation of hunting and extraction of some species	The young people have abandoned beliefs and customs because of evangelical religion, formal education or migration, thus they relegate traditional knowledge and practices
Animal species involved	Wild	Jaguar (*Panthera onca*)	X	X	X	X			X	X
		Puma (*Puma concolor*)		X		X			X	X
		Coyote (*Canis latrans*)								
		White-tailed deer (*Odocoileus virginianus*)				X	X		X	X

		Collared pecary (*Tayassu tajacu*)		X	X			X		X
		Baird's tapir (*Tapirus bairdii*)			X	X		X		X
		Gray fox (*Urocyon cineroargenteus*)				X		X	X	X

		Other wild species		Coati (Nasua spp.), Red brocket deer (*M. americana*), Armadillo (*D. novemcinctus*), Squirrels (Sciurus spp.), Paca (*A. paca*)	Deers (Mazama spp.), Agoutí (Dasyprocta spp.), Lowland paca (*C. paca*), Mexican agouti (*D. mexicana*), White-nosed coati (*N. narica*), Central american red brocket (*M. temama*)	Jaguarundi (*H. yagouaroundi*), Ocelot (*L. pardalis*), Margay (*L. wiedii*), Lynx (*L. rufus*), Rabbits (*S. brasiliensis* and *S. floridanus*), Squirrels (*S. aureogaster*), Collared peccary (*P. tajacu*), Central american red brocket (*M. temama*), Geoffroy's spider monkey (*A. geoffroyi*), Kinkajou (*P. flavus*), Neotropical otter (*L. longicaudis*), Tayra (*E. barbara*),	Mentionated birds: Eagle (Aquila spp.), "La chachalaca", "La gallinita", Hummingbird (Trochilidae), "trepatroncos", "vireos", "sonaja parda" y "matraca", "chepito serrano", and others. Mentionated mammals: “Opossum” (*D. virginiana*), Cacomixtle (*B. astutus*), Rabbits (Sylvilagus spp.), Carnivores, Deers (Mazama spp.), Wild	Lowland paca (*C. paca*), Collared peccary (*P. tajacu*), Mexican agouti (*D. mexicana*), Plain chachalaca (*O. vetula*), Scarlet macaw (*A. macao*), Geoffroy's spider monkey (*A. geoffroyi*), Mantled howler (*A. palliata*), White-nosed coati (*N. narica*), Jaguarundi (*H. yaguarundi*), Tayra (*E. barbara*), Eastern cottontail (*S.*	"Chicatana" (*A. mexicana*), Giant silk moth (*A. armida*), Green iguana (*I. iguana*) and the black one (*C. pectinata*), Mountain doves (*Z. macroura* and *Z. asiatica*), Torcaza dove (*L. cassinrii*), "Chachalacas" (*O. vetula*), Quail (*C. virginianus*), Macaws (*A. militaris*), small doves (Columbina spp.), Hummingbirds (several species, among them *A. violiceps* and *A.*	Wild pigs (Tayassu spp. or Pecari spp.), Lowland paca (*C. paca*), Red brocket deer (*M. americana*), Iguana (*I. iguana*), Woodpecker bird (Picidae), Doves (Zenaida spp.), Toucan (Ramphastos spp.), Parrot (Amazona spp.), Squirrels (Sciurus spp.), Porcupine (Coendou spp.).

						Hispid pocket gopher (*O. hispidus*), Virginia opossum (*D. virginiana*)	pigs (Tayassu spp. or Pecari spp.) and Squirrels (Sciurus spp.).	*floridanus*), White-lipped peccary (*T. pecari*), Armadillo (*D. novemcintus*), Tapir (*T. bairdii*) and others.	*latirostris*), White-nosed coati (*N. narica*), Squirrel (Sciurus spp.), Rabbit (Sylvilagus spp.), Armadillo (*D. novemicinctus*), Skunks (*S. putorus, M. macrura*), Virginia opossum (*D. virginiana*), Racoon (*P. lotor)*, Ocelot (*L. pardalis*), Mexican agouti (*D. mexicana*), Collared peccary (*P. tajacu*).	
	Domestic	Ovine	X							X
		Bovine	X		X			X		X

	species	Other species			Equines (*Equus spp.*)			Domestic dog (*C. lupus familiaris*)		
		Does not specify		X		X	X			
		Does not apply								
Wildlife ethnobiology use	Food use				X	X	X	X	X	X
	Medical use					X			X	
	Harmful						X			X
	Ornamental use (sing, scenic beauty, pets)				X	X	X	X		
	Ecological relevance		X				X		X	
	Sobrenatural (beliefs, "bad" and "good feeling" rituals related to bad and good luck)		X	X		X			X	Ritual, good luck, bad luck, taboo
	Comercial				X			X		

Anthropic activities associated		Cattle farming, corn agriculture and coffee plantations	Corn agriculture, coffe plantations and small-scale cattle farming.	Farming, agriculture and cattle farming.	Cattle farming, coffee plantations and trade but was not profitable	Low dependence on forest extraction, health services, education and a wide range of non-agricultural jobs, proffesion jobs, mining, commerce, craftworks and public service.	Agriculture, farming, huntiing and fishing.	Corn agriculture, production of fruit in homegardens, goat and cattle raising, and extraction of non-timber forest products.	The population is mainly engaged in the harvest of coffee (Coffea spp.), maize (*Z. mays*), bean (Phaseolus spp.) and male banana (*M. balbisiana*); they also carry out livestock activities (sheep and cattle) and practice hunting, mainly of mammals and birds.
Does the work evaluate or report the opinion on conservation or environmental awareness of the interviewees?	Yes	X	X	X		X		X	
	No				X		X		X

[a] Díaz González, R.T., and O. F. Guadarrama, dirs. 2010. Abuelo Jaguar [Film]. Oaxaca, Mexico

[b] Figel, J. J., E. Durán, and D. B. Bray. 2011. Conservation of the jaguar Panthera onca in a community-dominated landscape in montane forests in Oaxaca, Mexico. *Oryx* 45:554-560.

[c] Lira T. I., and F. G. Ramos. 2007. Situación del jaguar en la región de los Chimalapas, Oaxaca. In *Conservación y manejo del jaguar en México: estudios de caso y perspectivas*, edited by Ceballos, G., C. Chávez, R. List and H. Zarza, pp. 71–80. Conabio-Alianza WWF/Telcel–UNAM. Mexico City.

[d] Contreras–Díaz, R. G., and M. Pérez-Lustre. 2008. Etnoecología de mamíferos silvestres y los zapotecos del municipio de Santiago Camotlán, Villa Alta, Oaxaca. *Etnobiología* 6:56–67.

[e] Gómez–Jiménez, M. 2014. Percepción y conocimiento tradicional sobre la fauna silvestre por habitantes de la comunidad de Capulalpám de Méndez, Ixtlán, Oaxaca. Master's Thesis, Instituto Politécnico Nacional–Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Oaxaca, Mexico.

[f] Lira–Torres, I., and M. Briones-Salas. 2011. Impacto de la ganadería extensiva y cacería de subsistencia sobre la abundancia relativa de mamíferos en la Selva Zoque, Oaxaca, Mexico. *Therya* 2:217-244.

[g] Solís, L., and A. Casas. 2019. Cuicatec ethnozoology: traditional knowledge, use, and management of fauna by people of San Lorenzo Pápalo, Oaxaca, Mexico. *Journal of Ethnobiology and Ethnomedicine* 15:58.

[h] López, D. O., R. M. Méndez, D. S. Fita, A. N. Beutelspacher, and L. H. Gómez. 2017. Cacería y cosmovisión en una comunidad ayuuk en San José El Paraíso, Oaxaca, México. *Etnobiología* 15:54-66.

We examined the wildlife and domesticated species implicated. We focus on the carnivores' species that have a mention directly or indirectly in the research of section two (jaguar, puma and coyote). However, we keep the information of other carnivorous species that are significant for the population's cases (foxes, jaguarundi, ocelot, margay, lynx) and the species that are potential preys for jaguar, puma and possibly for the coyote (white–tailed deer, collared peccary, rabbits, squirrels, birds, etc.).

Afterward, we analyzed the main problem situation and six cases deal with cattle attacks or livestock predation. Five out of eight cases have two or more critical situations at the same time (cattle attacks or livestock predation, practice of extensive production methods, indiscriminate hunt of potential preys for own consumption, habitat loss and fragmentation, deforestation, wildlife traffic and others). The cases number #3 and #6 reported more than five environmental problems such as livestock attacks, indiscriminate hunting, habitat loss and fragmentation, deforestation and illegal wildlife traffic. In the cases #5 and #8 no environmental problems are reported, but they perceive wild animals as a food source and harmful to the human group. They also report a gradual loss of traditional knowledge because of lack of intergenerational communication. Being Zapotec (#5) and Mixe (#8) regional ethnicities.

In cases #1, #5 and #7, the ecological importance of wildlife is known and opinion on conservation or environmental awareness is also reported. Particularly the case #5 consider wild animals to be harmful however; there is an environmental awareness to care for them. This case is possibly an exception because environmental education is influencing, but it is proposed to follow up in the future to see if there is a community action plan to conserve the local wildlife.

In case #1, the outlook for carnivorous wild species was negative, as it was not part of the nearby environment of the population, because it affected the domestic animals–human bond.

However, after a restitution in the perception of carnivorous as part of the nearby environment, that is, to see the jaguar as a foreign and distant body, they came to see him as part of the community and worldview. And this contributed significantly within the environmental conservation of the place and within the human–nature community link.

In case #4 there is a high diversity of wild species and a wide variety of uses including ornamental use which is the appreciation of scenic beauty, singing and companionship that wild animals can grant but there is no environmental awareness so a conservation orientation is suggested. All cases, except for case #1, mention within the wild species involved the potential jaguar and puma prey that are white–tailed deer and tapir. Nevertheless cases #1, #2, #4, #7 and #8 specifically report to the jaguar and cougar within the registers.

For the domestic species, the principal mention is the bovine species followed by the ovine ones, but in three cases they don't mention the type of domestic species managed. We categorized the commonly uses for the wildlife fauna which are Alimentary, Medicinal, Harmful, Ornamental (singing, scenic beauty, pets), Ecological relevance, Supernatural or magical beliefs (*de mal agüero*, ritual, evilness, luckiness) and Commercial use (Monroy–Vilchis et al. 2008; Osbahr and Morales 2012; Gil and Guiascón 2012). In the total cases, six of them have the Alimentary use and five of them have a Supernatural or magical beliefs use in the local wildlife animals. Four out of the eight cases see the wildlife as ornamental use and three or fewer cases, see the wildlife animals as ecological relevance, medicinal use, harmful use, and commercial use. In all the cases, the principal anthropic activities associated were registered to know the different economic interests and if they have a principal or multiples of economic sources.

Discussion

We explored the long–term interactions between humans and carnivores, which can be established since the beginning of humankind. These interactions resulted in complex

relationships between humans and different carnivore species, ranging from predator–prey, hunting, and antagonistic behaviors. For instance, the overlapping distributions of human and wolves (*C. lupus*) in Eurasia resulted in different interactions, ranging from antagonistic to mutualistic (Arroyo–Cabrales and Castañeda 2009; Arroyo–Cabrales et al. 2016). For example, hunting of common prey initially resulted in a competitive interaction between humans and wolves. However, domestication of wolves resulted as highly advantages for both species in increasing hunting efficiency (Arroyo–Cabrales and Castañeda 2009; Barras 2020). In fact, this specific interaction dated 30,000 BC is one of the first interactions between human and wildlife species (Barras 2020), which eventually resulted in alliance and the domestication of dogs afterwards. Later, other wildlife species were domesticated for cattle, and dogs plays a crucial role in human daily life activities. Nonetheless, wolves and humans kept an antagonistic interaction due to competition for common preys, and predation to cattle. These sequences of events show in a simplistic manner, the complex interaction between humans and wildlife and domesticated species in Eurasia. However, these interactions did not occur in Mesoamerica given that cattle were brought from Europe by the Spanish arrival in the fifteenth century. For example, since the expeditions of Christopher Columbus introduced different species of cattle as horses, cows, sheep, goats, and pigs into the Americas, which were established in wide regions of the Continent (Beja–Pereira et al. 2006; Ajmone–Marsan et al. 2010; Pitt 2019). Of course, the introduction of cattle into the Americas had a significant impact on the interaction between the local cultures, the wildlife and the newly introduced domesticated species (Martínez et al. 2012).

In Mesoamerica, there has been a long–standing relationship between regional cultures and wildlife species, including carnivores. For example, in the Mixtec, Zapotec and Nahua cultures, large carnivore species as jaguar, puma, wolves, bobcats, among others were frequently included in the Pre–hispanic art, paintings, sculptures, legends, as well as for food

and medicinal purposes (Table 1). The cosmovision of interaction between these cultures and wildlife was established on a high recognition of their value. Moreover, wildlife species were regarded and respected as equivalent to our species. However, the impact of the introduction of domesticated species as cattle had a significant impact on regional cultures in Mesomerica. For example, during the 300 yrs of cattle and livestock close socioeconomic interactions, regional cultures were gradually changing the cosmovision of their environment, from a nature–based to an antropogenic–based perception of wildlife. The latter was predominantly focused on an economic and utilitarian perception of wildlife including a vision of species considered as competitors and antagonistics in their livelihoods. Several negative consequences resulted from this change in perception of the natural contour, particularly in the twentieth century. Such as, a rampant expansion of cattle and livestock in tropical areas with high rates of deforestation and consequently biodiversity loss (Martínez et al. 2012), and population of large carnivore eradication as the Mexican wolves (Servin 1993). Other large carnivores distributed in tropical regions suffered from rapid changes in tropical habitats and were listed in a high–risk conservation category nationwide (Goldman and Young 1964; Currier 1983; Hidalgo–Mihart et al. 2004).

Between 2003 and 2013 (years in which the cases were developed), livestock has a potential area of 2.8 million ha, representing 25% of rural land use in Oaxaca. At his time, the 70% of the livestock production in Oaxaca is extensive and these data are increasing annually (Gobierno del Estado de Oaxaca and WorldBank 2012; INEGI 2019). Human interactions with wildlife have been fluctuating in their historical perceptions, from positive to negative and vice versa, proactive attitude for their conservation (i.e. Table 2, case #1). This complex shifts of positive and negative human and wildlife interactions results from many factors and circumstances, like the potential economic impact due to livestock loss due to hunting from large carnivore species. Conversely, some traditions towards mystifying large carnivore

species help to intensify a positive attitude towards their conservation. Our study showed that for these indigenous communities, the perception of humans belonging as another species in the ecosystems facilitates the idea that humans and wildlife are part of the same environment. Thus, human and wildlife interactions turned proactive rather than utilitarian. From the eight reported cases (between 2003 and 2013) in Oaxaca, 3 out of 8 belong to the Zapotec indigenous community, which has been historically closely related to their environment and wildlife, including large carnivores (Table 2). The Zapotecs are widely distributed population in Oaxaca; thus, it is expected that more proactive cases towards a conservation attitude to wildlife emerge. In this respect, it is proposed to increase our knowledge of how other ethnic groups relate to wildlife, as the Chinantec, Cuicatec, Zoque and Mixe. There has been widely documented that these ethnic groups use wildlife species for many purposes as food, medicinal, ornamental, and trade, among others. Nonetheless, the cosmogony towards traditions, rituals, and beliefs play an important role in defining human and wildlife interaction of these ethnic communities. Interestingly, we noted that in the eight cases it doesn't mention the coyote, and we supposed that is because it is not a real menace in front of the menace that causes a large carnivore.

Further, humans are a social species that have tied close bonds with wildlife since early times. The domestication (i.e *C. lupus familiaris*) it is a clear example of the close bonds that the human has been able to develop, constructing an emotional bond and recognizing it as part of the same environment and same reality. The incorporation of wildlife, specifically top predators, considered as part of the same environment, reduces the sense of dichotomy and otherness and promotes positive linkage to them (Descola 2002). This is particularly important for large carnivores, given the key ecological role as top predators these species play in their ecosystems (Sillero–Zubiri and Laurenson 2001; Ray et al. 2013; Arroyo–Cabrales et al. 2016; Suraci et al. 2016). In this sense, a proactive attitude towards large

carnivores including recognizing the importance of their conservation bring human well–being. Of course, a platform of activities and actions, including environmental education, are needed to bring these proactive attitudes into concrete conservation programs.

Conclusions

In Mesoamerica, large carnivore species as the wild, jaguar, puma and coyote have a predominant role in the cosmogony of indigenous people related to religious beliefs. The long–standing proactive interaction between large carnivores and ethic groups is based on the perception of a high appreciation and respect towards nature, and the absence of utilitarian anthropogenic actions.

However, from colonization, perceptions of carnivores have changed, but they can be resumed from an alliance point of view. In Mexico and specifically in Oaxaca, it is of great importance to create consultancies in each locality to recommend what would be the best economic activities that could be used in that area, according to the historical, social and environmental factors of the area. The communities involved can improve their economic conditions by modifying productive activities so that fewer environmental impacts and ecosystem deterioration are generated.

As well as the administration of common goods (Ostrom 2000) inside the communities can contributing to social and wildlife conservation. This is substantial, because the connectivity and flow of individuals with other areas preserved by indigenous peoples could be the basis for a regional conservation strategy among the important native communities and the appreciation and conservation of the surrounding wildlife (Gadgil et al. 1993; Conforti and de Azevedo 2003).

Conservation must be supported in an integral and multidisciplinary manner involving both state administration and scientific and empirical knowledge, to find solutions in various aspects of an environmental nature. Conflicts between humans and carnivores can be an

opportunity for building models of ethno–biological and social intervention, in the understanding that indigenous populations and rural communities are a necessary and integral part of the efforts of conservation.

The resulting cases are limited due to the depth and specification of research of certain mainly carnivorous species, jaguar, cougar and coyote. In addition, studying human–wildlife interactions and perceptions involves and requires historical, biological and social criteria. The rare literature confirms the importance of deepening human peoples' perceptions of carnivores in order to carry out full management in the resolution of conflicts between humans and carnivores.

Notes

[1] Words in Spanish: tigre, león, indígenas.

[2] Words in Spanish: fieras, dañeros, interacción, carnívoros, conflicto, ganadería, ganado, tradición.

[3] Words in Isthmus Zapotec (*diidxazá*): *beedxe'* (tiger, beast, lion), *bedxe'* yaga (jaguar, puma, tiger), *gueu'* (coyote).

[4] Words in Mixtec (*Tu'un savi*): *kuììn* (jaguar), *ntíhà'a* (puma, lion), *ntiva'u* (coyote).

[5] Words in Nahuatl: *ocelotl* (jaguar), *tequani* (jaguar or the large animal), *miztli* (puma or the golden animal), *coyotl* (coyote, adive or fox).

[6] From that moment humans stored the grains of their harvests, and the problem of pests began; for that reason small wild feline species began to take advantage of the abundance of rodents in fields and granaries, and became accustomed to the presence of the first farmers (Driscoll et al. 2007). From that time onwards, cats (*F. silvestris*) joined the group of domesticate animals.

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Discusión general

Exploramos las interacciones a largo plazo entre humanos y carnívoros, que se pueden establecer desde el comienzo de la humanidad. Estas interacciones dieron lugar a interacciones complejas entre los seres humanos y diferentes especies de carnívoros, que van desde depredadores-presas, caza y comportamientos antagónicos. Por ejemplo, las distribuciones traslapadas de humanos y lobos (*C. lupus*) en Eurasia dieron lugar a diferentes interacciones, que van desde antagónicas hasta mutualistas (Arroyo-Cabrales y Castañeda, 2009). La caza de presas comunes inicialmente resultó en una interacción competitiva entre humanos y lobos. Sin embargo, la domesticación de lobos resultó beneficiosa para ambas especies en el aumento de la eficiencia cinegética (Arroyo-Cabrales y Castañeda, 2009; Barras, 2020). De hecho, esta interacción específica fechada en el año 30.000 a.C. es una de las primeras interacciones entre especies humanas y silvestres (Barras, 2020), que finalmente dio lugar a la alianza y la domesticación de perros. Más tarde, otras especies de vida silvestre fueron domesticadas para el ganado, y los perros desempeñaron un papel crucial en las actividades de la vida cotidiana humana. Sin embargo, lobos y humanos mantuvieron una interacción antagónica debido a la competencia por las presas comunes, y la depredación al ganado. Estas secuencias de eventos muestran de una manera simplista, la compleja interacción entre los seres humanos y la vida silvestre y las especies domesticadas en Eurasia. No obstante, estas interacciones fuertemente competitivas no se produjeron en Mesoamérica hasta después del siglo XV dado que el ganado fue traído de Europa. Los viajes de Cristóbal Colón introdujeron diferentes especies de ganado como caballos, vacas, ovejas, cabras y cerdos a América, que se establecieron en amplias regiones del continente (Beja-Pereira et al. 2006; Ajmone–Marsan et al. 2010; Pitt, 2019). Por supuesto, la introducción del ganado en América tuvo un impacto significativo en la interacción entre las culturas locales, la vida silvestre y las especies domesticadas recién introducidas (Martínez et al. 2012).

En Mesoamérica, ha habido una larga relación entre las culturas regionales y las especies de vida silvestre, incluidos los carnívoros. Por ejemplo, en las culturas mixteca, zapoteca y nahua, grandes especies carnívoras como jaguar, puma, lobos, linces, entre otros, fueron frecuentemente incluidos en el arte prehispánico, pinturas, esculturas, leyendas, así como la incorporación de estos con fines alimenticios y medicinales (Capítulo I, Tabla 1). La cosmovisión que refleja la interacción entre estas culturas y la vida silvestre era altamente valorada y reconocida. Además, las especies de vida silvestre eran consideradas y respetadas

como equivalentes a nuestra especie e inclusive, mensajeros de los dioses (López Austin, 2012, 2013). Sin embargo, el impacto de la introducción de especies domesticadas como ganado tuvo un impacto significativo en las culturas regionales en Mesoamérica. Durante los 300 años de interacciones socioeconómicas cercanas a la ganadería con el Viejo Mundo, las culturas regionales estaban cambiando gradualmente la cosmovisión de su entorno, desde una percepción basada en la naturaleza hasta una percepción antropogénica de la vida silvestre. Este último se centró predominantemente en una percepción económica y utilitaria de la vida silvestre, incluyendo una visión de especies consideradas como competidoras y antagónicas al modo de vida. Múltiples consecuencias negativas resultaron de este cambio en la percepción del entorno natural, particularmente en el siglo XX. Una expansión desenfrenada del ganado vacuno y ovino en zonas tropicales con altas tasas de deforestación y, en consecuencia, pérdida de biodiversidad (Martínez et al. 2012), y pérdida de poblaciones carnívoras como el lobo mexicano (*C. lupus baileyi*) (Servin, 1993). Otros grandes carnívoros distribuidos en regiones tropicales también sufrieron fuertes cambios en los hábitats y fueron incluidos en una categoría de conservación de alto riesgo a nivel nacional (Currier, 1983; Hidalgo–Mihart et al. 2004).

Entre 2003 y 2013 (Capítulo I; Tabla 2), la ganadería tenía un área potencial de 2.8 millones de ha, lo que representaba el 25% del uso de la tierra rural en Oaxaca. Actualmente, el 70% de la producción ganadera en Oaxaca es extensiva y estos datos aumentan anualmente (Gobierno del Estado de Oaxaca y Banco de México, 2012; INEGI, 2020). Actualmente, las interacciones humanas con la vida silvestre fluctúan en sus percepciones históricas, de actitud positiva a negativa y de negativa a positiva, proactiva para su conservación (i.e Capítulo I; Tabla 2; Caso #1). Este complejo cambio de interacciones de positivas a negativas entre humanos y vida silvestre, es el resultado de diversos factores y circunstancias históricas negativas, por ejemplo, la pérdida de ganado, ataques consecutivos de animales silvestres a pobladores o animales domésticos, etc. Por el contrario, nos enfocamos en recuperar y realzar algunas tradiciones y percepciones hacia las singulares especies del género Carnívora que ayudan a intensificar una actitud positiva hacia su conservación. La primera parte de nuestro estudio mostró que, para estas comunidades indígenas, los seres humanos que permanecen con una visión complementaria en el ecosistema, retomando la visión histórica de su cultura, facilitan la idea de que los seres humanos y la vida silvestre son complementarios y no antagónicos. Por lo tanto, las interacciones humanas y de vida silvestre se volvieron proactivas en lugar de una visión utilitaria. De los ocho casos reportados (Capítulo I; Tabla 2)

en Oaxaca, tres pertenecen a la comunidad indígena zapoteca, que ha estado históricamente relacionada estrechamente con su medio ambiente y vida silvestre, incluyendo a los grandes carnívoros (Capítulo I; Tabla 1). Los zapotecas y los mixtecas son poblaciones ampliamente distribuidas en Oaxaca; por lo tanto, se esperaba que ambas comunidades representaran más casos proactivos, sin embargo, sólo la comunidad zapoteca fue altamente mencionada en los casos con una actitud de conservación hacia la vida silvestre. En este sentido, se propone aumentar nuestro conocimiento de cómo otros grupos étnicos como, mixteco, chinanteco, cuicateco, zoque y mixe se relacionan proactivamente con la vida silvestre. Ya que la cosmogonía de las tradiciones, rituales y creencias históricas y actuales desempeñan un papel sustancial en la interacción humana con la vida silvestre de estas localidades.

En general, los casos reportados son limitados debido a la profundidad y especificación de la investigación de ciertas especies principalmente carnívoras como jaguar, puma y coyote. Además, el estudio de las interacciones y percepciones entre humanos y vida silvestre implica y requiere criterios históricos, biológicos y sociales. La rara literatura confirma la importancia de profundizar en la percepción y relación de los pueblos humanos sobre los carnívoros para llevar a cabo una gestión completa en la resolución de conflictos entre humanos y carnívoros.

Proponemos que para lograr llegar a una solución con conflictos entre humanos y carnívoros debe apoyarse de manera integral y multidisciplinar que involucre tanto a la administración estatal como al conocimiento científico y empírico, para encontrar soluciones en diversos aspectos de carácter ambiental. Los conflictos entre humanos y carnívoros pueden ser una oportunidad para construir modelos de intervención etnobiológico y social, en el entendimiento de que las poblaciones indígenas y las comunidades rurales son una parte necesaria e integral de los esfuerzos de conservación.

En el segundo capítulo analizamos la influencia de las comunidades indígenas zapotecas y mixtecas en el mantenimiento de los ecosistemas para apoyar a largo plazo las poblaciones de grandes especies de carnívoros. Dado que la historia (Capítulo I) y la alta autoadscripción indígena de estas comunidades implica una apreciación proactiva de la biodiversidad, asumimos que la superposición de hábitats idóneos con un alto valor etnocultural y biológico en la región, proporciona un escenario positivo para la conservación de estas grandes especies carnívoras. Demostramos que las áreas con idoneidad de hábitat de nivel medio y alto de jaguar y puma se correlacionaron positivamente con los territorios zapotecos y en menor

medida con los territorios mixtecos. A pesar de que no se observó una correlación positiva para el coyote, es probable que los coyotes se distribuyan en estas áreas también (Botello et al. 2008).

Además, los coyotes no mostraron una correlación positiva en áreas de alta autoadscripción zapoteca y mixteca, posiblemente debido a su alta plasticidad ecológica y adaptabilidad para dispersarse en hábitats antropológicos, como áreas urbanas y periurbanas (Hidalgo-Mihart et al.2004; Gehrt y Riley 2010; Hody et al. 2019).

Observamos que seis de las ocho regiones geoeconómicas de Oaxaca incluían zonas con alta idoneidad de hábitat de especies que coincidían con los valores más altos de autoadscripción indígena e inclusive con áreas AVDC. Sin embargo, no todas las áreas AVDC muestran valores de idoneidad de hábitat medio-alto para estas grandes especies carnívoras en la región. Esas zonas AVDC con valores de idoneidad bajos y medianos están en plena recuperación, ya que se incorporaron recientemente a programas gubernamentales de conservación en 2008 (LGEEPA 2008). Es probable que algunas de estas áreas AVDC necesiten más tiempo para alcanzar un hábitat medio o alto adecuado para recuperarse (Monroy et al. 2019). Por tanto, es de alta importancia que estas áreas deban priorizarse para la conservación de estas grandes especies carnívoras, dada la actitud positiva y proactiva de estas comunidades indígenas hacia la naturaleza.

Por lo tanto, es necesario incluir áreas adicionales o corredores de hábitats de alta idoneidad para estas especies superpuestas con áreas que poseen una alta autoadscripción indígena para asegurar la conservación de estos ecosistemas a largo plazo. Por ejemplo, más áreas AVDC y corredores con hábitats de alta idoneidad podrían estar conectados con grandes áreas protegidas como la Reserva de la Biosfera Tehuacán-Cuicatlán, el Parque Nacional Huatulco, el Parque Nacional Lagunas de Chacahua, el Parque Nacional Benito Juárez y pequeñas áreas protegidas como el Monumento Natural Yagul, el Santuario playa Escobilla, el Santuario playa de la Bahía de Chacahua y el Área de Protección de Flora y Fauna boquerón de Tonalá (Monroy-Gamboa et al. 2019; Wilson et al. 2011).

Los resultados de este capítulo representan una propuesta para la identificación de áreas prioritarias bioculturales a partir de atributos de paisaje, información cartográfica, información etnológica, análisis de actores, que permite una aproximación a la priorización de

áreas claves para la conservación de la fauna silvestre (González-Maya et al. 2013). La mayor parte de las amenazas sobre la biodiversidad requieren de acciones de conservación urgentes con información suficiente a tiempo (Knight et al. 2008), por ello este tipo de estudios etnobiológicos y espaciales nos permite enfocarnos en las zonas prioritarias para conservar el conocimiento indígena y la riqueza natural en México. Por lo tanto, un uso sostenible de los recursos naturales y la proporción de conectividad del hábitat con otras áreas de conservación fomentadas activamente por las comunidades indígenas podrían establecer una estrategia regional integrada de conservación de la biodiversidad.

Finalmente, involucrar a las comunidades indígenas en la planificación y acciones de conservación ambiental en los procesos de resolución locales y regionales es sumamente importante, ya que el 40% de las regiones terrestres prioritarias de Oaxaca pertenecen a territorios indígenas (Boege, 2008). Oaxaca tiene una alta diversidad de iniciativas de conservación, incluyendo áreas de pagos para la conservación de la biodiversidad y servicios ecosistémicos, áreas voluntarias para la conservación y manejo forestal, que han sido reconocidos a nivel internacional como ejemplos exitosos de participación de la comunidad local en los esfuerzos de conservación (Monroy-Gamboa et al. 2015, 2019). Este escenario, a su vez, puede generar no sólo una mayor independencia económica mediante el desarrollo de actividades que contribuyan a la conservación de la biodiversidad como su principal objetivo, sino que también podría apoyar y ajustar otras actividades para disminuir los impactos ambientales negativos (i.e. deforestación, expansión de la agricultura y la ganadería, etc.). En todo este proceso se deben considerar estas grandes especies carnívoras como piezas importantes no sólo para la conservación de procesos ecosistémicos y ecológicos, sino también para la protección y salvaguardia de la antigua cosmovisión de las comunidades locales.

Cuando una especie es apreciada y considerada como un símbolo de la naturaleza, una actitud proactiva impregna las áreas donde conviven las comunidades indígenas y estas especies carnívoras (Mech 1970; Toledo y Barrera-Bassols, 2008) (Capítulo II; Figuras 1-4). De esta manera, al considerarlos como parte del mismo entorno reduce el sentido de dicotomía y otredad y promueve la vinculación positiva hacia ellos (Descola, 2001; 2002) y aporta bienestar humano. Para los grandes carnívoros es particularmente importante dado el papel ecológico clave como principales depredadores que estas especies juegan en sus ecosistemas (Sillero-Zubiri y Laurenson, 2001; Ray et al. 2013).

Conclusiones generales

En Mesoamérica, las grandes especies de carnívoros como los, jaguares, pumas y coyotes tienen un papel predominante en la cosmogonía de los indígenas relacionados con las creencias y tradiciones. La interacción proactiva entre grandes carnívoros y grupos éticos se basa en la percepción de una alta apreciación y respeto hacia la naturaleza, y la ausencia de acciones antropogénicas meramente utilitarias. Sin embargo, a partir de la colonización, las percepciones de los carnívoros han cambiado, pero se pueden reanudar desde el punto de vista de la alianza. En México y específicamente en Oaxaca, es de gran importancia crear consultorías en cada localidad para recomendar cuáles serían las mejores actividades económicas que podrían ser utilizadas en esa área, de acuerdo con los factores históricos, etnológicos y ambientales de la zona. Las comunidades indígenas involucradas pueden mejorar sus condiciones económicas modificando las actividades productivas para que se generen menos impactos ambientales y el deterioro de los ecosistemas. Por supuesto, es forzosamente necesaria una plataforma de actividades y acciones, incluida la educación ambiental, para incorporar estas actitudes proactivas a programas de conservación concretos.

Además, la administración de bienes comunes (Ostrom 2000) dentro de las comunidades pueden contribuir a la conservación social y de la vida silvestre. Esto es sustancial, porque la conectividad y el flujo de individuos con otras áreas preservadas por los pueblos indígenas podría ser la base de una estrategia regional de conservación entre las importantes comunidades nativas y la apreciación y conservación de la vida silvestre circundante (Gadgil et al. 1993; Conforti y de Azevedo 2003).

Encontramos una relación positiva y proactiva entre la autoidentificación de las comunidades indígenas y una alta adecuación de hábitat de especies para la conservación de estos grandes carnívoros en las regiones Sierra Norte, Sierra Sur, Costera y Mixteca. Dado que la mayoría de estas áreas se producen fuera de las áreas naturales protegidas, la inclusión de las comunidades indígenas en la gestión y planificación de su territorio es crucial para preservar su historia y su visión etnocéntrica y al mismo tiempo garantizar la conservación de estos grandes carnívoros carismáticos y su hábitat. La conservación a largo plazo de los ecosistemas y su prestación de servicios ambientales beneficiarán en última instancia al bienestar de las comunidades indígenas en este punto crítico de la diversidad biológica.

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Anexo

ETHNOBIOLOGY AND CONSERVATION

RESEARCH ARTICLE

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Connecting worlds: indigenous territories, habitat suitability and conservation of three large carnivores (Mammalia: Carnivora) in southern Mexico

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ABSTRACT

Human and wildlife conflicts pose conservation challenges for several charismatic species worldwide. Given their close and long-standing interactions with wildlife, indigenous communities set an interesting framework to identify factors establishing these relationships. The first step is to account the perceptions and symbolisms of indigenous communities to define and complement conservation efforts. We used multi-temporal and multi-criteria analyses to assess species habitat suitability of the jaguar (*Panthera onca*), puma (*Puma concolor*), and coyote (*Canis latrans*), and quantified the overlap with the Mixtec and Zapotec indigenous territories in Oaxaca, located in southern Mexico. We observed a positive and proactive relationship between indigenous communities' self-identification and a high species habitat suitability for the conservation of these large carnivores in the Sierra Norte, Sierra Sur, Coastal, and Mixtec regions. Given that most of these areas occur outside natural protected areas, the inclusion of indigenous communities in the management of their territory is crucial for preserving their ethnocentric vision and ensuring long-term conservation of these charismatic top predator species and their habitat.

Keywords: Human-Wildlife Conflict; Jaguar; Puma; Coyote; Indigenous Communities.

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SIGNIFICANCE STATEMENT

This study assessed from a spatial ecology perspective, the relationship between indigenous communities and the conservation of large carnivore species. We used a multitemporal and a multicriteria habitat suitability analyses to infer the habitat suitability of the jaguar (*Panthera onca*), puma (*Puma concolor*), and coyote (*Canis latrans*), and its association with two indigenous territories in southern Mexico. The findings showed a high geographic overlap of a positive and proactive relationship between indigenous communities' self-identification and a high species habitat suitability for the conservation of these large carnivores. The inclusion of the indigenous communities in conservation actions is a crucial step to ensure the preservation of their ethnocentric vision, and long-term protections of these charismatic top predator species.

INTRODUCTION

The human population has been significantly increasing in the last 200 years along with an exponential demand for natural resources (FAO 2017). Rapid human population increase entailed overexploitation of natural resources, drastically degrading the landscapes and ecosystems. This has resulted in significant detrimental impacts on local indigenous communities, and the provision of environmental services and biodiversity conservation essential for their well-being (González-Maya et al. 2013; Ellis 2011; Ripple et al. 2014; Easter et al. 2020). The overexploitation of natural resources has increased human and wildlife conflicts worldwide, posing conservation challenges on several charismatic species. Further, the loss of large areas of ecosystems has reduced several environmental services of which indigenous communities are highly dependent (Redford 1992; Crooks 2002; Brooks et al. 2006; González-Maya et al. 2013; Williams et al. 2018). The consequences due to rampant natural habitat degradation have raised international concerns urging to establish conservation strategies that incorporate local inhabitants involved in programs of sustained use of natural resources and biodiversity conservation (United Nations 2019). However, some approaches to conservation were not adequately oriented so as to afford integral protection to biodiversity, it is necessary to include local inhabitants and their relationship with the environment (González-Maya et al. 2013; Williams et al. 2018).

In Mexico, the indigenous communities cosmovision linked to biodiversity is in many cases preserved, and this includes charismatic species as large carnivores (Saunders 1994; Seller 2004; López Austin 2012, 2013; Sánchez and Durán 2018). However, regional conservation of biodiversity sets some challenges as local indigenous communities face cultural distortions, given the vision of some stakeholders to apply a strict economic use of natural resources and the expansion of areas for agriculture and livestock (Toledo 2001; Toledo and Barrera 2008; Descola 2001). For this reason, conflicts between the local indigenous communities and wildlife arise, particularly in areas where livestock losses occur due to large carnivores' predation (Guerrero-Montes de Oca et al. in preparation). Hence, conservation actions need to incorporate an integrated and participatory vision for preserving the biodiversity perceptions and historical symbolism of the indigenous communities. An integrated strategy needs to include the preservation of indigenous identity, sustainable use of natural resources, and conservation of biodiversity and ecosystems that provide critical environmental services to local inhabitants (Stevens 1997; Carabias et al. 2010; González-Maya et al. 2013).

The Mexican State of Oaxaca has been identified with a high diversity of multiculturality holding a high percentage of the indigenous population in Mexico. It is estimated that approximately 70 - 80% of its territory shows a collective self-attribution to one or another indigenous community (Galindo 2010), including two of the main ethnolinguistic groups, the Mixtecs (*Ñuu savi*) and the Zapotecs (*Binnizá, Bene Xon, or Ben'zaa*) (INEGI 2015; INALI e INPI 2019). The Mixtecs and Zapotecs are among the most ancient groups in Oaxaca, where their presence has been recorded over the last 3,500 years. The Mixtecs are located in the Mixteca Alta, Mixteca Baja, and the Coastal Zone regions, and have been characterized by the depth and continuity of its beliefs (INALI e INPI 2019). The Zapotecs are the dominant group—in political, economic, and cultural spheres—in extensive regions of Oaxaca, including the Central Valleys and the Isthmus of Tehuantepec (Vela 2010; INALI and INPI 2019). For over 2,500 years, diverse records (e.g., sculptures and other artistic products, and narrative and mythical traditions) have been found documenting the positive and proactive vision of these ethnic groups on biodiversity and a close and long-standing interaction with large carnivore species occurring in Oaxaca (Guerrero-Montes de Oca et al. in preparation).

Oaxaca also holds an exceptional species richness and endemicity of flora and fauna, ranking top in terrestrial vertebrate species nationwide (García-Mendoza et al. 2004). It is considered a Mesoamerican biodiversity hotspot, although human-induced activities such as deforestation, livestock and urbanization expansion threaten its conservation (Monroy-Gamboa et al. 2019). However, Oaxaca includes few protected areas covering a small fraction of less than 5% of its territory and more recently a high number of conservation initiatives involving governmental agencies, non-governmental organizations, and local communities have established areas with specific objectives related to biodiversity conservation (Monroy-Gamboa et al. 2019).

We assessed the geographic overlap of two main indigenous groups (Mixtecs and Zapotecs) and the habitat suitability of jaguar (*Panthera onca*), puma (*Puma concolor*) and coyote (*Canis latrans*), three large top predators and charismatic carnivore species occurring in Oaxaca. Given that self-identification of these indigenous communities entails a proactive appreciation of biodiversity, we assumed that the overlap of suitable habitats with a high ethnocultural and biological value in the region provides a proactive scenario for the conservation of these large carnivore species. This is of particular importance not only for the long-term conservation, but also given that

in this region decision-making on territorial planning and regulation involves over 70% of woodlands and tropical forests, which enter into the demarcations of *ejidos* and indigenous communities (Galindo 2010).

MATERIAL AND METHODS

Study Area

The study area is located in the State of Oaxaca in southern Mexico (17.0732° N, 96.7266° W) with an area of 93,757 km^2 (4.85% of Mexico) (Figure 1). It is divided into 570 municipalities that are grouped into eight regions and 30 districts (INEGI 2017a). Oaxaca has a complex topographic and climatic composition, where the Sierra Madre del Sur and the Sierra Madre Oriental converge. Almost 70% of the area of Oaxaca shows a tropical humid climate mostly located in northern, eastern, and coastal regions; 15% of the area shows a temperate humid climate located in the highlands of the Sierras (> 2000); 11% of the area shows a dry climate in the center and northwest regions. Annual mean temperature is 22°C (range 12-3°C); annual mean precipitation is 1550 mm. The complexity of topographic and climatic conditions has favored the existence of a high ecosystem diversity. For example, it is estimated that close to 80% of the 32 main vegetation types occurring in Mexico are represented in Oaxaca, including temperate humid montane forest, pine, pine-oak, and oak forests, tropical dry and humid forests, and xeric vegetation (García-Mendoza et al. 2004). Main anthropogenic activities include increasing agriculture, livestock, and urbanization threatening biodiversity conservation statewide (Monroy-Gamboa et al. 2019).

Multi-temporal analysis of habitat suitability

To evaluate the habitats' conservation status for jaguar, puma, and coyote and their relation with the Mixtec and Zapotec territories, we conducted a multi-temporal analysis of habitat suitability using a multi-criteria inferential analysis. Then, we overlap these areas with the decreed protected areas and with the distribution of the Mixtec and Zapotec ethnic groups, and their respective spatial pattern of self-identification. This allowed us to identify the areas showing a biological and cultural interaction, and therefore the priority areas of biocultural conservation (Toledo and Barrera 2008; Granados-Peña et al. 2014).

Specifically, we evaluated the suitable habitats availability for these large carnivore species using a multi-criteria inferential analysis performed with the overlay geoprocessing spatial analyst tool via map algebra expression in the ArcGis 10.5 program (ESRI 2011). This technique facilitates decision-making processes that integrate two or more variables, such as those that emerge in conflicts of environmental management, where many attributes and relations are considered, occurring at a particular time-space or different times-spaces (Tecle and Duckstein 1993; Martinez-Alier et al. 1998; Munda 2005). This analysis was conducted based on variables and values ranges, starting with landscape and land cover (urban areas, agricultural areas, natural forest, woods and natural forest, shrubland, wetlands, natural pasture, permanent cultivated pasture, low secondary shrub vegetation, secondary high arboreal vegetation, without apparent vegetation, and degraded areas), distance from water bodies and main roads, elevation and terrain inclination, distance from human populations, and population densities in Oaxaca (Table 1). We used the data layers for Land Use and Land Cover maps (LULC) at 1:250,000 scale (modified by CONABIO) for three time periods: LULC 2009, LULC 2013, and LULC 2016 (INEGI 2009, 2013 and 2016). We chose these time periods because these data layers are closely linked to the INEGI's 2015 Inter-Censal Survey and are the current official data layers available. Afterward, a significance assessment was conducted to these group of variables, where a range and a weight values were assigned to each group according to the information previously published for the species and based on expert knowledge (González-Maya et al. 2010; Benítez et al. 2013, and Granados-Peña et al. 2014). These ranges were classified as not significant (1), little significant (2), neutral (3), significant (4), and very significant (5) (Table 1). The weight value was related to the importance of each group of variables according to the ecology and natural history of jaguar, puma, and coyote, respectively. This metric indicates the relative importance of each variable related to habitat use for each focal species. These weight values range from 0 to 100%, and the sum of the total variables' percentage should reach 100% for each species (see Penrod et al. 2010) (Table 1). Subsequently, all these variables were rasterized and projected to World Mercator Datum WGS 1984 with a resolution of 500 m^2. Then the resulting values were reclassified into three categories: high, medium, and low suitability values following published protocols (Rondinini et al. 2011; Crooks et al. 2017). This classification provides better understanding and criteria to select areas with suitable or unsuitable habitat conditions for a long-term occurrence and conservation of jaguar, puma, and coyote in Oaxaca. All these analyses were performed using the software ArcGis 10.5 (ESRI 2011).

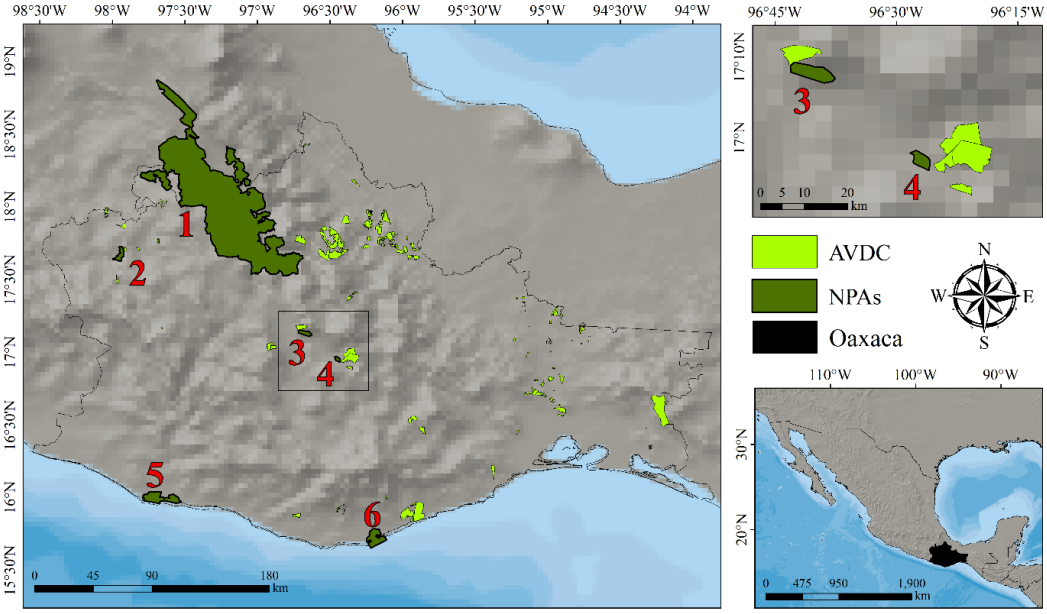

Figure 1. Study area depicting the State of Oaxaca in southern Mexico. The natural protected areas (NPAs, dark green) are: (1) Tehuacán-Cuicatlán Biosphere Reserve, (2) Boquerón de Tonalá Flora and Fauna Protection Area, (3) Benito Juárez National Park, (4) Yagul Natural Monument, (5) Lagunas de Chacahua National Park, (6) Huatulco National Park Areas. The areas voluntarily designated for conservation (AVDC, light green) are landed property (*predios*) donated for the conservation of biodiversity.

Table 1. List of variables and ranges, and habitat types included in the multi-criteria inferential analysis and used for the multi-temporal species habitat suitability for jaguar (*Panthera onca*), puma (*Puma concolor*), and coyote (*Canis latrans*). An assessment of significance was assigned to each group of variables and ranges, ranked as not significant (1), little significance (2), neutral (3), significant (4), and very significant (5). The weight values were related to the importance of each group of variables according to the ecology and natural history of jaguar, puma and coyote (see Materials and Methods section for details).

Variable	Ranges	Jaguar	Puma	Coyote	Jaguar Weight (%)	Puma Weight (%)	Coyote Weight (%)
Land use and land cover times series (INEGI 2009, 2013, and 2016)	Urban areas	1	2	3	35%	35%	30%
	Agricultural areas	2	3	4			
	Natural forests	5	5	5			
	Woods and semi-natural areas	3	4	4			
	Shrubland	3	4	4			
	Wetlands	5	3	2			
	Natural pasture	3	4	4			
	Permanent cultivated pasture	2	3	3			
	Low secondary shrub vegetation	2	3	4			
	Secondary high arboreal vegetation	4	4	4			
	Without apparent vegetation	1	2	2			
	Degraded areas	1	2	3			
Distance from water bodies (INEGI 2006)	1 km	5	5	5	11%	10%	10%
	3 km	5	5	5			
	6 km	5	4	4			
	10 km	2	3	3			
	50 km	1	2	2			
Inclination (CONABIO 2016)	<15%	5	5	5	10%	13%	12%
	15% - 30%	3	3	3			
	30% - 45%	3	3	2			
	45% - 60%	2	2	2			
	>60%	1	1	1			
Elevation (Worldclim 2019)	<500 masl	5	5	5	11%	12%	15%
	500 - 1000 masl	5	5	4			
	1000 - 1500 masl	4	5	3			
	1500 - 2000 masl	3	5	2			
	2000 - 3000 masl	2	4	2			
	>3000 masl	1	3	1			
Distances from main roads (INEGI 2017b)	<1 km	1	2	2	12%	10%	8,%
	1 - 3 km	3	3	3			
	3 - 6 km	3	4	4			

	6 - 10 km	4	4	4			
	>10 km	5	5	5			
Distance from human populations (CONABIO 2014)	1 km	1	2	2	11%	10%	10%
	3 km	2	3	3			
	6 km	3	4	4			
	10 km	4	5	5			
	50 km	5	5	5			
Population Density in Oaxaca (ind/km^2)	1.80 - 40.53	5	5	5	10%	10%	15%
	40.53 - 136.39	4	4	4			
	136.39 - 582.40	3	4	4			
	582.4 - 1,784.5	2	3	3			
	1,784.5 - 15,506.8	1	2	2			

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Ethnobiology and Conservation

Indigenous territory and species habitat suitability

Our initial assumption was that indigenous communities maintain proactive attitudes toward environmental conservation, and hence, higher species habitat suitability for wildlife (Durán et al. 2007). To establish whether such relationship exists between large carnivores' habitat suitability and the indigenous communities, we first determined the self-identification spatial distribution in Oaxaca. The degree of self-identification for each municipality was based on the "Estimators of the total population and its percentage distribution according to the database of municipalities indigenous self-identification and large age groups", in the Tabulated Data of the INEGI's 2015 Inter-Censal Survey (INEGI 2015). This information was spatially related to the municipalities layer and rasterized using the self-identification value, with a resolution level of 500 m^2. Then, this layer was reclassified ranging from 0% to 40% as low, 40% to 60% as medium, and > 60% as high indigenous self-identification level, respectively.

Afterward, we recompiled the punctual localities corresponding to these indigenous communities obtained from the INPI-INALI Atlas of indigenous populations belonging to Oaxaca (CARTO 2019) and related them with the corresponding habitat suitability value of jaguar, puma, and coyote for each LULC time series and the corresponding self-identification value using the extraction function of the spatial analysis tool (ArcGis 10.5). After that, a Pearson correlation analysis ($p < 0.05$) was performed between indigenous self-identification and large carnivores' habitat suitability for each LULC time series. The correlation index (r) ranges from −1 to 1, if $0 < r < 1$indicates a positive and direct correlation and if $-1 < r < 0$ indicates a negative and inverse correlation. Specifically, two analyses were conducted: one with species habitat suitability ranges > 3.0and indigenous self-identification values > 60%, and two with species habitat suitability ranges > 3.0 and indigenous self-identification values > 75%. These indigenous self-identification values were set at 60% and 75%, since we were interested in determining the municipalities with a preponderance of indigenous self-identification communities; that is, where > 60% of the communities regarded themselves as indigenous.

These values enabled a better visualization of each scenario of LULC for the correlations between species habitat suitability and indigenous self-identification. If the correlation was positive, we expected points occurrences with a high degree of indigenous communities' self-identification and a high species habitat suitability. These were areas with high potential for conservation. If the relation was negative, we expected no geographical concordance between indigenous communities' self-identification and species habitat suitability. Under this scenario, it is likely that other factors existed (environmental, social or economic) affecting indigenous communities' self-identification and/or species habitat suitability. Likewise, correlations were identified between the areas of medium and high species habitat suitability with the current geo-economic regions of Oaxaca (Istmo, Papaloapan, Cañada, Sierra Norte, Valles Centrales, Sierra Madre del Sur, Sierra Mixteca, and Costa) (Irazoque and Barbosa 1962). For this purpose, we performed a density analysis using correlation graphs for visualizing changes affecting species habitat suitability in the Zapotec and Mixtec territories, using the R Studio platform version 3.5.3 (R Core Team 2015).

Finally, we compared areas of species habitat suitability models, with jaguar, puma, and coyote records in natural protected areas (NPAs) and areas voluntarily designated for conservation (AVDC), between 2000 and 2019 (Table 2). The aim was to analyze whether the species habitat suitability models matched the large carnivores' occurrences (these occurrences were not used to estimate the habitat suitability models for each species). These records were searched from commonly used sources as GBIF Backbone Taxonomy (https://doi.org/10.15468/39omei), SNIB (http://enciclovida.mx), VertNet (http://portal.vertnet.org/search), the digitized Collection of Biological Photo-Specimens (Colección de Fotocolectas Biológicas, http://ibdata.ib.unam.mx/web/colecciones.php) of the Institute of Biology UNAM, and the database of Biological Monitoring of the Protected Natural Areas of the CONANP (https://simec.conanp.gob.mx/monitoreo.php). This process was conducted using the R Studio platform version 3.5.3 (R Core Team 2015).

Table 2. Number of occurrence records from 2000 to 2018 for jaguar, puma, and coyote in natural protected areas (NPAs) and areas voluntarily designated for conservation (AVDC) in Oaxaca, Mexico.

Conservation areas	Name of NPAs and AVDC	Species	Number of records	Year
NPAs	Tehuacán-Cuicatlán Biosphere Reserve	Puma	4	2004
			1	2005
			5	2007
			3	2008
			12	2010
			6	2011
			10	2012
			7	2013
		Coyote	10	2003
			13	2004
			5	2005
			2	2007
			1	2010
			7	2011
			11	2012
			6	2013
	Boquerón de Tonalá Flora and Fauna Protection Area	Puma	50	2012
			16	2013
			9	2014
			5	2015
		Coyote	1	2013
			3	2014
	Benito Juárez National Park	Puma	1	2014
			1	2015
		Coyote	1	2014
	Huatulco National Park	Coyote	1	2018
	Yagul Natural Monument	Coyote	1	2012
			4	2014
			25	2015
			2	2016
AVDC	Barranca del Epazote	Coyote	1	2014
	Camino a la Calavera	Jaguar	1	2012
		Puma	2	2012
		Coyote	2	2012
	Corral de Piedra	Coyote	1	2015
	El Baño	Puma	7	2013
	El Huerto	Puma	2	2012
			4	2013
			1	2014
	El paredón	Puma	5	2016
		Coyote	5	2016
	El Pie de la Peña	Puma	1	2013
			5	2014
			1	2015
		Coyote	1	2013
			1	2014
	El Portillo	Coyote	7	2013
	El Sauz 1	Puma	1	2012
	El Sauz 2	Puma	5	2012
	El Tular	Coyote	1	2014
			2	2015

AVDC	Hermenegildo	Coyote	5	2016
	La 2000	Puma	2	2013
			4	2014
			3	2015
			3	2016
		Coyote	2	2013
			1	2014
			5	2016
	La Cañada de Gregorio	Puma	1	2015
			11	2016
	La Cruz	Puma	4	2014
			3	2015
	La Cuevita	Puma	2	2014
			1	2015
	La Peña del Corral	Puma	6	2015
	La Rosa de Gacha	Coyote	9	2013
	La Ventana	Puma	2	2014
	Las Cuevas	Puma	1	2014
	Los Cajetes	Coyote	3	2015
	Los Lavaderos	Puma	1	2012
	Los Tepetates	Puma	1	2014
	Mogote del Pozo	Puma	18	2014
			1	2015
			19	2016
		Coyote	5	2016
	Paredones 2	Puma	2	2013
			11	2014
		Coyote	1	2014
	Río Concha	Coyote	2	2013
	Río del Jaguar	Jaguar	1	2013
	Río del Jaguar 2	Puma	1	2015
	Río Vaquero	Puma	1	2014
			2	2015
		Coyote	1	2014
	La Lima	Jaguar	2	2014
			3	2015
	La Manzanita	Jaguar	3	2014
	Xhachue	Jaguar	1	2015
	Arroyo del Aguacatal	Puma	5	2014
	Camino a Yelagago	Puma	3	2015
	Camino de Conducción de Agua Potable	Puma	2	2015
	Guia Dhao	Puma	1	2015
	La Lima	Puma	1	2014
	La Manzanita	Puma	1	2014
			1	2015
	Nhiza Yoya	Puma	1	2015
	Piedra Flor 2	Puma	2	2014
	Pozo del Aguacatal	Puma	3	2014
			1	2015
	Río de la Palma	Puma	2	2014
	Roa Gulabexho	Puma	1	2015
	Xhachue	Puma	1	2015
	Rancho Cajón	Coyote	1	2014

RESULTS

Multi-temporal analysis of species habitat suitability

In general, the suitable habitats (medium and high) for the three large carnivore species consisted mainly of areas covering natural and semi-natural forest, as well as secondary vegetation, wetlands and natural shrubland. Likewise, these areas included water bodies in the vicinity and showed a low or medium anthropic and agricultural and livestock impact (Figure 2). For the jaguar, there were fewer areas with a medium and high habitat suitability values than for the puma and coyote, respectively. These areas were found mainly in eastern and southern Oaxaca, and to a lesser extent in northern and western portions of the State. The areas of low habitat suitability included larger villages or towns and main cities, and areas crossed by major roads and highways (Figure 2).

With respect to the three time periods, the high habitat suitability areas showed a decrease for jaguar and coyote from LULC 2009 to LULC 2013, but an increase from LULC 2013 to LULC 2016. For example, high habitat suitability areas decreased 0.28% for coyote and 3.21% for jaguar from 2009 to 2013 and increased 0.93% for coyote and 6.51% for jaguar from 2013 to 2016. In contrast, for puma, high habitat suitability areas decreased 0.30% from 2009 to 2013, and 0.77% from 2013 to 2016. These high suitability differences between species may result from high elevational habitat preferences of puma (> 1500 masl; Table 1) compared to low and medium elevation habitat preferences of coyote and jaguar (Figure 2).

We observed a high number of records of the puma (130 and 159) and coyote (93 and 55) in both NPAs and AVDC, respectively. For example, the Tehuacán-Cuicatlán Biosphere Reserve, the Boquerón de Tonalá Flora and Fauna Protection Area, the Yagul Natural Monument, and the Benito Juárez National Park ranked top in the number of records, as well as some AVDC (Table 2). Only 11 records of jaguars were observed for AVDC, and no records were observed for NPAs. These conservation areas showed a medium-to-high habitat suitability for the three large carnivore species (Figure 2; Add file 1, 2, 3). However, the Boquerón de Tonalá Flora and Fauna Protection Area, the Yagul Natural Monument and the Benito Juárez National Park showed low-to-medium habitat suitability areas for these species (Figures 1 and 2).

Indigenous territories and species habitat suitability

The areas of higher overlap between indigenous territories and species habitat suitability were found in western, southern, and eastern portions of Oaxaca. These areas included local inhabitants that described themselves as indigenous communities, with self-identification values of over 60% (Figure 3). The high rates of indigenous self-identification and high values of species suitability models overlapped in six of the eight geo-economic regions of Oaxaca: Sierra Norte, southeastern and western parts of the Sierra Sur, the Coastal Region, and some municipalities of the Mixtec region (Figures 2 and 3).

The correlation analyses comparing > 60% of species habitat suitability with indigenous communities' self-identification showed the following trends (Figure 4A). The Zapotec areas showed a significant positive correlation with medium-to-high habitat suitability values (CI = 95% for all correlations) for jaguar (LULC 2009, r = 0.063; LULC 2013, r = 0.099; LULC 2016, r = 0.108, $p < 0.05$), and puma (LULC 2009, r = 0.058; LULC 2013, r = 0.097; LULC 2016, r = 0.107, $p < 0.05$). For coyote, a negative significant correlation was observed (LULC 2009, r = -0.177; LULC 2013, r = -0.166; LULC 2016, r = -0.201, $p < 0.05$). The Mixtec territories showed a negative significant correlation with the coyote (LULC 2009, r = -0.210; LULC 2013, r = -0.188; LULC 2016, r = -0.205, $p < 0.05$), but not with the puma (LULC 2009, r = -0.386; LULC 2013, r = -0.028; LULC 2016, r = -0.019, $p > 0.1$), nor the jaguar (LULC 2009, r = 0.003; LULC 2013, r = 0.013; LULC 2016, r = 0.017, $p > 0.1$) (Figure 4A).

Moreover, the correlation analyses comparing the species habitat suitability values > 75% with indigenous communities' self-identification showed a more pronounced trend (Figure 4B). The Zapotec territories showed a significant positive correlation with the puma and a significant negative correlation with coyote ($p < 0.05$). The Mixtec areas showed a significant negative correlation with the coyote, and a negative tendency for the puma. For the jaguar, the Mixtec self-identification showed a positive tendency (except for 2013) and a significant positive correlation with Zapotec communities in the LULC 2009 ($p < 0.05$), LULC 2013 ($p < 0.05$) and LULC 2016 ($p < 0.05$), respectively (Figure 4).

DISCUSSION

The perceptions and the cultural heritage of indigenous communities are key components to establish strategies for ecosystem and biodiversity conservation, including these large carnivore species. In

Meso-American indigenous cultures, for instance, the jaguar plays an important role within their communities cosmovision (Saunders 1994; Seller 2004; Sahagún 2005; López Austin 2012; Olivier 2016; Sugiyama 2016). Thus, according to their inclination and perceptions, this cosmovision may have important implications for ecosystems and resources maintenance in the long-term (Conforti and de Azevedo 2003; Treves and Karanth 2003; Campbell and Torres Alvarado 2011; Fita 2018). This is the result of nature ancestral perception and the large carnivore species awareness, referred as their "bio-cultural memory" (Toledo and Barrera 2008). For example, in Zapotec culture, jaguar, puma, and coyote are present in their common language (Seller 2004) and there are jaguar and puma clay figures representation from Monte Albán (i.e. a pre-Columbian archaeological site) (López Austin 2013). There are also stories and legends about the Zapotec origins involving the jaguar as an animal associated with gods, stories that remain until today (Henestrosa 2003). In Mixtec culture, the jaguar and coyote are represented in the Nutall Codex as an important species for their history and cosmovision (Zouche-Nutall 1987; Seller 2004).

The close and long-standing interactions of Mesoamerican indigenous communities with these large carnivore species have been gradually changing over time, because of the European influence (i.e. perceptions and land used dynamics) brought to America (Seller 2004; López-Austin 2013; Sánchez and Durán 2018). This result in some changes of the indigenous collective imaginary that generates a distortion towards a more utilitarian vision of natural resources, as seen in part of our results, in terms of communities' self-identification distribution and habitat suitability trends, so directly impacting the ecosystems where these large carnivores occur. This emphasizes the importance of empowering the collective and bio-cultural memory of these indigenous communities with the ecosystems and biodiversity conservation, which in turn play an important role

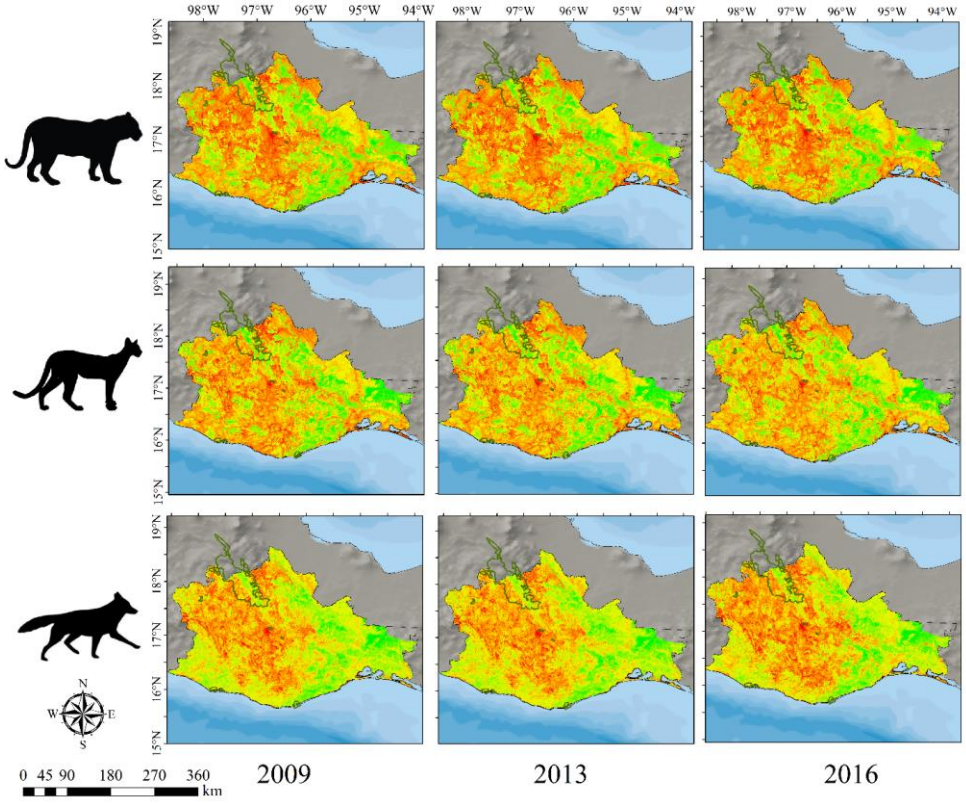

Figure 2. Distribution of high (green), medium (yellow), and low (red) habitat suitability for jaguar, puma, and coyote, in the INEGI land use and land cover map of LULC 2009, LULC 2013, and LULC 2016 of Oaxaca, respectively.

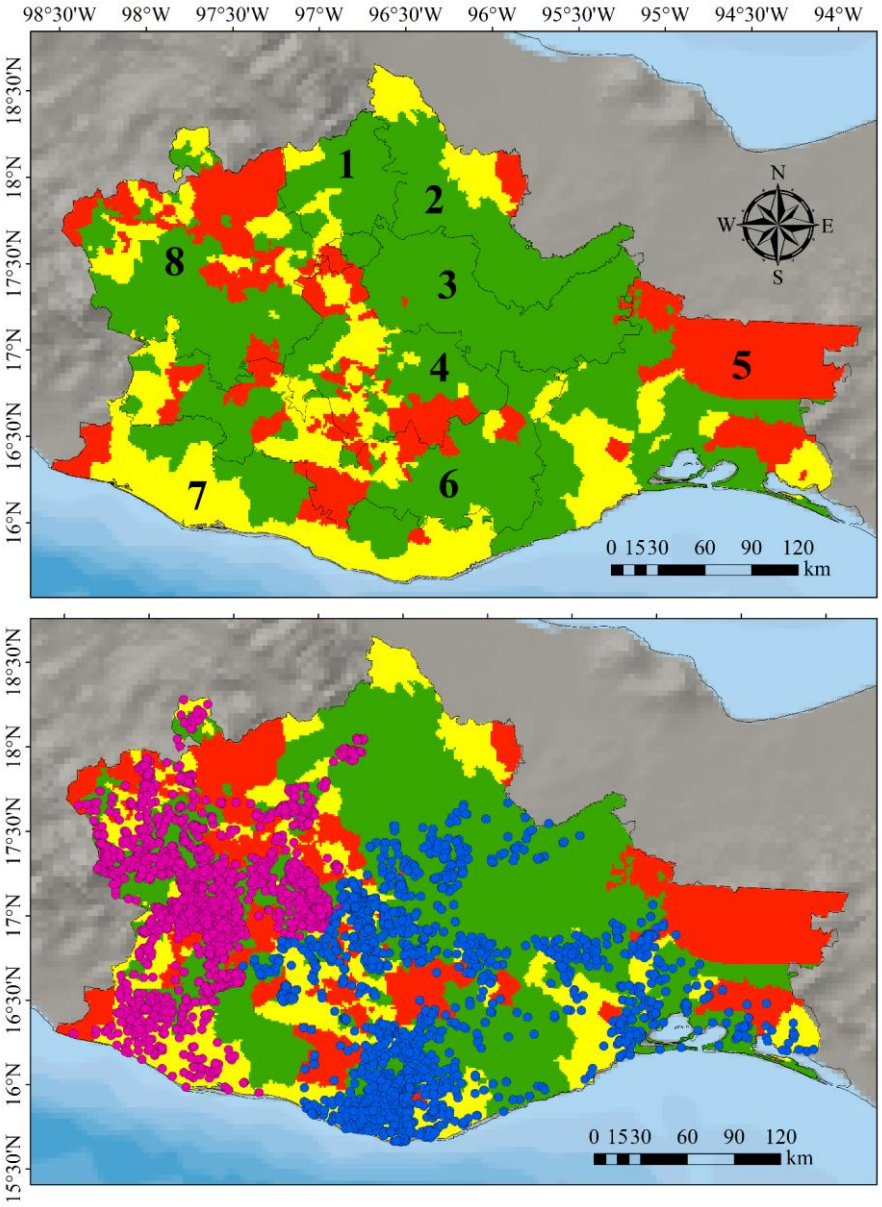

Figure 3. Spatial distribution of high (green), medium (yellow), and low (red) indigenous self-identification communities by geo-economic regions (top panel), and by indigenous Zapotec (blue points) and Mixtec (magenta points) villages (bottom panel). The geo-economic regions are: Cañada (1), Papaloapan (2), Sierra Norte (3), Valles Centrales (4), Istmo (5), Sierra Sur (6), Costa (7), and Mixteca (8).

for the environmental services availability and well-being of local indigenous communities (Buenrostro-Silva et al. 2015; Espinoza-Ramírez et al. 2017).

Our study also documented an important influence of the Zapotec and Mixtec indigenous communities on the ecosystems maintenance to support the

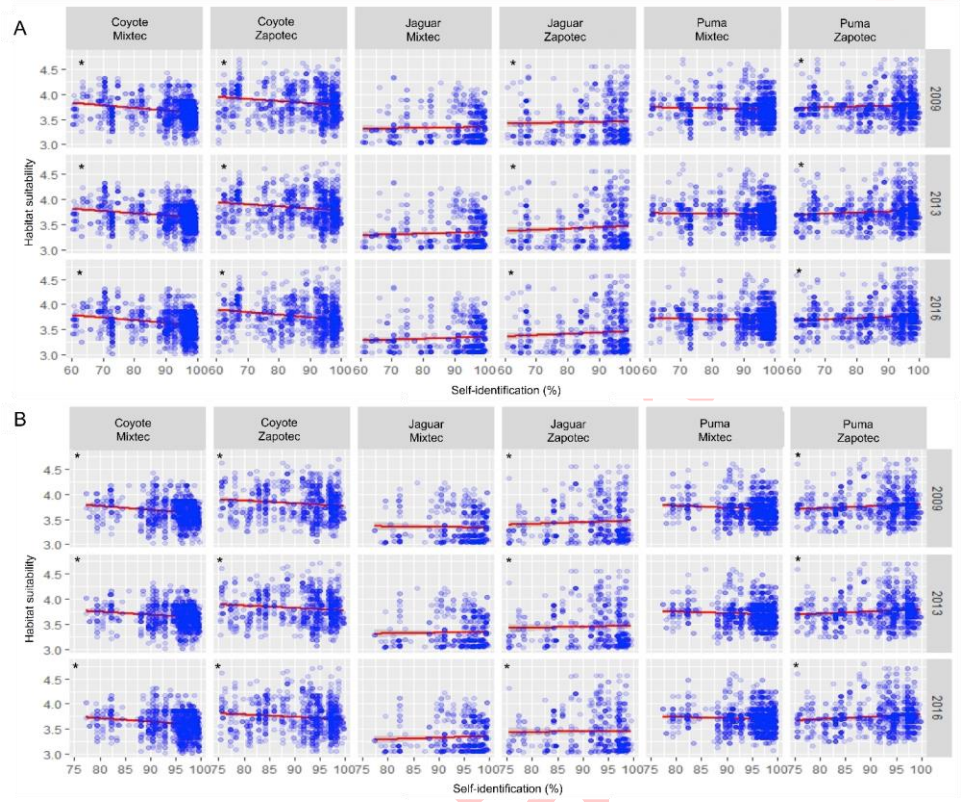

Figure 4. Pearson correlation ranks between jaguar, puma, and coyote habitat suitability (> 3.0) and areas holding indigenous self-identification communities. Indigenous self-identification with > 60% (A), and > 75% (B) are depicted for the Zapotec and Mixtec communities, respectively. Correlations are indicated for the LULC 2009 (upper panel), LULC 2013 (central panel), and LULC 2016 (bottom panel) time periods, respectively. *Significant correlation ($p < 0.05$).

populations of these large carnivore species in the long-term. We showed that the areas with medium-to-high species habitat suitability overlapped meanly with the Zapotec territories and to a lesser extent with Mixtec territories. Despite no positive correlation was observed for the coyote, it is likely that coyotes also actually occur in these areas as well (Botello et al. 2008). These areas should be prioritized for the conservation of these large carnivore species, given the proactive attitude of these indigenous communities toward nature. However, it is possible, that the potential of these large carnivore species as key top predator has been largely overlooked (Sanderson et al. 2002; Hunter 2005; Ray 2005; Granados-Peña et al. 2014). Additionally, coyotes did not show a positive correlation in areas of Zapotec and Mixtec high self-identification, possibly due to their high ecological plasticity and adaptability to disperse into anthropized habitats, as urban and peri-urban areas (Hidalgo-Mihart et al. 2004; Gehrt and Riley 2010; Hody et al. 2019). Moreover, some areas outside the NPAs and AVDCs showed high ecosystem degradation due to external factors of these indigenous communities (e.g., extensive expansion of the agricultural and livestock, development of infrastructure, human demographic growth), that negatively affect this correlation result, but shows a real perspective about biodiversity conservation of the region (Botello et al. 2008; Buenrostro-Silva et al. 2015).

We observed that six of the eight geo-economic regions in Oaxaca included areas with high species habitat suitability that coincided with the highest values of indigenous self-identification. Nonetheless, not all the AVDC areas show medium-high habitat suitability values for these large carnivore species in the region. The AVDC areas with low-medium habitat suitability values were highly degraded until they were incorporated recently into governmental conser-

vation programs in 2008 (LGEEPA 2008). It is likely that some of these AVDC areas should need more time to reach a medium or high suitable habitat recover (Monroy et al. 2019). Thus, it is necessary to include additional areas or corridors of high suitable habitats for these species overlapping with areas holding a high indigenous self-identification to ensure the conservation of these ecosystems in the long term. For example, additional areas and corridors with high suitable habitats could be connected with large protected areas as the Tehuacán-Cuicatlán Biosphere Reserve, the Huatulco National Park, the Lagunas de Chacahua National Park, the Benito Juárez National Park, and small protected areas as Yagul Natural Monument, Playa Escobilla Sanctuary, Playa de la Bahía de Chacahua Sanctuary and Boquerón de Tonalá Flora and Fauna Protection Area (Monroy-Gamboa et al. 2015, 2019; Wilson et al. 2011).

It is important to involve the indigenous communities in the environmental conservation planning and actions in local and regional resolution processes, since 40% of the priority terrestrial regions of Oaxaca belong to indigenous territories (Boege 2008). Oaxaca holds a high diversity of conservation initiatives, including areas of payments for biodiversity conservation and ecosystem services, voluntary areas for conservation, and forestry management, which have been recognize at international level as successful examples of local community participation in conservation efforts (Monroy-Gamboa et al. 2015, 2019). For example, there are over one hundred conservation areas that have been voluntarily proposed by local communities such as the *Unión de Comunidades Zapotecas-Chinantecas* located north of Oaxaca, and the *Sistema Comunitario para la Biodiversidad* in the coast that have established very successful conservation programs protecting biodiversity hotspots (Monroy-Gamboa et al. 2015, 2019). In addition, some governmental agencies as the National Commission of Forestry have established reforestation areas (CONAFOR 2010). There are also programs of payment for conserving areas for their importance to biodiversity and provision of environmental services (Martin et al. 2011).

This scenario, in turns, may generate not only a higher economic independence by developing activities contributing to biodiversity conservation as their main objective, but also could support and adjust other activities to decrease negative environmental impacts (e.g., deforestation, expansion of agriculture and livestock, etc.). In all this process considering these large carnivore species as important pieces not only for the ecosystem and ecological processes conservation, but also for the protection and safeguarding of the ancient cosmovision of local communities. When a specie is appreciated and regarded as a symbol of nature, a proactive attitude permeates the areas where indigenous communities and these carnivore species coexist (Mech 1970; Toledo and Barrera-Bassols 2008) (Figures 1-4). Therefore, a sustainable use of natural resources and the proportion of habitat connectivity with other conservation areas actively fostered by the indigenous communities could establish an integrated regional strategy of biodiversity conservation. This strategy should involve indigenous communities, stakeholders, and federal and local governmental and non-governmental organizations (Gadgil et al. 1993; Conforti and de Azevedo 2003) in order to generate a change in the negative perception towards these carnivore species, turning them as beneficial rather than threatening species (Millar et al. 2016) and then achieve a peaceful coexistence in all these territories.

CONCLUSION

Our study assessed species habitat suitability of the jaguar (*P. onca*), puma (*P. concolor*), and coyote (*C. latrans*), and quantified the overlap with the Mixtec and Zapotec indigenous territories in a biodiversity hotspot in southern Mexico. We found a positive and proactive relationship between indigenous communities' self-identification and a high species habitat suitability for the conservation of these large carnivores in the Sierra Norte, Sierra Sur, Coastal, and Mixtec regions. Given that most of these areas occur outside natural protected areas, the inclusion of indigenous communities in the management and planning of their territory is crucial for preserving their ethnocentric vision, and ensuring the conservation of these charismatic large carnivores and their habitat. The long-term conservation of ecosystems and their provision of environmental services will ultimately benefit the well-being of the indigenous communities in this biodiversity hotspot.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

CONTRIBUTION STATEMENT

Conceived of the presented idea: EG-M, AA-A. Carried out the experiment: EG-M, CGH, FMF, AA-A. Carried out the data analysis: EG-M, AA-A. Wrote the first draft of the manuscript: EG-M, AA-A, FB, VS-C. Review and final write of the manuscript: EG-M, FB, VS-C, AA-A. Supervision: FB, VS-C, AA-A.

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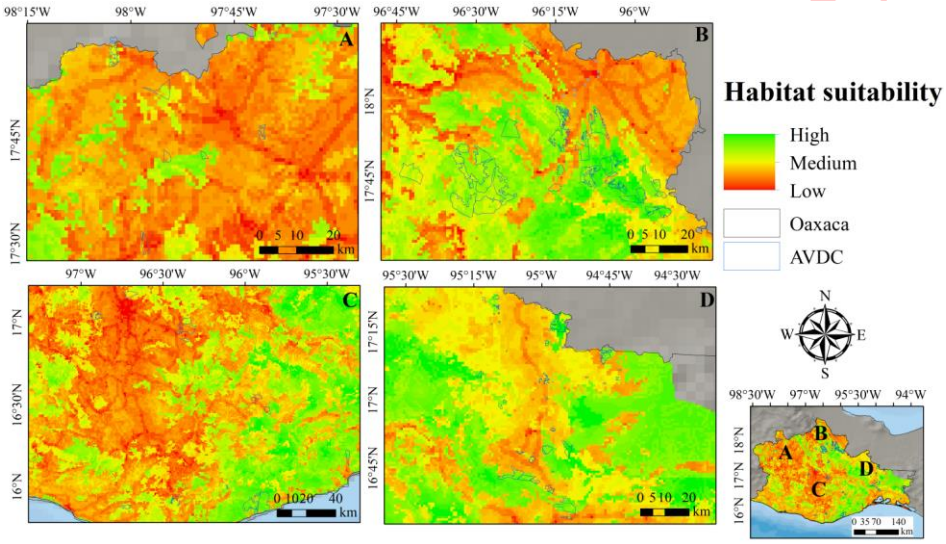
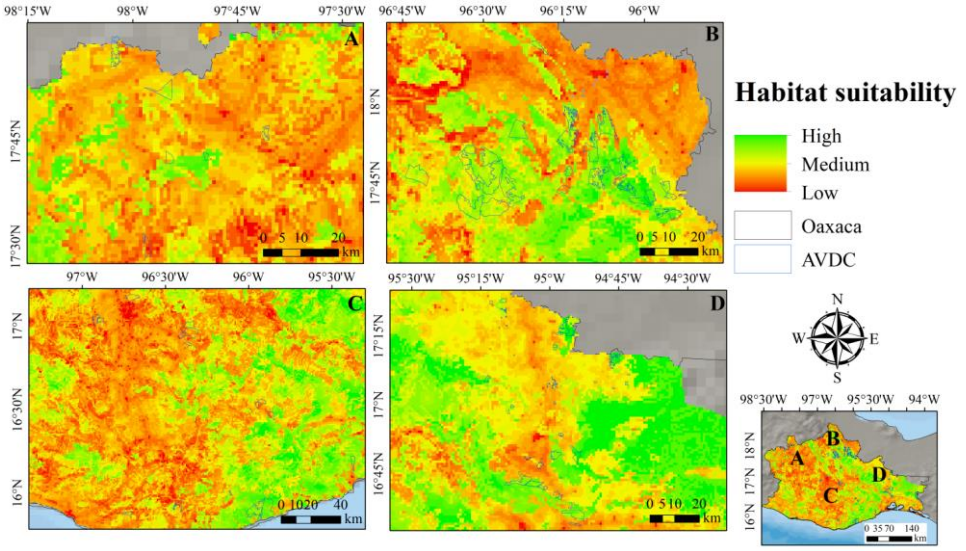
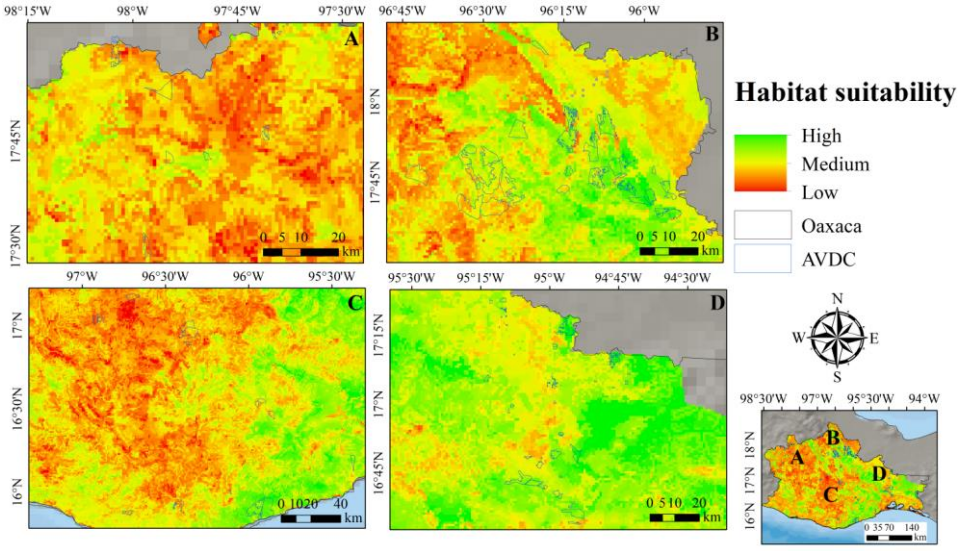
Additional Files



Add File 1. A closer view of high, medium, and low jaguar habitat suitability trend for the LULC 2009 and its relationship with the Areas Voluntarily Designated for Conservation (AVDC in blue).



Add File 2. A closer view of high, medium, and low puma habitat suitability trend for the LULC 2009 and its relationship with the Areas Voluntarily Designated for Conservation (AVDC in blue).



Add File 3. A closer view of high, medium, and low coyote habitat suitability trend for the LULC 2009 and its relationship with the Areas Voluntarily Designated for Conservation (AVDC in blue).