UNIVERSIDAD AUTÓNOMA DEL ESTADO DE MÉXICO

MAESTRÍA Y DOCTORADO EN CIENCIAS AGROPECUARIAS Y RECURSOS NATURALES

FACTORES AMBIENTALES Y SOCIOECONÓMICOS RELACIONADOS CON LA DEPREDACIÓN DE GANADO POR GRANDES CARNÍVOROS EN MÉXICO

T E S I S

QUE PARA OBTENER EL GRADO DE DOCTOR EN CIENCIAS AGROPECUARIAS Y RECURSOS NATURALES

PRESENTA:

FRANCISCO REYNA SÁENZ

El Cerrillo Piedras Blancas, Toluca, Estado de México. Septiembre 2019

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Resumen

Los conflictos con los seres humanos son una de las principales causas de la disminución de las poblaciones de carnívoros grandes, por lo que es un problema de conservación en todo el mundo. En México, se ha reportado la depredación de ganado por jaguar (*Panthera onca*), puma (*Puma concolor*) y oso negro americano (*Ursus americanus*) así como su persecución en represalia. Los sitios donde ocurre la depredación se distribuyen en todo el país y difieren no solo en las características ambientales, sino también en las prácticas sociales, económicas y de manejo del ganado. Sin embargo, debido al enfoque general de los estudios realizados hasta ahora, las medidas de mitigación propuestas también son generales. Es necesario considerar las condiciones regionales que favorecen la depredación en el diseño de estrategias para que sean más efectivas. El objetivo del proyecto de investigación fue identificar los factores ambientales, antrópicos y de manejo de ganado que influyen en los ataques a ganado por grandes carnívoros en México. Se aplicaron diversos métodos y técnicas de análisis como estadística multivariada, sensores remotos y sistemas de información geográfica. Los resultados muestran que existe una relación de los eventos de depredación particularmente con las variables de manejo de ganado, así como la existencia de patrones espaciales de agrupación de los casos. Asimismo, se pone de manifiesto la necesidad de contar con información a escala detallada para estudios locales. Se realizaron propuestas de mitigación para disminuir la incidencia de depredación de ganado por grandes carnívoros para diferentes regiones del país. Se considera fundamental la inclusión del componente antrópico y de las prácticas de manejo de ganado en los planes de conservación de grandes carnívoros en México.

Abstract

Conflicts with humans are one of the main causes of the decline of large carnivore populations, making it a conservation problem worldwide. In Mexico, depredation of livestock by jaguar (*Panthera onca*), puma (*Puma concolor*) and American black bear (*Ursus americanus*) has been reported as well as their persecution in retaliation. The sites where depredation occurs are distributed throughout the country and differ not only in environmental characteristics, but also in social, economic and livestock management practices. However, due to the broad-based approach of the studies carried out so far, the proposed mitigation measures are also general. It is necessary to consider the regional conditions that affect predation in the design of strategies to make them more effective. The objective of the research project was to identify the environmental, anthropic and livestock management factors that influence livestock attacks by large carnivores in Mexico. In the different works carried out, various methods and analysis techniques were applied, such as multivariate statistics, remote sensing and geographic information systems. The results of the investigation show that there is a relationship between the events of predation with various spatial variables, particularly those related to livestock management, as well as the existence of spatial patterns of grouping of predation events according to various variables associated with them. The need for detailed scale information for local studies is also highlighted. Mitigation proposals were made to reduce the incidence of livestock predation by large carnivores for different regions of the country. The inclusion of the anthropic component and livestock management practices in the conservation plans of large carnivores in Mexico is considered fundamental.

Agradecimientos

Hago un extenso agradecimiento al Consejo Nacional de Ciencia y Tecnología (CONACyT) por la beca otorgada para realizar los estudios de doctorado y a la Universidad Autónoma del Estado de México por financiar este estudio. Agradezco a la Confederación Nacional de Organizaciones Ganaderas por proporcionarnos invaluable información sobre registros de depredación. También quiero agradecer a Fernanda Núñez y Alejandra López por su apoyo para compilar la base de datos de registros de depredación por oso negro americano.

Un agradecimiento especial a mi tutora académica Dra. Martha Mariela Zarco González, por compartir sus invaluables conocimientos conmigo y por toda la orientación que me proporcionó durante el desarrollo de la investigación. A los doctores Dr. Octavio Monroy Vilchis y Dra. Xanat Antonio Némiga por la valiosa codirección de este trabajo y por su excelente asesoría científica.

Un amplio reconocimiento al Laboratorio de Análisis Geoespacial del Instituto de Geografía de la Universidad Nacional Autónoma de México por las facilidades proporcionadas para el desarrollo de la investigación.

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I. Introducción general

En la presente investigación se aborda un aspecto clave en la conservación de tres especies de grandes carnívoros de México, jaguar (*Panthera onca*), puma (*Puma concolor*) y oso negro americano (*Ursus americanus*), la depredación de ganado, la cual es un factor que origina su persecución, cacería y la disminución de sus poblaciones (Juárez-Casillas y Varas, 2013; Zarco-González *et al*., 2014). La evaluación de la depredación de ganado por grandes carnívoros se realizó a escala nacional bajo un enfoque que integra variables antrópicas y de manejo de ganado, además de las variables ambientales tradicionalmente empleadas, es decir, se hace énfasis en la consideración de la dimensión humana en el manejo integral de estos conflictos. Asimismo, la evaluación de esta problemática se realiza desde un enfoque espacial.

En México, la persecución de jaguar, puma y oso negro debido a que son percibidos como una amenaza para el ganado, es un fenómeno documentado por los medios de comunicación, en documentales de organizaciones de la sociedad civil e instituciones vinculadas a la conservación en el país y en la literatura científica (Rosas-Rosas *et al*., 2008; Chávez y Zarza, 2009; Villordo-Galván, 2009; Rosas-Rosas *et al*., 2010; Juárez-Casillas y Varas, 2013; Zarco-González *et al*., 2013). El desarrollo de investigaciones para conocer el estado y los problemas de conservación de estas especies es una tarea crucial, especialmente porque de acuerdo a la norma oficial mexicana de la Secretaría de Medio Ambiente y Recursos Naturales NOM-059-SEMARNAT-2010 las especies *Panthera onca* y *Ursus americanus* se encuentran en peligro de extinción. Si bien la especie *Puma concolor* no está clasificada en alguna categoría de riesgo en esta norma, la Unión Internacional para la Conservación de la Naturaleza (UICN), la clasifica como de preocupación menor (Least concern), a la vez que manifiesta que ha sido extirpada de diferentes zonas dentro de su rango de distribución y que en general las poblaciones están declinando.

La presente investigación aporta conocimiento al fenómeno de depredación de ganado por grandes carnívoros, desde un enfoque diferente y complementario a otros estudios realizados en México (Zarco-González *et al*., 2013), con el propósito de contribuir con propuestas de medidas que puedan ser implementadas para la mitigación de la problemática. El trabajo de investigación fue conceptualizado para tener un alcance nacional e identificar y desarrollar información requerida para estudios locales, en una zona específica, representada por la Reserva Natural Sierra Nanchititla.

En la literatura de la conservación biológica, una de las demandas más frecuentes es por mayor cantidad y calidad de información sobre tópicos particulares (Linnell *et al*., 2001; Graham *et al*., 2004). En esta investigación se emplearon los datos más recientes disponibles. A nivel nacional se evaluó la asociación de variables ambientales, antrópicas y de manejo de ganado con los registros de depredación, con el propósito de identificar patrones espaciales donde las variables empleadas tienen atributos similares. El resultado de este análisis muestra regiones del territorio donde la depredación está determinada por un conjunto particular de factores y a partir de esta regionalización se estructuran una serie de propuestas de mitigación.

En la segunda parte de la investigación, se evaluaron los cambios de cobertura del suelo en la Reserva Natural Sierra Nanchititla (RNSN), en el periodo comprendido entre 1986 y 2017, a través del procesamiento de imágenes de satélite Landsat 5 TM y Sentinel 2. El propósito de la evaluación de cambio de cobertura del suelo en la reserva fue analizar la relación entre la ubicación de los registros de depredación con la ubicación de los cambios de cobertura registrados. El análisis de los cambios de cobertura del suelo en esta área donde existen registros de depredación de ganado por jaguar y puma es un insumo fundamental para posteriores estudios orientados a la conservación de ambas especies.

II. Revisión de literatura

Los conflictos humano-fauna silvestre son uno de los factores centrales que amenazan la biodiversidad a escala global y con frecuencia son un factor que socava los objetivos de conservación de la fauna y las iniciativas de uso sostenible (Woodroffe *et al*., 2005; Dickman et. al., 2014; Aryal et. al., 2014; Miller *et al*., 2015; Bargali y Ahmed, 2018). Uno de los principales conflictos entre humanos y grandes carnívoros se deriva de la depredación de ganado, fenómeno que incide directamente en los medios de vida de la población rural y ocasiona la persecución y cacería de los depredadores en represalia (Treves y Karanth, 2003; Inskip y Zimmermann, 2009; Zarco-González *et al*., 2013; Hanley *et al*., 2018), por lo que constituye en la actualidad uno de los temas más urgentes en la conservación de grandes carnívoros.

Las interacciones cada vez más frecuentes entre depredadores y ganado doméstico se relacionan principalmente con la expansión constante de los asentamientos y de las actividades humanas, degradación, fragmentación y pérdida de hábitat, amplio rango de distribución de muchos carnívoros, reducción de la disponibilidad de presas naturales e inadecuadas prácticas de manejo del ganado (Polisar *et al*., 2003; Michalski *et al*., 2006; Palmeira *et al*., 2008; Karanth y Chellam, 2009). En México, las altas tasas de deforestación (Cuevas *et al*., 2010; Velázquez *et al*., 2002) y en general la propagación de usos del suelo antrópicos acrecientan la competencia entre humanos y carnívoros por espacio y recursos.

Los sitios donde las especies de carnívoros cazan están caracterizados por una combinación de elementos del paisaje donde pueden encontrar y cazar a sus presas con mayor facilidad. Este principio se extiende a los sitios donde se presenta la depredación de ganado (Kissling *et al*., 2009; Chardonnet *et al*., 2010; Miller *et al*., 2015), mismo que ha sido usado para la evaluación de riesgo potencial de depredación en diversos estudios (Zarco-González *et al*., 2013; Miller *et al*., 2015; Recio *et al*., 2018).

Los datos analizados en los estudios que abordan esta problemática varían de acuerdo al enfoque de las investigaciones, así como a su escala temporal y geográfica. Las investigaciones desde una perspectiva espacial en las cuales se evalúa la problemática de depredación de ganado incluyen principalmente el análisis de las características ambientales donde ocurren los eventos de depredación (Michalski *et al*., 2006; Kissling *et al*., 2009; Rosas-Rosas *et al*., 2010). Entre las variables biofísicas usualmente consideradas que se relacionan con la frecuencia de ataques se encuentran los tipos de cobertura vegetal, cobertura del suelo, altitud y pendiente del terreno, densidad de presas silvestres y ubicación de fuentes de agua (Baruch-Mordo *et al*., 2008; Zarco-González *et al*., 2013).

En los estudios de caso, a escala local, es más frecuente el empleo de variables socio-culturales y sobre el emplazamiento de infraestructura, abordando tópicos como la percepción y tolerancia de la población local a los carnívoros (Conforti y Cascelli, 2003; Hemson *et al*., 2009; Iftikhar *et al*., 2009; Carter *et al*., 2013; Lindsey, *et al*., 2013; Suryawanshi *et al*., 2013; Yirga *et al*., 2014) o la valoración de impacto de depredación y pérdidas económicas (Butler, 2000; Mazzolli *et al*., 2002; Cascelli y Murray, 2007; Karamanlidis *et al*., 2011; Aryal *et al*., 2014; Harihar *et al*., 2014; Widman y Elofsson, 2018). Debido a la extensión geográfica más reducida, en general, es factible acceder a una mayor cantidad de información a través del trabajo directo en las comunidades afectadas. Lo anterior hace posible delinear medidas específicas para la mitigación de esta problemática que aplican para sitios particulares.

La información sobre la presencia humana usualmente empleada en estudios realizados en regiones extensas o a escalas nacionales, incluyen la distancia a asentamientos humanos, la distancia a carreteras y a áreas naturales protegidas, así como la densidad de ganado y algunas prácticas de manejo del mismo (Zarco-González *et al*., 2013; Rosas-Rosas *et al*., 2010).

Las particularidades de gestión del territorio, distribución de la población, cultura, nivel socioeconómico, entre otros factores, influyen en prácticamente cualquier plan de manejo del territorio y de los recursos naturales. Cuando se abordan conflictos entre humanos y fauna silvestre, la dimensión humana debe ser incluida como una parte importante de la problemática. Dentro de la investigación científica y el diseño de programas gubernamentales de gestión del territorio, la necesidad de integrar la dimensión humana ha sido reconocida desde hace varias décadas (Primack *et al*., 2001). En el análisis de conflictos entre humanos y grandes carnívoros, aun cuando se señala la necesidad de realizar investigaciones que contemplen una visión integral de los subsistemas ambiental y humano, en pocos estudios se aborda de manera conjunta la influencia de variables ambientales y socioeconómicas en la depredación de ganado (Bagchi y Mishra, 2003; Graham *et al*., 2005; Kolowski y Holekamp, 2006; Carvalho *et al*., 2015), lo cual dificulta tanto el entendimiento de la problemática como el diseño e implementación efectiva de estrategias de conservación (Bagchi y Mishra, 2003).

Las tendencias observadas de crecimiento poblacional y de la creciente demanda de recurso naturales, permiten predecir que la interacción entre la sociedad y los grandes depredadores será más frecuente en el futuro, debido a la disminución constante de los espacios naturales, por lo que es fundamental pensar en estrategias de convivencia, entre ellas, la modificación o adecuación de las prácticas de manejo pecuario, lo cual es considerado un elemento clave en la mitigación de la depredación de ganado por la fauna silvestre.

En México, las mayores especies de grandes carnívoros que sobreviven en hábitats naturales son el jaguar, el puma y el oso negro americano. La depredación de ganado por ambas especies de felinos ha sido documentada en regiones diversas del país (Rosas-Rosas *et al*., 2008; Chávez y Zarza, 2009; Villordo-Galván, 2009; Rosas-Rosas *et al*., 2010; Zarco-González *et al*, 2012; Zarco-González y Monroy-Vilchis, 2014) así como la depredación por osos negros (Juárez-Casillas y Varas, 2013). La depredación de ganado por estas especies de carnívoros en México afecta a la economía de las familias rurales por la pérdida de cabezas de ganado; asimismo, la cacería de depredadores que usualmente ocurre en consecuencia ocasiona la disminución de sus poblaciones y en última instancia incrementa la posibilidad de su extinción local (Rosas-Rosas *et al*., 2008; Rosas-Rosas *et al*., 2010; Zarco-González y Monroy-Vilchis, 2014; Zarco-González *et al*, 2012). En la Sierra Nanchititla, la alta fragmentación del hábitat de jaguares y pumas registrada en las últimas décadas, así como la expansión de las actividades humanas en esa zona han aumentado la frecuencia de los conflictos con los seres humanos.

III. Justificación

Los conflictos con los humanos constituyen una de las mayores causas de la mortalidad y la disminución de las poblaciones de muchas especies de grandes carnívoros (Azevedo y Murray, 2007). La mitigación de este tipo de conflictos requiere de un sólido entendimiento de sus patrones subyacentes, desde una perspectiva integral que contemple aspectos biológicos y condiciones socioeconómicas. La conservación efectiva de la naturaleza requiere considerar factores complejos en el ámbito biológico, físico-geográfico, social y económico implicados en la integridad ecológica de un sitio.

Sin embargo, no obstante la gran cantidad de estudios realizados, pocos analizan la información ecológica y socioeconómica específica de estos conflictos (Graham *et al*., 2004), son escasas las investigaciones realizadas donde se aborde de manera integral los patrones espacio temporales de los conflictos entre humanos y depredadores, las características ambientales y de hábitat así como las condiciones socioeconómicas prevalecientes.

La presente investigación aporta conocimiento sobre una de las múltiples facetas relacionadas con el tema de conservación de las tres especies de grandes carnívoros de México, dos de ellas en peligro de extinción (jaguar y oso negro americano). Las propuestas generadas pueden apoyar la toma de decisiones para incrementar la efectividad de las estrategias de conservación de estas especies.

IV. Objetivos

Objetivo general:

Generar una regionalización del territorio mexicano de acuerdo con los factores ambientales y socioeconómicos asociados con la depredación de ganado por grandes carnívoros.

Objetivos específicos:

a) Identificar patrones espaciales con base en las variables que caracterizan los sitios donde se presentan los eventos de depredación.

b) Jerarquizar propuestas regionales para la mitigación de la depredación de ganado por grandes carnívoros.

d) Evaluar los cambios de cobertura del suelo ocurridos en las últimas décadas en la Reserva Natural Sierra Nanchititla y su relación con la ubicación espacial de los eventos de depredación registrados para la reserva.

V. Materiales y métodos

1.1 Área de estudio

La primera etapa del estudio se realizó a nivel nacional. México se localiza en Norte América, entre las coordenadas extremas 86°42'-118°22' de longitud oeste y 32°43'-14° 32' de latitud norte, cuenta con una superficie de 1,959,247.98 Km^2 (INEGI, 2016). Se presentan climas de los grupos A (lluvioso tropical), B (seco), C (templado) y E (frío) (García, 2004). La variedad de asociaciones florísticas abarca desde bosques tropicales, bosques templados y vegetación del desierto, hasta vegetación alpina (Rzedowski, 2006). El relieve está dominado por sistemas montañosos, altiplanicies y planicies costeras.

El país registró un fuerte crecimiento poblacional a mediados del siglo pasado, con un pico máximo en la década 1960-1970, con una tasa de crecimiento promedio anual de 3.4. En el último periodo censal, entre 2010 y 2015, la tasa de crecimiento media anual de la población fue de 1.4 (INEGI, 2010; INEGI, 2015). Para el año 2015 México presentó una población total de 119 530 753 habitantes (INEGI, 2015), con una densidad de población de 65.61 personas por Km^2 en 2015, sin embargo, la distribución de la población tiene grandes diferencias regionales, en los extremos, la densidad de población de Baja California Sur es de 10 y en la Ciudad de México es de 5,967 habitantes/Km^2. México ocupa el octavo lugar mundial en producción ganadera, con aproximadamente 33 millones de cabezas y una densidad de 16.77 por kilómetro cuadrado (FAO, 2014; INEGI, 2015, 2016; Fig. 1).

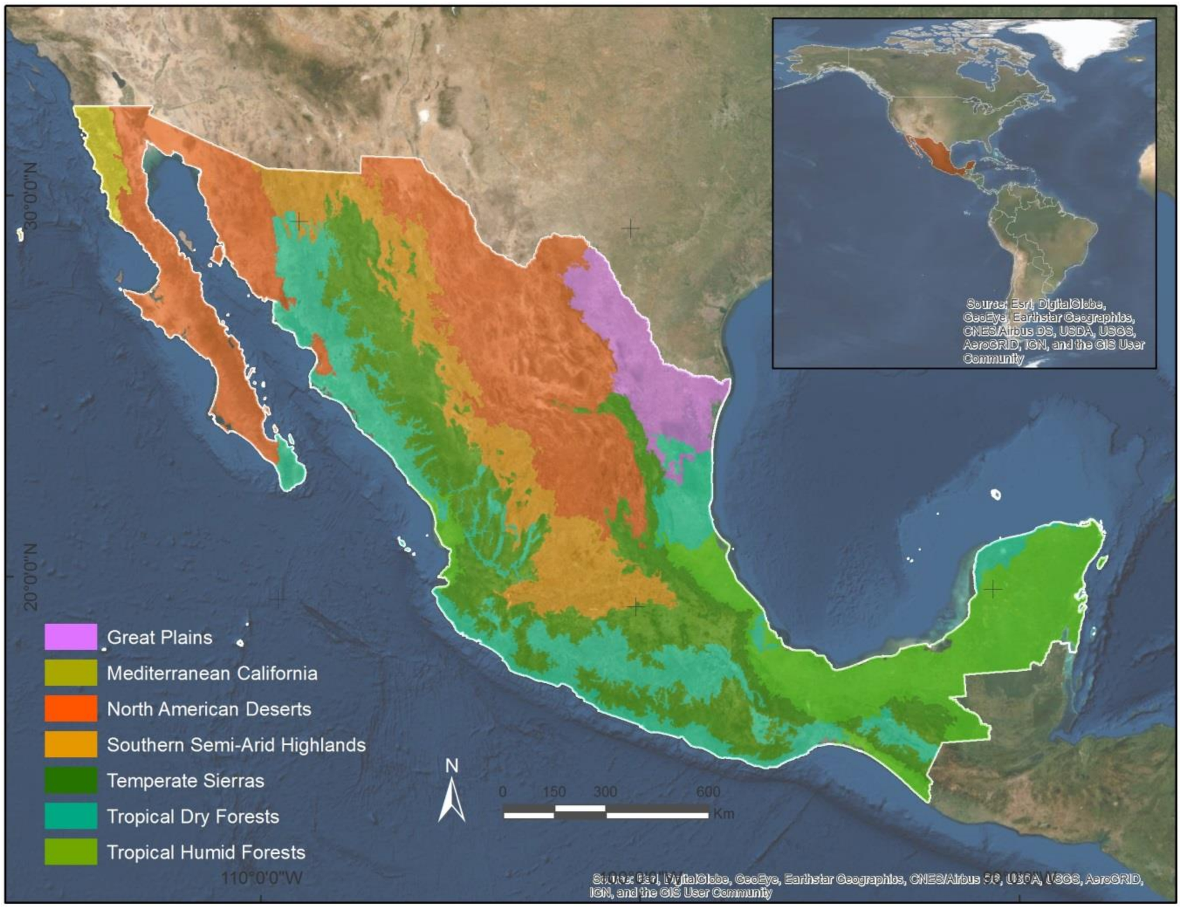

Figura 1. Área de estudio y ecorregiones de México nivel I (http://www.cec.org/naatlas/. Regiones ecológicas de Norteamérica).

Para obtener los insumos relativos a cobertura del suelo, se seleccionó como área de estudio a la Reserva Natural Sierra de Nanchititla, la cual constituye uno de los sitios en el centro del país donde ha sido documentada la presencia de jaguar y puma, así como del problema de depredación de ganado. La Sierra de Nanchititla se localiza en la región centro-sur de México en la provincia biogeográfica Depresión del Balsas, entre las coordenadas extremas 100°16'0.393"-100°36'45.7164" de longitud oeste y 18°45'33.1194"-19°4'30.2808" de latitud norte, tiene una superficie de 65,301.56 ha y fue decretada el 12 de octubre de 1977 con la categoría de Parque Estatal (CONABIO, 2015). Geomorfológicamente, la región está conformada por sierras, lomeríos y valles fluviales (INEGI, 2001; IG-INE, 2003), dentro de un rango altitudinal entre 399 y 2074 msnm (ASF, 2015). Los climas predominantes son cálido subhúmedo y semicálido subhúmedo, con un porcentaje de precipitación invernal inferior a 5 y poca oscilación térmica anual (entre 5°C y 7°C) (IGECEM, 1993). Las asociaciones florísticas están representadas esencialmente por selva baja caducifolia y bosques de encino y pino. Los usos del suelo antrópicos predominantes son pastizal inducido y zonas de cultivos. De acuerdo a los últimos datos censales, en la reserva existen 145 localidades pertenecientes a los municipios de Luvianos y Tejupilco, en el Estado de México, con un total de 11,912 habitantes (INEGI, 2010).

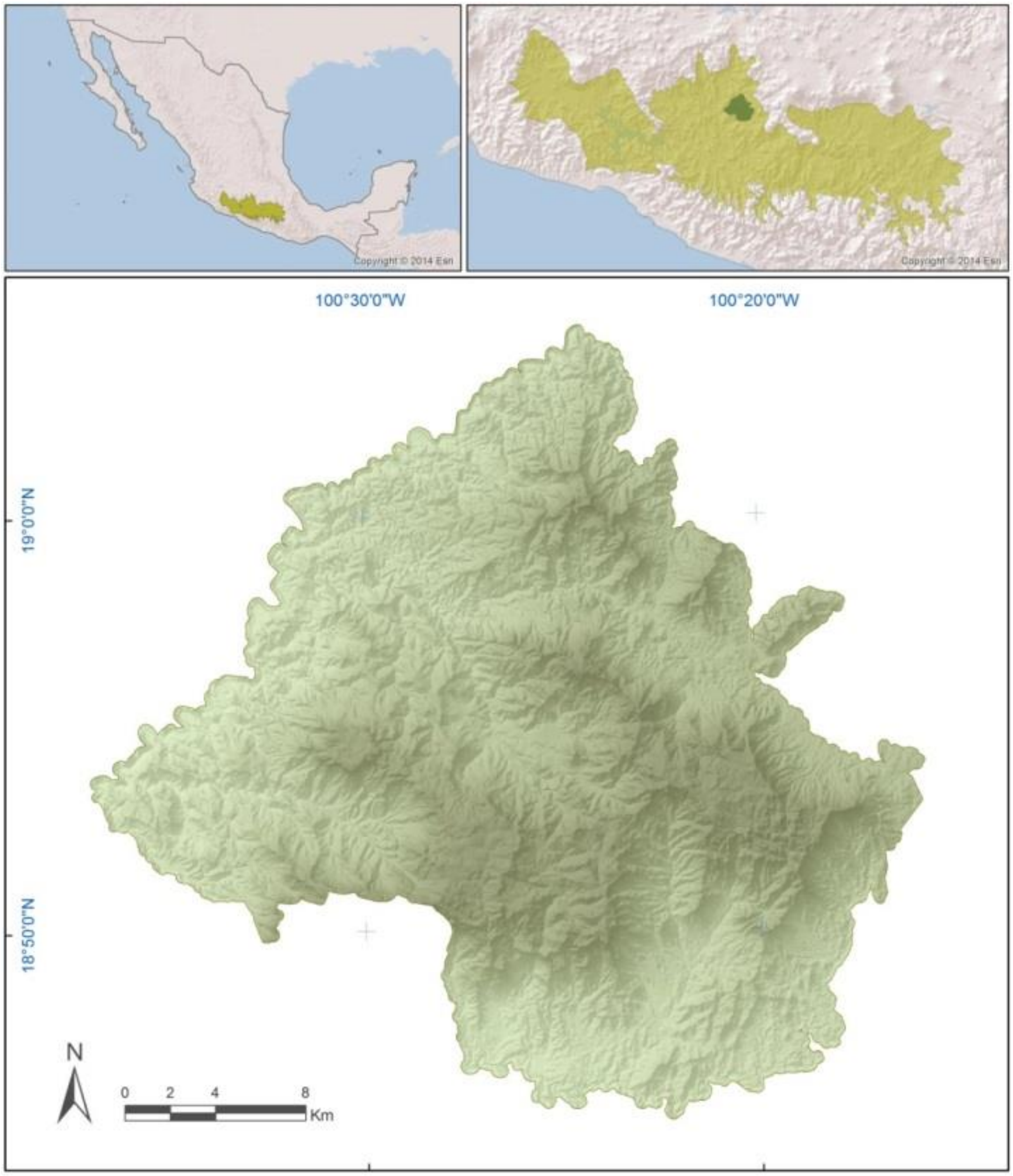

Figura 2. Localización de la Reserva Natural Sierra Nanchititla (RNSN) en el contexto nacional y en la provincia biogeográfica Depresión del Balsas.

1.2 Registros de depredación

Los registros de depredación de ganado por *Panthera onca*, *Puma concolor* y *Ursus americanus* fueron obtenidos a partir de cuatro fuentes: a) bases de datos y reportes de instituciones oficiales del gobierno mexicano (Secretaría del Medio Ambiente y Recursos Naturales –SEMARNAT-, Procuraduría Federal de Protección al Ambiente -PROFEPA-, Secretaría de Medio Ambiente y Recursos Naturales del estado de Guerrero –SEMAREN-); b) Confederación Nacional de Organizaciones Ganaderas (CNOG); c) literatura científica (Brown y López, 2001; Rosas-Rosas y López-Soto, 2002; Bueno-Cabrera, 2004; Caso, 2007; Cruz *et al*., 2007; Leyequién y Balvanera, 2007; Lira y Ramos-Fernández, 2007; Navarro *et al*., 2007; Núñez, 2007; Rosas-Rosas *et al*., 2008; Chávez y Zarza, 2009; Villordo-Galván, 2009; Zarco-González *et al*., 2012; Zarco-González *et al*., 2013); y d) organizaciones no gubernamentales. Las ubicaciones de los sitios de depredación fueron obtenidas a partir de coordenadas de geolocalización y descripciones presentadas en las fuentes originales. El rango de temporalidad del total de los registros corresponde al periodo 1990 – 2014.

1.3 Variables ambientales, antrópicas y de manejo de ganado

Fue obtenida y sistematizada información geográfica sobre variables ambientales y antrópicas, identificadas en la literatura como relacionadas con la depredación de ganado por carnívoros (Treves *et al*., 2004; Bagchi y Mishra, 2006; Kolowski y Holekamp, 2006; Michalski *et al*., 2006; Azevedo y Murray, 2007; Iftikhar, et. al, 2009; Inskip y Zimmermann, 2009; Chávez y Zarza, 2009; Gusset *et al*., 2009; Kissling *et al*., 2009; Rosas-Rosas *et al*., 2010; Zarco-González *et al*., 2013; Carvalho *et al*., 2015; Miller *et al*., 2015).

Las variables empleadas para caracterizar los sitios de ataque fueron clasificadas en tres grupos: ambientales, antrópicas y relacionadas con el manejo de ganado. El primer grupo incluye variables topográficas (altitud y pendiente del terreno -INEGI, 2016) e información sobre la cobertura vegetal y cobertura del suelo (porcentaje de cobertura arbórea –NASA, 2010-; distancia a pastizales inducidos –INEGI, 2013- y distancia a zonas urbanas y áreas agrícolas –INEGI, 2013-, estas dos últimas únicamente utilizadas en el análisis realizado para oso negro). En las variables antrópicas fueron consideradas la distancia a carreteras (INEGI, 2015) y la densidad de población (INEGI, 2010). En relación con el manejo de ganado se incluyeron la densidad de ganado bovino, densidad de ganado ovino, densidad de ganado caprino, porcentaje de ganado bovino con alimentación suplementaria, porcentaje de ganado caprino con alimentación suplementaria, porcentaje de ganado ovino con alimentación suplementaria, porcentaje de ganado bovino con vacunación, porcentaje de ganado ovino con vacunación, porcentaje de ganado caprino con vacunación y porcentaje de ganado bovino en libre pastoreo, a partir de los valores por municipio reportados en el Censo Agrícola, Ganadero y Forestal 2007 (INEGI, 2009).

1.4 Imágenes de satélite de la Reserva Natural Sierra de Nanchititla

Para la clasificación del uso de suelo se emplearon imágenes de satélite Landsat 5 TM con resolución de 30 m (año 1986) e imágenes de satélite Sentinel 2 con resolución de 10 metros (año 2017). Los datos satelitales de la zona de estudio se obtuvieron del sitio web de Earth Explorer (http://earthexplorer.usgs.gov/) y del sitio de Google Earth Engine (https://code.earthengine.google.com/).

1.5 Procesamiento de la información

Análisis espacial

La homogeneización, adecuación y/o preparación de las capas de información espacial para su análisis integrado requirió del desarrollo de diversos procesos dentro de herramientas de sistemas de información geográfica. Todos los procesos de entrada de datos, manejo y análisis fueron realizados por medio del software GIS ArcGIS versión 10.0 (ESRI Inc.). La información fue almacenada en un sistema de referencia geográfica homogéneo para hacer posible su combinación y análisis integral. La escala cartográfica básica del estudio fue 1:250,000, por lo tanto, todos los temas de información fueron remuestreados o en su caso rasterizados a una resolución espacial de 150 metros de acuerdo a Tobler (1987).

El mapa de pendiente fue generado a partir del modelo de elevación digital previamente remuestreado con la función *slope*. Posteriormente con análisis zonales se obtuvo el promedio del valor de la pendiente dentro de un área del tamaño promedio del ámbito hogareño de las tres especies de carnívoros (Rabinowitz y Nottingham, 1986; Dickson y Beier, 2002; Onorato *et al*., 2003).

Con el propósito de evitar el empleo de información socioeconómica generalizada disponible a nivel municipal, se recurrió al uso de las estadísticas censales existentes a nivel de localidades, las cuales tienen una ubicación puntual. Debido a la distribución discreta de estos datos, se generó una unidad espacial de tipo polígono compuesta por la sobreposición de los mapas de vegetación y cobertura del suelo (INEGI, 2013) y el mapa de formas del relieve (INE-SEMARNAT-UNAM, 2000). Los datos cuantitativos de las localidades fueron sumados y asignados al polígono dentro del cual se ubican. El cálculo de las distancias de los sitios de depredación a carreteras y áreas naturales protegidas se realizó en formato vectorial con la función *near*, dentro de las herramientas de análisis espacial de proximidad.

La asignación de los atributos de las variables ambientales, socioeconómicas y ganaderas a los sitios de depredación de ganado, con excepción de las variables donde fueron empleadas las funciones de proximidad, se realizó por medio de la función *identity* la cual forma parte de las herramientas de análisis de sobreposición (para la información en formato vectorial). Para los datos en formato raster, se empleó la función *Extract values to points*, la cual forma parte de las herramientas de análisis espacial.

Análisis estadístico

Para disminuir el número de variables y determinar cuáles están más asociadas con los casos de depredación, se llevó a cabo un análisis factorial (Gotelli y Ellison, 2004), evaluando por separado cada una de las tres especies de carnívoros. Se aplicó la prueba Kaiser-Meyer-Olkin (KMO), en todos los casos el valor KMO fue superior a 0.6. Fueron extraídos los factores con autovalores (*eigenvalues*) iguales o mayores a 1.

Con base en las variables que presentaron los coeficientes más altos en cada factor se realizó un análisis de conglomerados con algoritmos jerárquicos acumulativos, para agrupar los casos de depredación, a partir de la técnica Ward y el cuadrado de la distancia euclidiana. Para ilustrar el patrón espacial de agrupamiento de los registros de depredación fue usado el software ArcGIS 10.0 (ESRI Inc.).

Clasificación de imágenes de satélite y detección de cobertura del suelo

Para la clasificación del uso de suelo se emplearon imágenes de satélite Landsat 5 TM con resolución de 30 m (año 1986) e imágenes de satélite Sentinel 2 con resolución de 10 metros (año 2017). Estos conjuntos de datos se importaron en el software para el procesamiento de información satelital ENVI versión 5.4 (Harris Geospatial). Se extrajo el subconjunto de datos del área de estudio de ambas imágenes con el límite de la RNSN (región de interés, ROI). Previamente se generó un área buffer de 100 metros a partir de este límite, con el propósito de asegurar que no existieran vacíos de información en los bordes del área de estudio inherentes al manejo de datos raster.

Para realizar la clasificación de cobertura del suelo, se aplicó el método de clasificación supervisada, empleando como sitios de entrenamiento (*training samples*) datos colectados en campo de julio de 2015 a agosto de 2016, por medio de GPS (54 sitios) y sitios obtenidos a partir de imágenes Google Earth (https://earth.google.com, 22 sitios). Como información de referencia se utilizó el mapa de vegetación y uso del suelo del INEGI serie VI (INEGI, 2017) y el mapa de cobertura del suelo de Norte América del 2010 con resolución de 30 metros (http://www.cec.org).

Se aplicó el algoritmo de máxima verosimilitud (MLC), que es uno de los métodos más precisos para la clasificación supervisada de imágenes de satélite (Ahmad y Quegan, 2012).

Este método se basa en el teorema de Bayes, utilizado para calcular la probabilidad de aspectos causales a partir de efectos observados. El método de máxima verosimilitud hace uso de una función de discriminantes para asignar cada pixel a la clase de probabilidad más alta (Ahmad y Quegan, 2012). No obstante, las clases derivadas pueden no ser estadísticamente separables, el método asume una distribución normal de los valores de las bandas de entrada y muestra una tendencia a sobre clasificar valores de las firmas espectrales relativamente grandes en la matriz de covarianza (Rawat y Kumar, 2015).

Después de la revisión de la información sobre cobertura y uso del suelo disponible para la RNSN y de los recorridos de campo, la clasificación se orientó a la identificación de 10 clases de cobertura del suelo: bosque templado, selva baja caducifolia, vegetación de galería, vegetación secundaria de bosques templados, vegetación secundaria de selva baja caducifolia, pastizal, agricultura, zonas sin vegetación aparente, cuerpos de agua y asentamientos humanos. En las categorías de vegetación secundaria se incluye tanto a la vegetación que se encuentra en alguna fase de desarrollo sucesional, como a la vegetación perturbada. La evaluación de la clasificación se realizó a través de la matriz de confusión y el coeficiente Kappa (Zhu *et al*., 2010; Butt *et al*., 2015; Rwanga y Ndambuki, 2017), el cual es usado para medir la concordancia (*agreement*) entre los valores de las clasificaciones asignadas y los valores de las clasificaciones predichas por el algoritmo.

Análisis del cambio de cobertura del suelo

El post-procesamiento de las clasificaciones de las imágenes de satélite de los dos periodos se realizó en los programas Arcgis 10.1 (ESRI, Inc.) e Idrisi Selva (Módulo Land Change Modeler). La unidad mínima cartografiable para los mapas de cobertura del suelo de los dos periodos analizados fue de 0.25 ha, el cual es un valor ligeramente inferior al sugerido por algunos autores (Chuvieco, 1995; USGS, 2011) y basados en los principios de flexibilidad y de privilegiar el empleo de valores bajos de unidad mínima cartografiable (Knight, J. F. and Lunetta R. S. 2003). Fue aplicado el mismo valor de unidad mínima cartografiable a ambos mapas durante el proceso de generalización cartográfica para hacerlos compatibles con relación a la escala previo al análisis de cambio de cobertura. La comparación de las imágenes clasificadas se llevó a cabo en formato vectorial a través de técnicas de sobreposición de capas (Butt et al., 2015). A partir de la sobreposición se genera una capa de información con los datos geométricos y de atributos de los dos mapas de entrada. En esta capa se registró para cada polígono la clase de cobertura del suelo identificado para los dos periodos analizados, 1986 y 2017. A través de la comparación de los atributos de cada polígono y de la elaboración de resúmenes estadísticos se cuantificaron los tipos y la magnitud de los cambios registrados, así como las áreas donde no se registraron modificaciones en el cobertura del suelo. Se realizó la comparación del grado de fragmentación de la vegetación de bosque y selva baja caducifolia, a través del índice de continuidad de Vogelmann (Galván-Guevara *et al*., 2015).

VI. Resultados

Regionalization of environmental and anthropic variables associated to livestock predation by large carnivores in Mexico

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Keywords:

Human-wildlife conflict regionalization, livestock predation, large carnivores, Mexico, livestock management practices, anthropic variables

Short title for page headings

Livestock predation by large carnivores in Mexico

Abstract

Conflicts with humans are one of the main causes of the decline in populations of large carnivores, making it a crucial conservation issue worldwide. In Mexico, jaguar (*Panthera onca*), puma (*Puma concolor*), and American black bear (*Ursus americanus*) are involved in livestock predation and are persecuted in retaliation. The sites where predation occurs are distributed throughout the country and differ not only in environmental characteristics, but also in social, economic, and livestock management practices. However, due to the general focus of the studies carried out so far, the proposed mitigation measures are also general. It is necessary to consider conditions that encourage predation in the design of strategies to be more effective. In this study, environmental, anthropic, and livestock management characteristics of livestock predation by large carnivores were analyzed for conflict regionalization. The variables most related to predation sites were identified, with a high percentage of them being livestock management practices. Based on these variables, we formed clusters of similar sites and analyzed their spatial distribution, which presented grouping patterns in the cases of predation by puma and black bear, in contrast to the jaguar clusters, which presented a dispersed distribution. Considering the characteristics of the clusters, the following mitigation measures are proposed: confinement of livestock, construction or improvement of corrals, and improvement of management practices. The anthropic component and livestock management practices are closely related to the predation events and therefore its inclusion in the conservation programs of carnivores in Mexico is fundamental.

Introduction

Persecution and killing, whether in retaliation or motivated by negative perception, has been one of the major causes of the decline of large carnivore populations in the world (e.g. Woodroffe, Thirgood & Rabinowitz, 2005; Northrup *et al*., 2012; Aryal *et al*., 2014; Miller *et al*., 2015). A frequent conflict between humans and large carnivores is the result of predation on livestock, a problem that directly affects the economy of rural communities and encourages retaliatory killings of predators (Treves & Karanth, 2003; Zarco-González, Monroy-Vilchis & Alaniz, 2013; Carvalho *et al*., 2015). The causes of this situation are related to the expansion of settlements and human activities, loss of wildlife habitat and, in some cases, the reduction of populations of wild prey (Michalski *et al*., 2006; Palmeira *et al*., 2008; Karanth & Chellam, 2009; Márquez *et al*., 2012).

The areas where predation by large carnivores occurs presents a pattern of landscape variables that are easier for predators to find and hunt their prey, either wild or domestic (Kolowski & Holekamp 2006; Kissling, Fernandez & Paruelo, 2009; Zarco-González *et al*., 2013; Miller *et al*., 2015). Livestock predation sites are characterized by a combination of environmental and anthropic variables, as well as livestock management practices (Kolowski & Holekamp, 2006), which make them significantly different from other sites.

Some studies have analyzed the relationship between livestock predation and landscape variables (Michalski *et al*., 2006; Kissling *et al*., 2009). Among the environmental variables related to the frequency of attacks are vegetation cover, land use, topography, density of wild prey, and the location of water sources (Baruch-Mordo *et al*., 2008; Zarco-González *et al*., 2013). Anthropic variables and local actions to mitigate this problem are frequently analyzed in the studies at a fine-scale. These usually consider the perception, tolerance of the human population (Hemson *et al*., 2009; Carter *et al*., 2013; Suryawanshi *et al*., 2013; Yirga *et al*., 2014), and quantification of economic losses (Mazzolli, Graipel & Dunstone, 2002; Cascelli & Murray, 2007; Karamanlidis *et al*., 2011; Harihar, Ghosh-Harihar & MacMillan, 2014). At the regional or national level (broad-scale), the aspects analyzed in relation to this topic have included the distance of predation sites to human settlements, roads, natural protected areas, livestock density, and some management practices (Zarco-González *et al*., 2013).

There are few studies that analyze the integration of environmental and anthropic variables on livestock predation (Bagchi & Mishra, 2003; Graham, Beckerman & Thirgood, 2005; Kolowski & Holekamp 2006; Carvalho *et al*., 2015). The lack of an integral approach in the evaluation of human-carnivore conflict makes it difficult to understand the problem, as well as to design and implement effective conservation strategies (Bagchi & Mishra, 2003; Treves *et al*., 2011). Interactions between humans and large predators will be more frequent in the coming years due to the loss of natural habitat. Therefore it is essential to design strategies of coexistence, such as, the modification of livestock management practices, which is a key element in the mitigation of the predation on livestock by wildlife.

The objective of this study was to identify the environmental and anthropic conditions in which livestock predation occurs by jaguar, puma, and American black bear in Mexico, as well as to identify clusters of similar cases and to propose priority actions for the mitigation of predation in each cluster. The landscape features associated with livestock predation are related to the species (carnivore and prey), environment, human infrastructure, and management interventions (Miller, 2015). These are distributed in nonrandom patterns (Treves *et al.*, 2011; Miller *et al.,* 2015), rather show distinct spatial clustering (Baruch-Mordo *et al.*, 2008). The identification and analysis of those patterns enable target efforts to mitigate damage by focusing on areas with high clustering of events, increasing the probability of been effective. The focus of the study is to take advantage of information generated by governmental institutions in order to obtain, in conjunction with spatial and statistical analyses, an integral overview (including environmental, social and economic aspects) of livestock predation by wild carnivores in Mexico.

Methods

a) Study area

Mexico is a mountainous tropical country where a variety of climates of groups A (tropical rainy), B (dry), C (temperate) and E (cold) are present (García, 2004). The variety of floristic associations ranges from tropical, temperate forests, and desert vegetation to alpine vegetation (Rzedowski, 2006). The population density in Mexico was reported at 65.61 people per km^2 in 2015, however, the distribution of the population has large regional differences, in the endpoints, Baja California Sur population density is 10/km^2 and Mexico City is 5,967/km^2. Mexico ranks eighth in world livestock production with about 33 million head and a density of 16.77/km^2 (FAO, 2014; INEGI, 2015, 2016; Fig. 1).

b) Obtaining data

Predation records

Livestock predation records by jaguar, puma, and American black bear were obtained from five sources: a) databases and reports from official institutions of the Mexican government (Environment, Natural Resources & Fisheries Ministry- SEMARNAT, Federal Attorney for Environmental Protection -PROFEPA-, Ministry of Environment and Natural Resources of the state of Guerrero -SEMAREN-); b) livestock organizations (National Confederation of Livestock Organizations -CNOG-); c) review of scientific literature (Chavez & Zarza, 2009; Zarco-González *et al*., 2012; Zarco-González *et al*., 2013); d) non-governmental organizations; and e) fieldwork of authors, in different states of the country (Estado de Mexico, Chihuahua, Yucatán, Campeche, Baja California and Guerrero). The fieldwork consisted of visiting the sites where livestock attacks were reported, verifying the cause of death according to the published predation protocols (Hoogesteijn, 2001; Shaw *et al.,* 2007), and, in cases when predation was confirmed, recording the geographic coordinates and the species of the predator.

In order for a record to be included in the analysis it needed to have geographic coordinates, obtained with GPS devices by the staff of the institutions, the CNOG adjusters, during the fieldwork or reported in scientific papers. Records with inconsistencies in the registered location coordinates and those with uncertainty in the data source were omitted. To reduce the spatial autocorrelation of data, only one record per square kilometer (randomly chosen) was considered for analysis (Zarco-González *et al*., 2013).

Environmental and anthropic variables

Using findings from previous studies, variables related with livestock predation by carnivores were identified (Kolowski & Holekamp, 2006; Honda *et al*., 2009; Iftikhar, *et. al*, 2009; Inskip & Zimmermann, 2009; Chávez & Zarza, 2009; Kissling *et al*., 2009; Zarco-González *et al*., 2013). We obtained national maps of forest cover, altitude, slope, vegetation types, and land use, generated by scientific and governmental institutions (Table 1). Some variables were generated through GIS processes, such as the map of population density prepared from databases with information on the coordinates of human settlements and number of inhabitants (INEGI, 2010). Distance maps to urban areas and roads were made with spatial analysis functions (Euclidean distance). Cattle density, percentage of animals with supplementary feeding, vaccination and extensive grazing, were included as indicators of livestock management. Animals in extensive grazing are those that are not stabled at any time. These variables of livestock management were generated using the information of the agricultural, livestock, and forestry census. This census is made by the National Institute of Geography and Statistics (INEGI, by its initials in Spanish), constitutes a primary source of data that allows to characterize the structure and functioning of the agricultural and forestry sector, since it captures basic information on the identification, location and characteristics of all productive units, through a questionnaire applied to agricultural and forestry producers in urban and rural localities throughout the country, the results are published at the municipal level.

The variables were classified into three groups: environmental, anthropic (i.e. human population density, related with infrastructure and anthropic land use) and, related to livestock management (Table 1).

Table 1. Variables included in the characterization of sites where with reported predation on livestock by large carnivores in Mexico.

Category	**Variable**	**Source and year of publication**
Environmental	Elevation	Digital elevation model (INEGI, 2016)
	Slope	
	Tree cover percentage	MODIS 44B (NASA, 2010)
Anthropic	Distance to induced grasslands	Vegetation and land use V (INEGI, 2013)
	Distance to urban areas	
	Distance to agricultural areas	
	Human population density	National census of population and housing 2010 (INEGI, 2010)
	Distance to roads	National Road Network 2015 (INEGI, 2015)
Livestock management	Livestock density	Agricultural, Livestock and Forestry Census 2007 (INEGI, 2009)
	Livestock percentage with supplementary feeding	
	Livestock percentage with vaccination	

Cattle percentage in extensive grazing	

b) Spatial analysis

The tabular data, such as the agricultural and human population censuses, were associated to the geometric information of municipalities through the union of tables (*function join field*). The slope variable was generated with the *slope* function from the digital elevation model. The calculation of distances from predation sites to roads, natural protected areas, and types of vegetation was done in vector format, using the *near function*, which belongs to the group of functions of proximity analysis. The cartographic scale of the variables was 1:250000, were resampled and rasterized at a spatial resolution of 150 meters, in the conical projection of Lambert (INEGI, 2013), using the software ArcGIS version 10.0 (ESRI Inc, 1999-2010).

Predation records were represented by a pair of coordinates, however, to consider the influence of the conditions of the surrounding area, a buffer was generated around each one. Buffer size equaled the average of the home range of the three carnivore species (Rabinowitz & Nottingham, 1986; Dickson & Beier, 2002; Onorato *et al*., 2003). Within each buffer, the average of the values of altitude, slope, and tree cover percentage was calculated, as well as the density of human population by adding the inhabitants of the localities in each one.

The final step of the processing of spatial information was to assign a value for each of the variables to each predation record.

c) Statistical analysis

To identify the variables with the greatest contribution to the variance of the data, a factorial analysis was carried out for each species of carnivore (Gotelli & Ellison, 2004; Yong

& Pearce, 2013). We first verified the data matrix was suitable for this analysis with the Kaiser-Meyer-Olkin sampling adequacy measure (KMO, Kaiser, 1974) and Bartlett's test of sphericity (Bartlett, 1954). The factorial analysis was selected due to its potential to extract the highest percentage of variance explained, increasing the correlation between the variables within the same factor and decreasing it between different factors (Gotelli & Ellison, 2004; Yong & Pearce, 2013). Factorial analysis was run with principal component extraction, recommended for non-normally distributed data. We retained only the factors whose eigenvalues were greater than 1.0, according to the Kaiser criterion. In order to obtain non-correlated factors, orthogonal rotation was chosen with the Varimax method (Gotelli & Ellison, 2004).

The variables with the highest scores in each factor were used to make a cluster analysis with cumulative hierarchical algorithms. The Ward method and the square of the Euclidean distance were used to obtain the clusters. The selection of one variable for each factor avoided collinearity between variables. Half of the Euclidean distance was the criterion to define the number of clusters for each species of carnivore. Subsequently, a map was generated to project the spatial distribution of clusters. The description and analysis of the clusters were performed using the mean value and the standard deviation for each variable. In order to evaluate the grouping level of the clusters, the Moran analysis was performed in the ArcGIS 10.0 software (ESRI Inc. 1999-2010).

Results

Governmental institutions and scientific literature were the main sources of records (Table 2). 359 records of predation were obtained and after filtering so thatonly one per square kilometer, 313 were retained here were 197 records for jaguar, 60 for puma, and 56 for American black bear (Fig. 1). The records correspond to the period 1990-2014.

Table 2. Source and number of livestock predation records for each predator species (jaguar, puma, and American black bear).

	Jaguar	Puma	American black bear
Official institutions of the Mexican government	79	1	49
Livestock organizations	41	22	
Scientific literature	74	21	7
Non-governmental organizations	2		
Fieldwork	1	16	

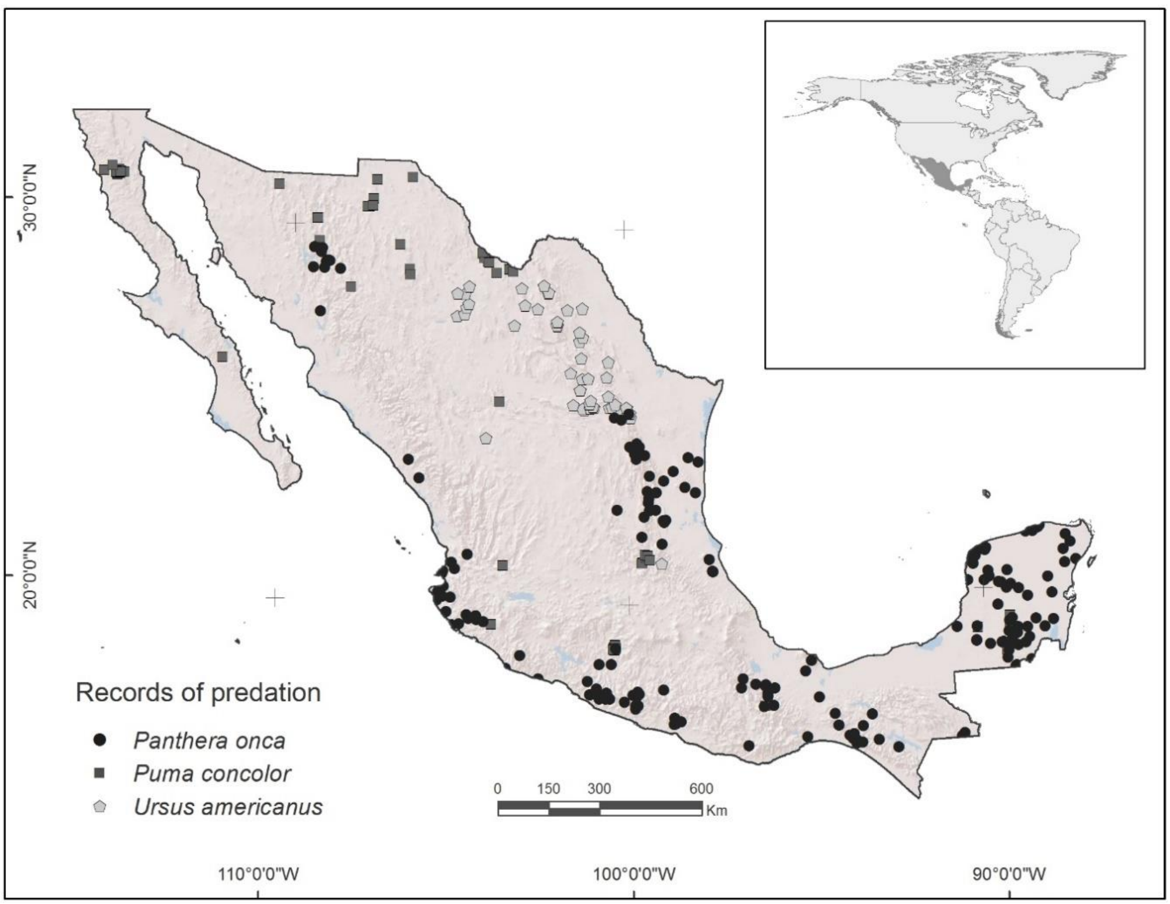

Figure 1. Locations for the records of livestock predation by jaguar, puma, and American black bear in Mexico.

Variables related to sites of predation

The data matrix was suitable for factorial analysis with values > 0.6 in Kaiser-Meyer-Olkin sampling adequacy measure (KMO, Kaiser, 1974) and statistically significant according to Bartlett's test of sphericity (Bartlett, 1954). It was determined that the 12 original variables could be reduced to six factors for jaguar and puma and five for black bear, explaining in the three cases more than 70% of the variance (Table 3).

Table 3. Tests of sample adequacy for factorial analysis and results for each predator species (jaguar, puma and American black bear).

Species	Kaiser-Meyer-Olkin (KMO)	Number of factors	Cumulative variance percentage
Jaguar	0.66	6	71.98
Puma	0.69	6	72.11
American black bear	0.74	5	71.90

Regarding jaguar predation events, four determining variables were related to livestock management, one to anthropic, and one to environmental topics. Likewise, puma predation events were explained by four livestock management variables and two environmental variables. Black bear attacks were associated with four livestock management variables and one environmental variable. Overall, the cases of predation were mainly related to livestock management (70.59%), environmental (23.53%) and anthropic variables (5.88%, Table 4).

Table 4. Variables associated with livestock predation sites in order of contribution to variance, for each species of carnivore (jaguar, puma and American black bear).

Species	Variables
Jaguar	Sheep percentage with supplementary feeding
	Goat density
	Elevation
	Percentage of vaccinated goats
	Population density
	Percentage of cattle in extensive grazing
Puma	Percentage of vaccinated sheep
	Cattle density
	Elevation
	Tree cover percentage
	Percentage of vaccinated goats
	Cattle percentage with supplementary feeding
American black bear	Cattle percentage with supplementary feeding
	Percentage of vaccinated sheep
	Cattle density
	Slope
	Percentage of cattle in extensive grazing

Clusters of predation records

Five clusters for jaguar and three for puma and black bear were identified (Table 5). The spatial location of the clusters shows the distribution of common explanatory variables in different regions of the country.

Table 5. Number of records in each cluster for predator species (jaguar, puma and American black bear).

Cluster	Jaguar	Puma	American black bear
1	33	25	3
2	76	17	27
3	30	18	26
4	22		
5	36		
Total	197	60	56

Spatial autocorrelation analyzes showed spatial-clustered patterns for all three species. Also, the z-score and p-value indicated that spatial patterns are not attributed to random processes. The confidence level of this index was 90% for jaguar and more than 99% for puma and black bear (Table 6).

Table 6. Moran’s index of records of predation by each carnivore species.

	Jaguar	Puma	American black bear
Moran's Index	0.736	1.302	0.948
z-score	1.794	3.093	3.318
p-value	0.073	0.002	0.001

Jaguar

Cluster 1. The records of this group are located in or around mountainous areas, in the states of Oaxaca, Guerrero, San Luis Potosí, Nuevo León, and Tamaulipas. The abrupt relief favors the breeding of goats. This group presents the lowest percentage of cattle under extensive grazing.

Cluster 2. The sites in this cluster are characterized by low human population density (8.61 inhabitants/km^2). The distribution of this group was the most heterogeneous, as it covers cases in mountainous areas of three biogeographic provinces (Sierra Madre Occidental, Sierra Madre del Sur and Los Altos de Chiapas), as well as in broad plains of Yucatán and Golfo de México. Cattle grazing is predominantly extensive in these areas (87.06%).

Cluster 3. The sites are mainly in the states of Nayarit, Oaxaca, and Península de Yucatán. The supplementary feeding of sheep occurs in 29.7% of the cases, the cattle percentage under free grazing is low, and the vaccination of goats occurs in few cases.

Cluster 4. This cluster corresponds to the most anthropised areas, with population density of 55.05 inhabitants/km^2 (86.62%), i.e. above the national average, and comprises areas with predominantly flat relief, distributed almost throughout the national territory, except in the northwest region. It also presents a high percentage of cattle under extensive grazing.

Cluster 5. This cluster is distributed in the central and southern plains of the Península de Yucatán, where native vegetation is more continuous. It has the lowest density of goats

(0.05 head per km^2) and the lowest human population density (6.24 inhabitants/km^2, Fig. 2).

Puma

Cluster 1. More livestock management actions were applied in this group (vaccination of goats and sheep, as well as supplementary feeding of cattle). It is distributed in the western, north, and northwest of the country, in areas with scant vegetation cover and low cattle densities.

Cluster 2. This cluster is located in areas with high tree cover percentage (Campeche, northern Oaxaca, northern Querétaro and mountains of the state of Chihuahua), practically no cattle management actions are applied.

Cluster 3. It is distributed predominantly in northern Mexico, in the states of Sonora and Chihuahua, in areas with high cattle density and low levels of sheep and goat sanitary management (Fig. 3).

Black bear

Cluster 1. Livestock predation was recorded in mountainous sites in the states of Nuevo León and Hidalgo. Cattle were under extensive grazing and their average densities were higher than other clusters (14.69 heads/km^2). High cattle vaccination percentages (79.6% on average) were presented.

Cluster 2. Represents the largest distribution cluster, covering large areas of the states of Chihuahua, Coahuila, and Durango. The predation events occurred at low-slope sites (5.4 degrees on average), with a high cattle percentage under extensive grazing (86.98%).

Cluster 3. Predation events in the Sierra Madre Oriental, in the states of Coahuila and Nuevo León. The cattle percentage under extensive grazing was relatively low (63.28%) and the density of this domestic species was the lowest of the three clusters (Fig. 4).

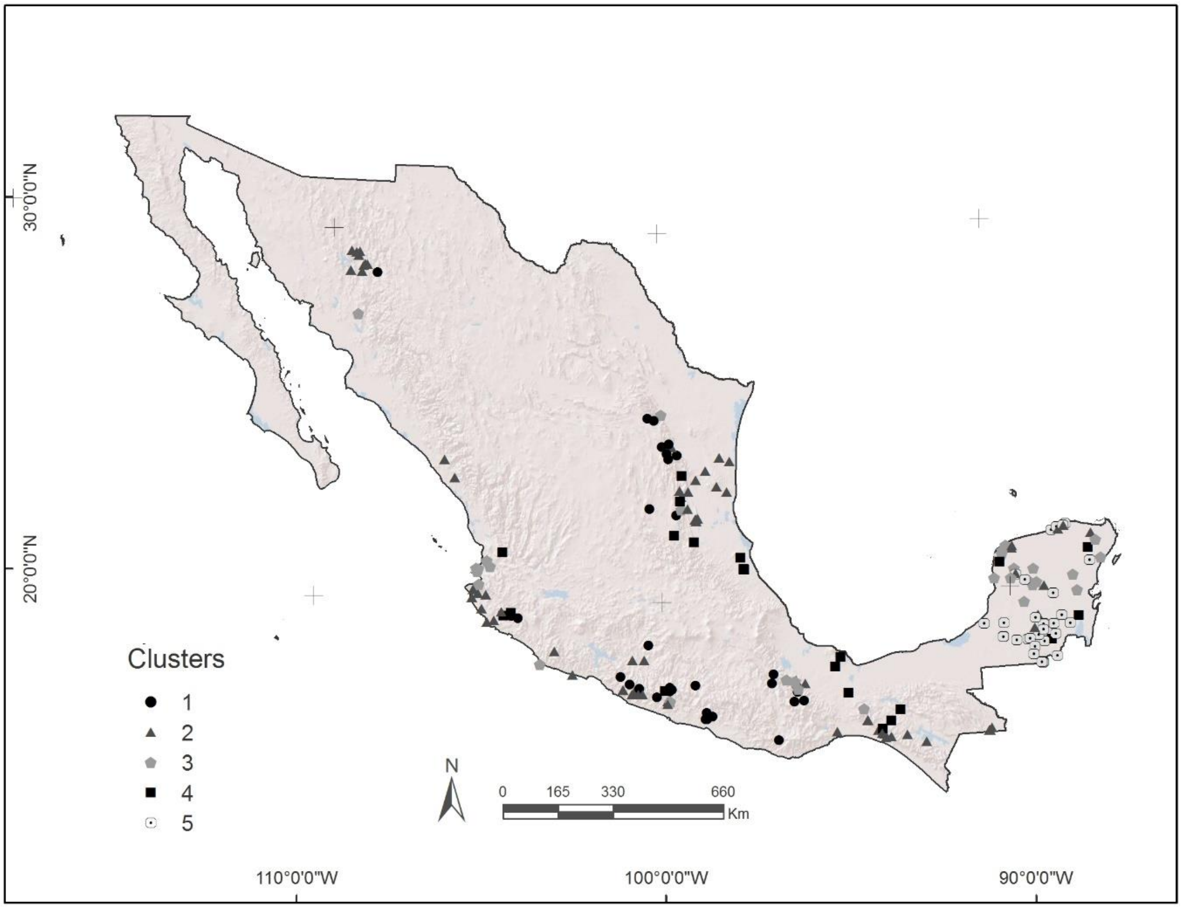

Figure 2. Spatial distribution of clusters of predation records by jaguar.

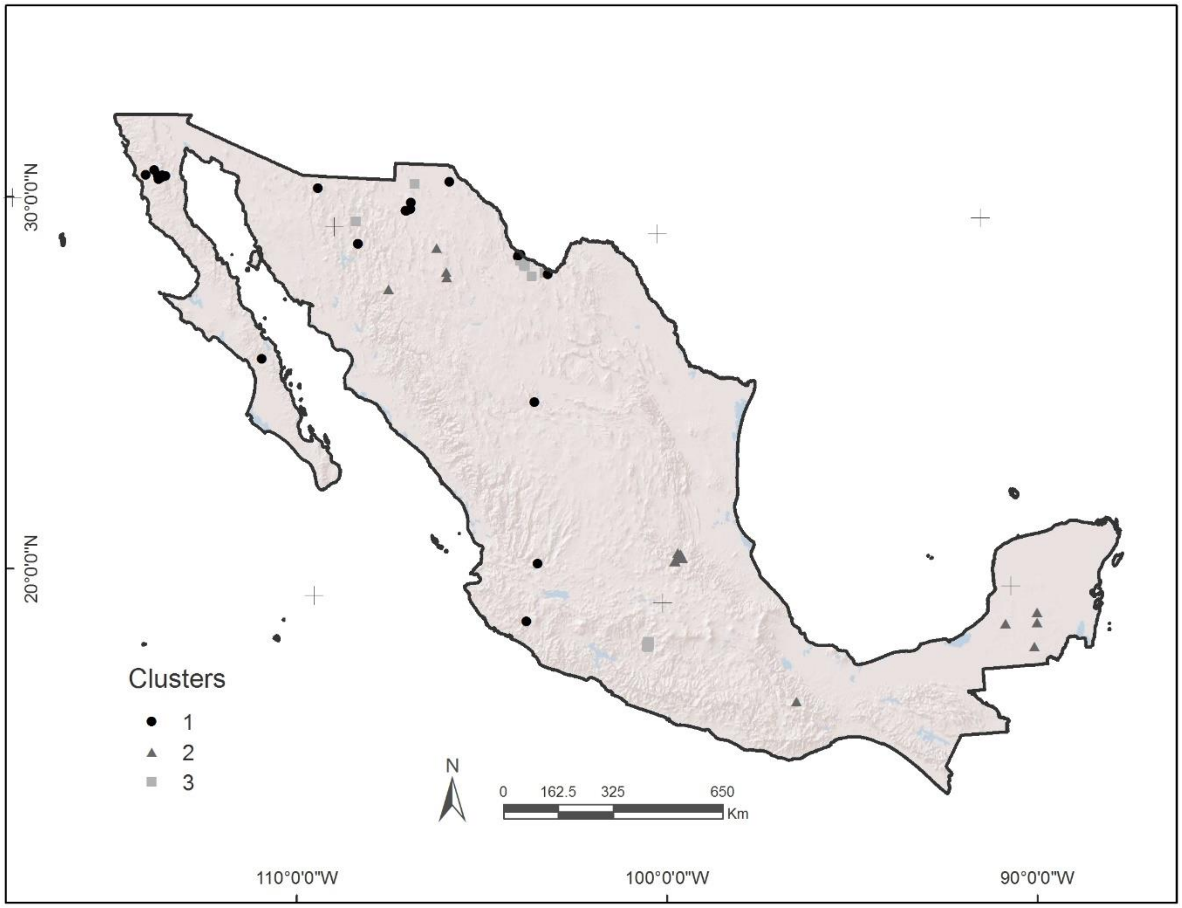

Figure 3. Spatial distribution of clusters of predation records by puma.

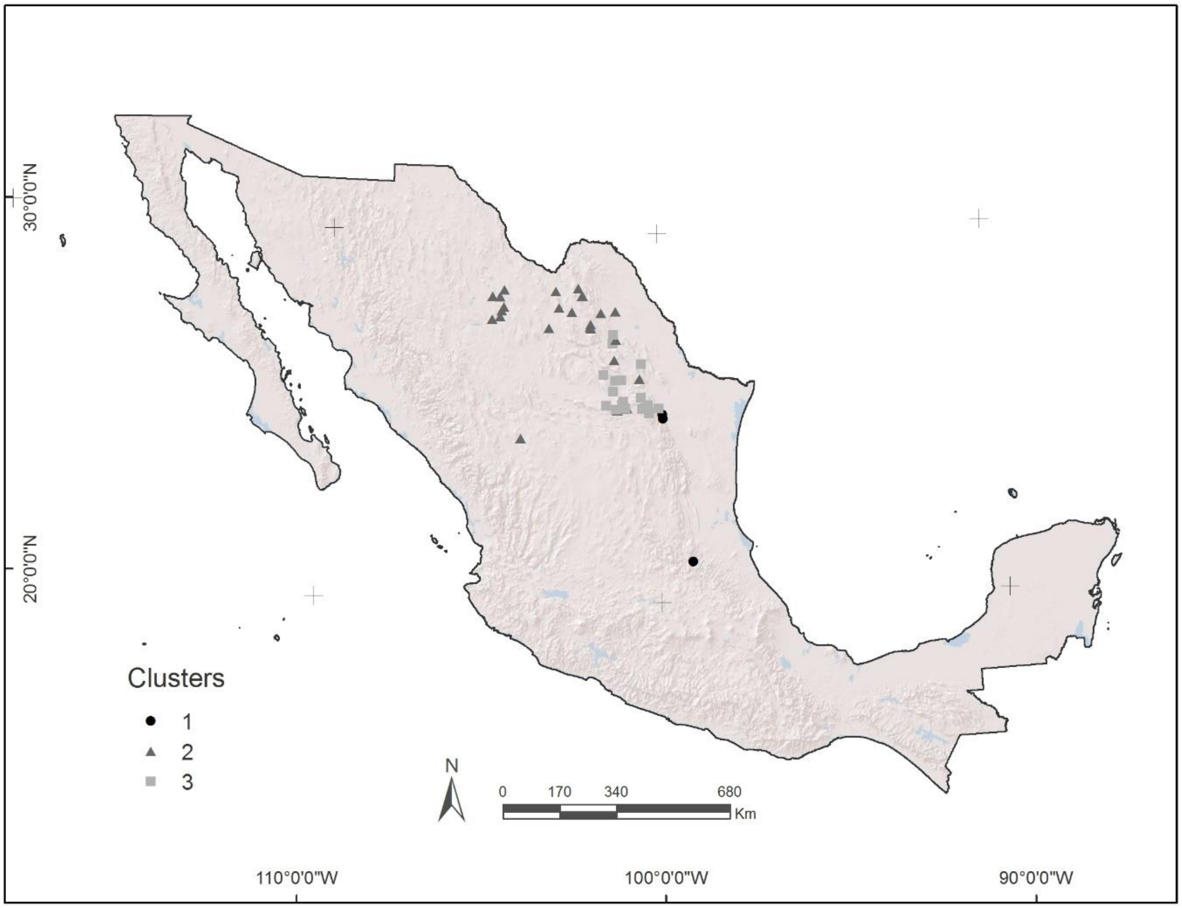

Figure 4. Spatial distribution of clusters of predation records by American black bear.

Discussion

In this study, the most complete, recent, and highest quality data about predation and landscape variables were used. Information with higher spatial resolution was used (150 meters) compared with other broad-scale studies related to human-predator conflict (Zarco-González *et al*., 2013; Miller *et al*., 2015). Recording predation events at a national level has been carried out mainly by the National Confederation of Livestock Organizations -CNOG- since 2010. In the period between 2010 and 2016, the CNOG registered 641 predation complaints (including other species of predators and feral dogs), however, the absence of precise coordinates of most of these records prevented its use in spatial analysis. It is advisable to systematize the monitoring of cases for future research, especially at local levels so that data can scale-up for regional and national use

Livestock predation records are explained mainly by variables related to livestock density and management indicators (70.59%), and secondly by anthropic and environmental factors (29.41%). These results show the importance of livestock management in the problem of predation and the need to incorporate complementary data to the environmental variables usually analyzed in previous studies (Graham *et al*., 2005; Kolowski & Holekamp, 2006; Cascelli & Murray, 2007; Marchini & Macdonald, 2012; Dickman *et al*., 2014; Harihar *et al*., 2014). This study also shows that the integrated analysis of environmental, anthropic, and livestock management variables when analyzing human-wildlife conflicts facilitates the design of management programs (Bagchi & Mishra, 2006).

In previous studies, it is frequent to find proposals for risk mitigation including daytime vigilance, nocturnal confinement (Ogada *et al*., 2003; Yirga *et al*., 2014), limiting free grazing (Zarco-González & Monroy-Vilchis, 2014), use of protective physical structures or improvement of existing corrals, use of guard dogs (Ogada *et al*., 2003; Yirga *et al*., 2014), shelter of females in breeding season (Landa *et al*., 1999), grazing of calves with bulls (Conforti & Cascelli, 2003), and others (Kissling *et al*., 2009; Harihar *et. al.* 2014; Schulz, Printes & Oliveira, 2014; Alexander *et al*., 2015). However, the analysis of livestock management practices, as well as the conditions in which predation cases occur, allowed us to prioritize for each cluster which of the measures proposed in previous studies can be more effective. The mitigation of the predation impact by applying the proposed measures can directly decrease the number of animals predated or help optimize livestock production by minimizing losses due to other causes such as diseases or malnutrition.

The variables considered in this paper differ from those used in other studies carried out in Mexico (Chávez and Zarza, 2009; Rosas-Rosas *et al*., 2010; Zarco-González *et al*., 2013), due to the national extension and approach. Even so, we found that jaguar predation sites are associated with high percentages of cattle under extensive grazing (88.84% on average) and tree cover (46.82% on average). While low cattle densities (7.74 heads/km^2 on average) and the altitudinal gradient (1,398 masl on average) are related to predation sites by puma, which coincides with that reported by Zarco-González *et al.,* (2013).

Spatially, clusters of predation records by black bear and puma showed more defined grouping patterns. There were two homogeneous clusters for puma, one from the central region to the north of the country and a second from the center to the southeast region. While the two most defined clusters in the analysis for black bear were located north of the Sierra Madre Oriental and in the Altiplano chihuahuense. Clusters were less defined for the jaguar, except for one with a marked spatial concentration in the southern part of the Península de Yucatán. The irregular spatial arrangement of some clusters with similar characteristics, especially for jaguar, suggests that livestock predation is influenced by environmental factors. However, the primary determining factor in the occurrence of predation events are related to the livestock management practices, which had higher spatial variability is higher compared to environmental variables.

As demonstrated by our study's findings, three strategies are proposed for predation mitigation. These can be complementary and their joint application can contribute to reduce livestock vulnerability and loss to predation. However, unlike other studies, we propose an order of priority for the application of strategies in each cluster, which considers its socio-environmental characteristics.. Due to the fact that some actions can have relatively high costs compared to the income of some rural stakeholders, implementation might need financing schemes through the support of government programs. Mitigation strategies should be discussed with the stakeholders in order to get feed-back and validation to complement the biological perspective. The first proposed strategy is the stabling of livestock, that is, the permanent confinement of animals in corrals where they have feeders and drinkers (Aryal *et al*., 2014). The second is to establish or improve the infrastructure needed to increase livestock security with fences (which differs from stabling because this measure does not necessarily imply permanent confinement) (Butler, 2000; Ogada *et al*., 2003). The third measure, encompasses a set of management practices related to the choice of grazing areas, including constant vigilance of livestock, use of guard dogs and deterrents, differentiated management of the most vulnerable animals, selection of less vulnerable livestock species, and investment in sanitary management (Butler, 2000; Kissling *et al*., 2009; Schulz *et al*., 2014; Yirga *et al*., 2014) (Table 7).

Although both livestock husbandry and infrastructure construction (fencing) are also strictly livestock management techniques, they were individually considered by their specific weight as elements to reduce predation risk. The actions encompassed by the third strategy are predominantly linked to the manipulation of animals, especially when extensive grazing practices are being implemented.

Table 7: Proposed management to mitigate the impact of predation on livestock by large carnivores in Mexico (jaguar, puma, and American black bear), considering anthropic variables and livestock management practices.

Cluster	Jaguar	Puma	American black bear
1	Increase management actions for goats and sheep	Confinement Improve infrastructure	Increase management actions for cattle and sheep Confinement
2	Confinement Increase management actions for cattle	Increase management actions for cattle and goats Confinement	Confinement Increase management actions for sheep
3	Increase management actions for goats Improve infrastructure	Improve infrastructure Increase management actions for cattle, sheep and goats	Improve infrastructure Increase management actions for sheep
4	Confinement		
5	Confinement Increase management actions for cattle		

Cattle confinement is proposed for areas with high percentages of extensive grazing (83.6-87.06%), these areas are mainly located in arid and semi-arid zones of the country, where the scarce vegetation cover also leads to a low cattle load per unit area (Pérez & Cañez, 2003). This strategy should be accompanied by projects for the production and storage of supplementary food. The alternative of livestock confinement and to offer supplementing food is considered to be a more ecologically costly production system compared to extensive grazing, so it could be implemented preferentially in areas with higher risk of predation (Lasanta, 2010) or implemented with time constraints such as only confining animals during nocturnal periods.

The occurrence of predation in anthropised areas (population density between 52.40-91.55 inhabitants/km^2), with relatively low proportion of cattle under extensive grazing (63.28-72.62%) and with high cattle density (3.51-14.84 heads/km^2), suggest that new infrastructure needs to be created or strengthened. These measures apply especially to the central states of the country (Querétaro, Estado de México), as well as some areas of the states of Nuevo León, Tamaulipas and Coahuila.

In general, livestock farming in the country is carried out with low levels of sanitary management and supplementary feeding, as well as the prevalence of extensive grazing (Leos-Rodríguez, 2008; Bravo, 2010). The areas where the implementation of management practices is suggested, have a heterogeneous distribution in almost all the national territory. The spatial differentiation of environmental and anthropic characteristics of predation sites can be added to a national policy for the mitigation of this problem, considering the particularities of each region, so that the policies and strategies are oriented to their conditions and particularities, making it possible to manage the limited economic and human resources more efficiently.

Acknowledgments

We thank Consejo Nacional de Ciencia y Tecnología (CONACyT) for the scolarship granted to Francisco Reyna-Sáenz (268135), to Universidad Autónoma del Estado de México for financing this study, to the National Confederation of Livestock Assurance Fund for providing predation records. We thank Carl Mitchell and Deanna Seil for the language corrections. We also thank Fernanda Núñez and Alejandra López for their support to compile the database of black bear predation records.

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Detection of land use change in the Sierra Nanchititla Natural Reserve, Mexico, through remote sensing and geographic information systems techniques

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Abstract

Digital techniques for detecting changes in vegetation and land use through the use of multi-temporal satellite images help to understand the dynamics of the landscape. The study that was carried out illustrates the spatio-temporal dynamics of land use of the Sierra Nanchititla Natural Reserve, located in the State of Mexico, Mexico. Landsat satellite images and Sentinel 2 images were acquired from the USGS website https://earthexplorer.usgs.gov/, and from the Google Earth Engine website (https://code.earthengine.google.com/), in order to quantify and evaluate the changes that took place in the period from 1986 to 2017, that is, in a lapse of 31 years. The supervised classification methodology was used using the maximum likelihood estimation (MLE) in the ENVI 5.4 software. The satellite images of the study area were classified into 10 different classes called temperate forest, tropical deciduous forest, temperate secondary forest, tropical secondary deciduous forest, gallery vegetation, grassland, farming, area without apparent vegetation, water body and human settlement.

The results indicate that during the last three decades, the temperate forests and the tropical deciduous forest have been reduced by 3.91% (2,555.74 ha) and 3.87% (2,529.20 ha), respectively, while the grasslands, the agricultural areas and the areas of secondary vegetation of tropical deciduous forest have increased by 4.61% (3,007.72 ha), 2.22% (1,448.40 ha) and 1.10% (719.24 ha), respectively. The other land uses did not have significant variations in the period analyzed.

Keywords

Land use change

Remote sensing

Geographic information systems

Sierra Nanchititla

Mexico

1. Introduction

The change in land use is a dynamic process resulting from natural and socioeconomic factors. It generally involves degradation of the landscape and has direct repercussions on soil, water and atmosphere; therefore it is directly related to environmental problems of global importance (Koomen and Stillwell, 2007, Figueroa and Sánchez-Cordero, 2008, Liu *et al*., 2011). Changes in land use that involve deforestation are considered one of the main causes of habitat loss and fragmentation and, therefore, biodiversity (Zebisch *et al*., 2004, Poschlod *et al*., 2005, Reidsma *et al*., 2006; Polasky *et al*., 2010; Blackman *et al*., 2015). Although the impact of these factors can be different between taxonomic groups, in general the probability of occurrence of a species in a given site is closely related to the existing land use (Newbold *et al*., 2014). At the local level, changes in land use may lead to a decline or extinction of species as well as a decrease of natural habitats, affecting the functioning of ecosystems (Martínez *et al*., 2009). Throughout the world, human-modified habitats are causing a decline in species richness, changes in dominance and abundance of certain taxa, altering the ecological structure of communities (Zebisch *et al*., 2004; Newbold *et al*., 2014), as well as the connectivity and ecosystems heterogeneity (Zebisch *et al*., 2004).

The analysis of land use change is essential for planning the management and use of resources. Periodic and accurate land use inventories are fundamental to understand the dynamics of the socio-environmental processes that define the current landscape configuration to identify the factors that determine them, the effects on the dynamics of natural processes and to implement schemes of sustainable management resources (Rawat and Kumar, 2015). The identification of habitats altered by humans through land cover and land use maps may support the selection of priority areas for ecological restoration. Likewise, in combination with other spatial variables such as slope, geomorphology and soil properties, it can lead to the design of integral conservation and landscape restoration strategies. Land cover maps are the basic input for assessing habitat fragmentation and connectivity (Di Giulio *et al*., 2009, Wilson *et al*., 2016), the anthropization degree of the territory (Hill *et al*., 2002) or the water yield potential of the landscape (Redhead *et al*., 2016), among other possible applications.

In the literature, the distinction between the terms land cover and land use is common (Koomen and Stillwell, 2007, Rawat and Kumar, 2015, Rujoiu-Mare and Mihai, 2016). Land cover refers to the physical and biological characteristics that can be observed on the land surface (for example, agriculture, infrastructure). Land use has an economic connotation and refers to the land use purpose (for example subsistence agriculture, housing areas). In this document, the term land use will be used predominantly to refer both concepts: land cover and land use.

Changes in land use can be identified through current and historical remote sensing data (Jaiswal *et al*., 1999, Álvarez Béjar, 2003; Koomen and Stillwell, 2007, Diallo *et al*., 2009, A fify, 2011, Setiawan and Yoshino, 2011; Butt *et al*., 2015, Rawat and Kumar, 2015, Abuelaish and Camacho, 2016, Rujoiu-Mare and Mihai, 2016). In particular, satellite images imply important advantages by providing periodic and systematic information of the territory, as well as greater accuracy and lower cost (Rawat and Kumar, 2015; Rujoiu-Mare and Mihai, 2016), compared with other methods such as inventories carried out exclusively by means of field observations. Advances in remote sensing technology in recent decades have led to the current availability of satellite images with greater spatial, temporal and spectral resolution, which, coupled with advances in technologies for image processing, have enhanced monitoring capabilities and modeling of land use patterns (Rawat and Kumar, 2015).

The physical parameter measured by a satellite sensor is the electromagnetic energy reflected or emitted by the surface of the earth (Campbell and Wynne, 2011), which is different for different ground coverings. The determination of changes in land use requires the use of multi-temporal information from remote sensors and further analysis and quantification processes (Afify, 2011, Butt *et al*., 2015). The Geographic Information Systems (GIS) technology is usually used in conjunction with Remote Sensing for processing satellite information (Diallo *et al*., 2009, Gajbhiye and Sharma, 2012, Butt *et al*., 2015, Rujoiu-Mare and Mihai, 2016; Haque and Basak, 2017). GIS technology is applied mainly in the post-processing and data analysis derived from remote sensing information.

Mexico, like other Latin American countries, has presented in the last decades high rates of deforestation and land use change (Velázquez *et al*., 2002; Mas *et al*., 2009), mainly due to the expansion of agriculture and grazing (Boucher *et al*., 2011). This is a problem with multiple regional connotations and therefore there is a heterogeneous distribution of the characteristics and rates of changes in coverage in the country (Mas *et al*., 2009). In the Sierra Nanchititla Natural Reserve (SNNR), one of the most important protected natural areas in the center of the country, several problems have been documented that have caused the loss and degradation of the original vegetation cover, among them, the opening of lands for agricultural activities and livestock, legal and illegal logging, fires and extensive grazing in forest areas (Zepeda and Velázquez, 1999, Casas-Andreu and Aguilar-Miguel, 2005, Enríquez *et al*., 2010, Monroy-Vilchis *et al*., 2011). The historical and current processes of ecosystems degradation in this protected natural area represent a risk for the conservation of biodiversity (Zepeda and Velázquez, 1999, Enríquez *et al*., 2010, Monroy-Vilchis *et al*., 2011). The studies on diverse groups of plants and animals conducted in the zone denote its importance, both for the richness of species and the existing endemisms. In relation to the mastofauna, the Mastogeographic Volcanic-Transverse province where the SNNR is located is considered one of the richest in the country (Monroy-Vilchis *et al*., 2011).

The land use and land cover information available for Mexico includes several models produced, both globally and continentally, and nationally. Among the first are the products of the 30 Meter Global Land Cover project, carried out by the USGS and the University of Maryland (https://landcover.usgs.gov/glc/); North American land cover maps with a resolution of 30 meters, prepared within the North American Land Change Monitoring System (NALCMS) initiative, where the governments of Canada, Mexico and the United States collaborate (http://www.cec.org) and the land cover data series of MODIS products (Moderate Resolution Imaging Spectroradiometer) generated by NASA (National Aeronautics and Space Administration, https://modis.gsfc.nasa.gov/about/). Systematic inventories of land cover and land use carried out by Mexican institutions have been prepared at a scale of 1: 250,000, including the vegetation and land use mapping of the National Institute of Statistics and Geography (INEGI, www.inegi.org.mx/, series I-VI), as well as national forest inventories made by the Institute of Geography of the National Autonomous University of Mexico (UNAM, Mas *et al*., 2009).

However, the existing cartographic information does not have the precision necessary to be used in studies at regional scales or it is not updated. For detailed studies at the local level, the use of data from remote sensors has been an alternative to generate information that fulfills specific requirements. Within this context, the objective of this study was to analyze the changes in land use in the Sierra Nanchititla Natural Reserve from 1986 to 2017, using geospatial techniques.

2. Materials and methods

2.1 Study zone

The Sierra Nanchititla Nature Reserve (SNNR) is located in the central-southern region of Mexico in the biogeographic province Depresión del Balsas, between the extreme coordinates 100 ° 16 '0.393 "- 100 ° 36' 45.7164" west longitude and 18 ° 45 '33.1194 "- 19 ° 4 '30.2808" north latitude. The natural protected area has an area of 65,301.56 ha and was established on October 12, 1977 with the category of State Park (CONABIO, 2015). Geomorphologically, the region is made up of mountains, hills and river valleys (INEGI, 2001, IG-INE, 2003), within an altitudinal range between 399 and 2,074 m.a.s.l. (https://www.asf.alaska.edu/sar-data/palsar/terrain-corrected-rtc/). The prevailing climates are warm subhumid and semi-warm subhumid, with a percentage of winter precipitation less than 5° C and little annual thermal oscillation (between 5 ° C and 7 ° C) (IGECEM, 1993). The floristic associations are represented essentially by tropical deciduous forest and oak and pine forests. The predominant anthropogenic land uses are induced grassland and crop zones. According to the latest census data, in the reserve there are 145 towns belonging to the municipalities of Luvianos and Tejupilco, in the State of Mexico, with a total of 11,912 inhabitants (INEGI, 2010).

2.2 Data processing

For the land use classification, Landsat 5 TM satellite images with a resolution of 30 m (year 1986) and Sentinel 2 satellite images with a resolution of 10 meters (year 2017) were used. Satellite data from the study area were obtained from the Earth Explorer website (http://earthexplorer.usgs.gov/) and from the Google Earth Engine site (https://code.earthengine.google.com/). These data sets were imported into the software for processing satellite information ENVI version 5.4 (Exelis Visual Information Solutions, Boulder, Colorado).

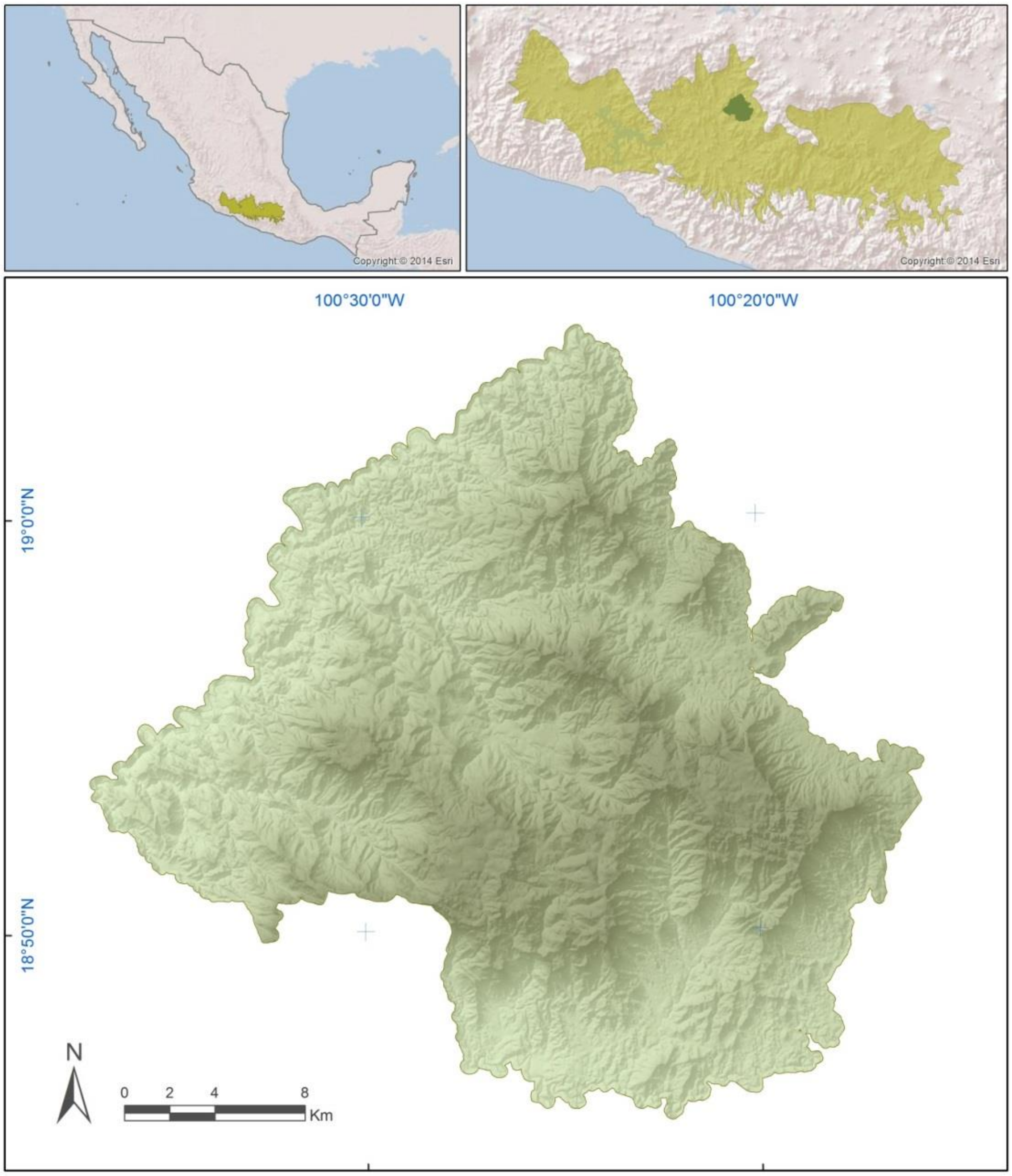

Figure 1. Geographical location of the Sierra Nanchititla Natural Reserve (SNNR) in the national context and in the biogeographic province Depresión del Balsas.

The subset of data from the study area of both images was extracted with the SNNR limit (region of interest, ROI). Previously, a buffer area of 100 meters was generated from this limit in order to ensure that there were no information gaps in the edges of the study area inherent to the handling of raster data.

2.3 Detection of land use

To carry out the land use classification, the supervised classification method was applied, using as training sites data collected in the field from July 2015 to August 2016 through GPS (54 sites) and sites obtained from Google Earth images (https://earth.google.com, 22 sites). As reference information, the vegetation and land use map of the INEGI series VI (INEGI, 2017) and the 2010 North American land cover map with a resolution of 30 meters were used (http://www.cec.org).

The maximum likelihood algorithm (MLE) was applied, which is one of the most accurate methods for supervised classification of satellite images (Ahmad and Quegan, 2012). This method is based on the Bayes' Theorem, used to calculate the probability of causal aspects from observed effects. The maximum likelihood method makes use of a discriminant function to assign each pixel to the highest probability class (Ahmad and Quegan, 2012). However, the derived classes may not be statistically separable, the method assumes a normal distribution of the values of the input bands and shows a tendency to over-classify values of relatively large spectral signatures in the covariance matrix (Rawat and Kumar, 2015).

After reviewing the information on land use – land cover available for the SNNR, the classification was oriented to the identification of 10 land use classes: temperate forest, tropical deciduous forest, temperate secondary forest, tropical secondary deciduous forest, gallery vegetation, grasslands, farming, areas without apparent vegetation, water bodies and human settlements.

The secondary vegetation includes both the vegetation that is in some successional development phase and the disturbed vegetation. The evaluation of the classification was done through the matrix confusion and the Kappa coefficient (Zhu *et al*., 2010; Butt *et al*., 2015; Rwanga and Ndambuki, 2017), which is used to measure the agreement between the values of the assigned classifications and the values of the classifications predicted by the algorithm.

2.4 Analysis of land use change

The post-processing of the results of the satellite images classifications for both periods was done in the software Arcgis 10.1 (ESRI, Inc.) and Idrisi Selva (Land Change Modeler Module). The comparison of the classified images was carried out in vector format through layer overlay techniques (Butt *et al*., 2015). From the overlay, a layer is generated which contains the geometrical information and attribute data of the two input maps. In this layer, the land use classes identified for both analyzed periods were recorded for each polygon, 1986 and 2017. By comparing the attributes of each polygon and the elaboration of statistical summaries, the types and magnitude of the registered changes were quantified, as well as the areas where there were no changes in land use. the comparison of the degree of fragmentation among forest and tropical deciduous forest was made through the Vogelmann continuity index (Galván-Guevara *et al*., 2015).

3. Results

The evaluation of the classification of land use recorded an overall precision of 90.15% for the year 1986 and 92.67% for 2017. The Kappa coefficients for the images classification were 0.883 and 0.904, for the first and second periods analyzed, respectively, which represents a strong agreement between the identified land uses and assigned land uses (Zhu *et al*., 2010).

Land use in 2017 reflected the predominance of anthropogenic uses, particularly induced grasslands and agricultural areas (36.74%), while only 31.2% of the SNNR had primary vegetation coverage. Altogether, the surface of the secondary vegetation of temperature forest and tropical deciduous forest represented 25.9% of the area. Gallery vegetation, areas without apparent vegetation, water bodies and human settlements, covered small areas and depicted 2.1% of the total area of study.

Spatially, the tropical deciduous forest vegetation is distributed mainly in the northwestern strip that borders the state of Michoacán, from the locality of El Cirián de Hermiltepec in the north, to the locality of Ojo de Agua-Palo Gordo in the west, as well as to the south of the reserve, in the vicinity of Bejucos, in Las Anonas and El Ciruelo, among other places. The largest patch of temperature forest is located in the central part of the protected natural area, above 1600 m.a.s.l. Other forest patches can be found to the north, in elevated areas located between the localities of Mesa Colorada and Huiztepec. The most anthropized areas are located in Bejucos, El Paso, Barro Prieto, Rincón del Guayabal, El Reparo, La Estancia, San Simón and the areas surrounding these communities.

In the analysis of changes between 1986 (figure 2) and 2017 (figure 3) it was observed that the largest decrease in area corresponds to the temperate forest and tropical deciduous forest with percentages of -3.91 and -3.87, respectively, in relation to the total area. The greatest increases were recorded in grasslands and cultivation areas with 4.61 and 2.22% respectively. The gallery vegetation, areas without apparent vegetation, water bodies and areas of human settlements did not show appreciable changes in the period analyzed (Table 2).

In total 9,699.26 ha, which represents 14.8% of the SNNR showed some type of land use change between 1986 and 2017. The patches with changes have a heterogeneous distribution in the SNNR, however, most of them occurred in the transition areas between temperate forests and tropical deciduous forest, in the zones located to the south of the mountainous areas, in the eastern edge of the SNNR area and in the lower areas located in the north and west (Figure 4).

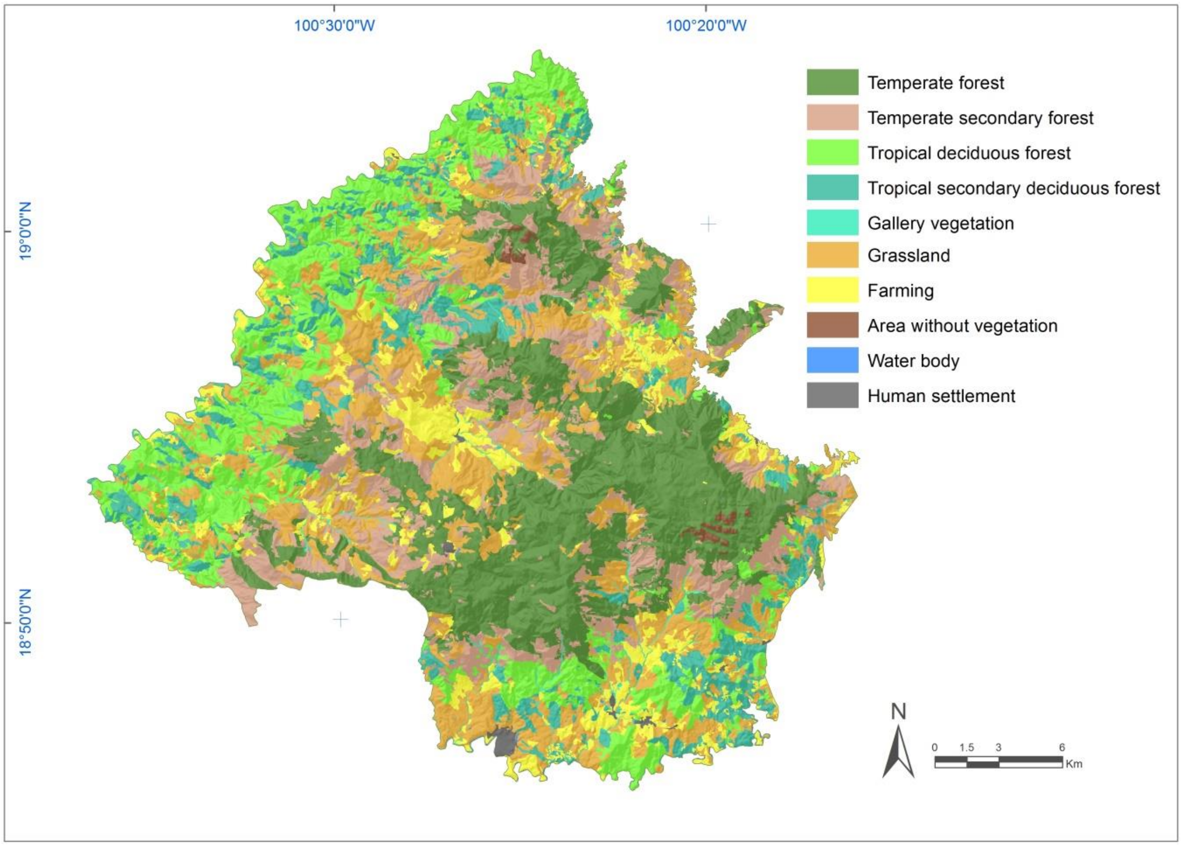

Figure 2. Land use in 1986 in the Sierra Nanchititla Natural Reserve.

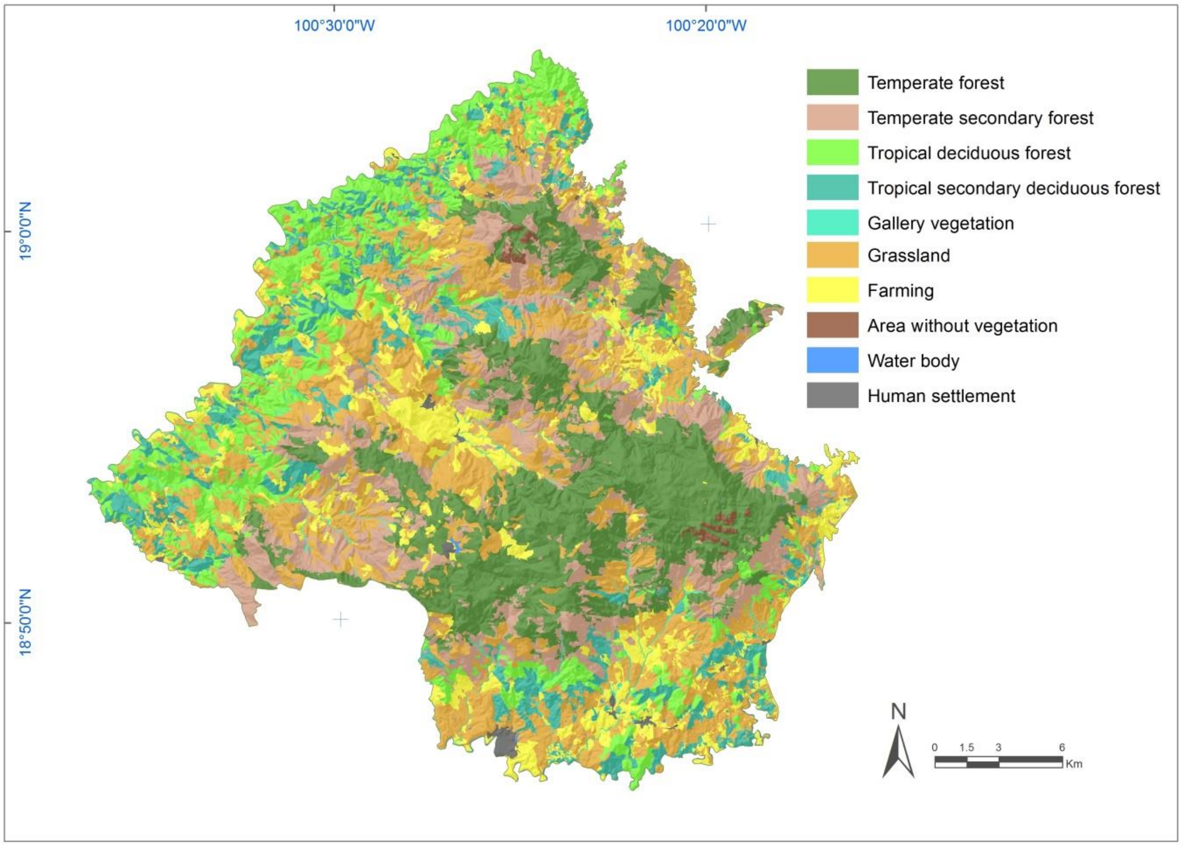

Figure 3. Land use in 2017 in the Sierra Nanchititla Natural Reserve.

Table 2. Area and magnitude of change in different land use categories for the period 1986 – 2017 in the Sierra Nanchititla Nature Reserve.

Land use	**1986**		**2017**		**Change from de 1986 to 2017**	
	Hectares	**%**	**Hectares**	**%**	**Hectares**	**%**
Temperate forest	16,756.36	25.66	14,200.62	21.75	-2,555.74	-3.91
Forest secondary vegetation	9,916.27	15.19	10,635.50	16.29	719.24	1.10
Tropical deciduous forest	11,363.41	17.40	8,834.21	13.53	-2,529.20	-3.87
Tropical secondary deciduous forest	6,470.84	9.91	6,281.76	9.62	-189.08	-0.29
Grassland	13,899.39	21.28	16,907.11	25.89	3,007.72	4.61
Farming	5,635.51	8.63	7,083.91	10.85	1,448.40	2.22
Gallery vegetation	647.90	0.99	647.90	0.99	0.00	0.00
Without apparent vegetation	269.16	0.41	269.16	0.41	0.00	0.00
Water bodies	89.51	0.14	105.14	0.16	15.63	0.02
Human settlements	253.20	0.39	336.23	0.51	83.03	0.13

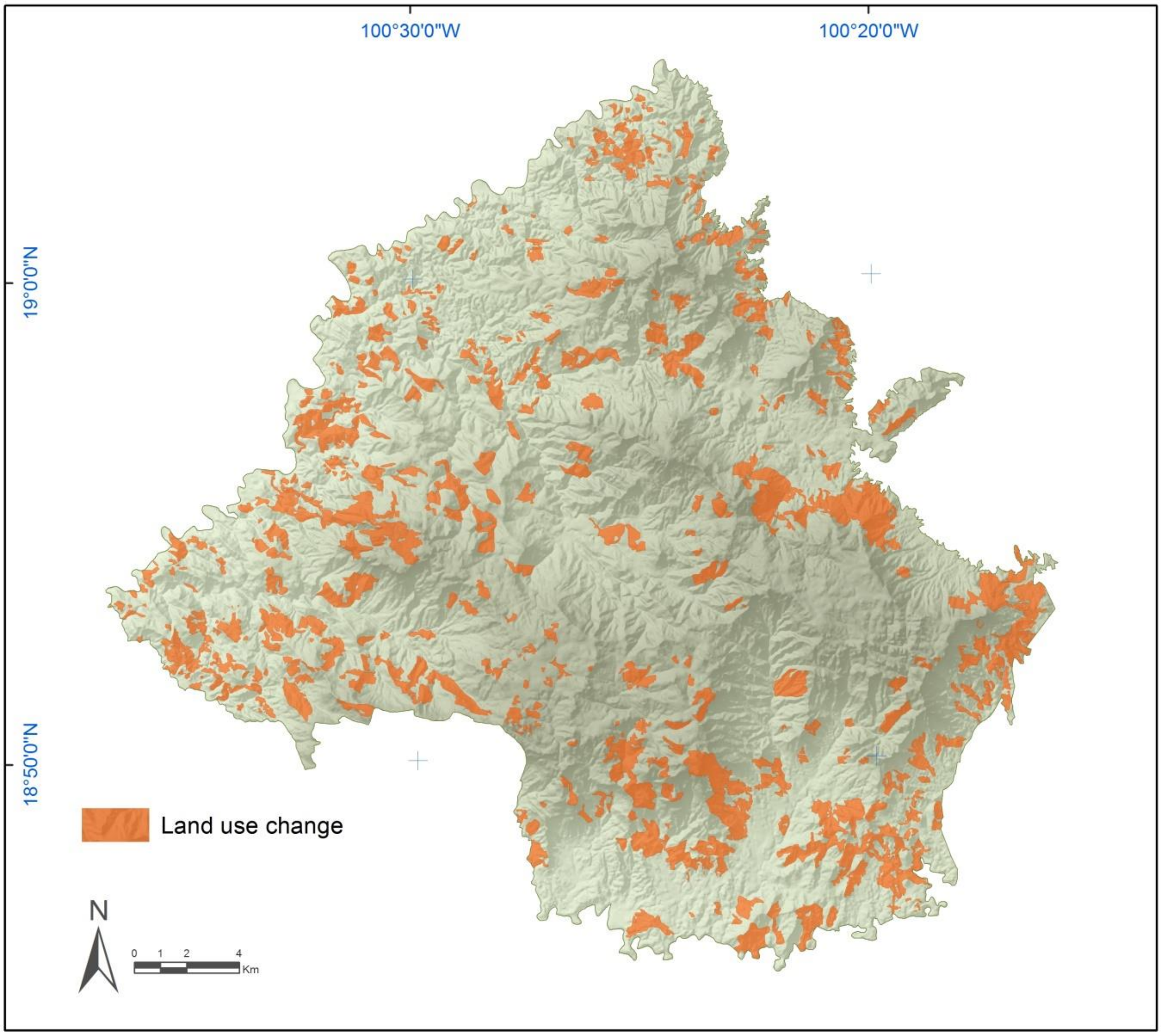

Figure 4. Patches that recorded land use changes in the Sierra Nanchititla Natural Reserve, between 1986 and 2017.

A conversion tendency of primary vegetation to secondary vegetation was found, both in temperate forest and in tropical deciduous forest. The most dynamic classes were grassland and farming that gained surface at the expense of the other coverages that registered changes. Based on land use changes dynamics, a general transition trend is observed: primary natural vegetation> secondary vegetation> grassland> farming (Table 3).

Table 3. Gains and losses resulting from changes in land use for the period 1986 – 2017 in the Sierra Nanchititla Nature Reserve.

	Decrease					
Increase	**Temperate forest**	**Temperate secondary forest**	**Tropical deciduous forest**	**Tropical secondary deciduous forest**	**Grassland**	**Farming**
Temperate forest		52.33				
Temperate secondary forest	2,133.80				113.93	40.06
Tropical deciduous forest				18.47		
Tropical secondary deciduous forest			1,690.49		109.86	2.41
Grassland	389.67	1,210.49	729.37	1,577.12		19.22
Farming	150.23	233.28	136.19	381.19	612.48	
Gallery vegetation	1.10		0.27	0.23	14.04	
Without apparent vegetation		5.71		6.18	67.85	3.29

Areas expressed in hectares.

Uses of grassland, farming, secondary vegetation of temperate forests, human settlements and water bodies registered net gains in surface area, while temperate forests, tropical deciduous forest and tropical secondary deciduous forest showed net decreases (Figure 5). The gallery vegetation and zones without vegetation did not present apparent changes in the period analyzed.

The values of the Vogelmann continuity index of temperate forests and tropical deciduous forest for the year 1986 were 5.28 and 4.62, respectively, and for 2017 were 5.16 and 4.45, respectively. This means that temperate forests have a greater spatial continuity than the tropical deciduous forests.

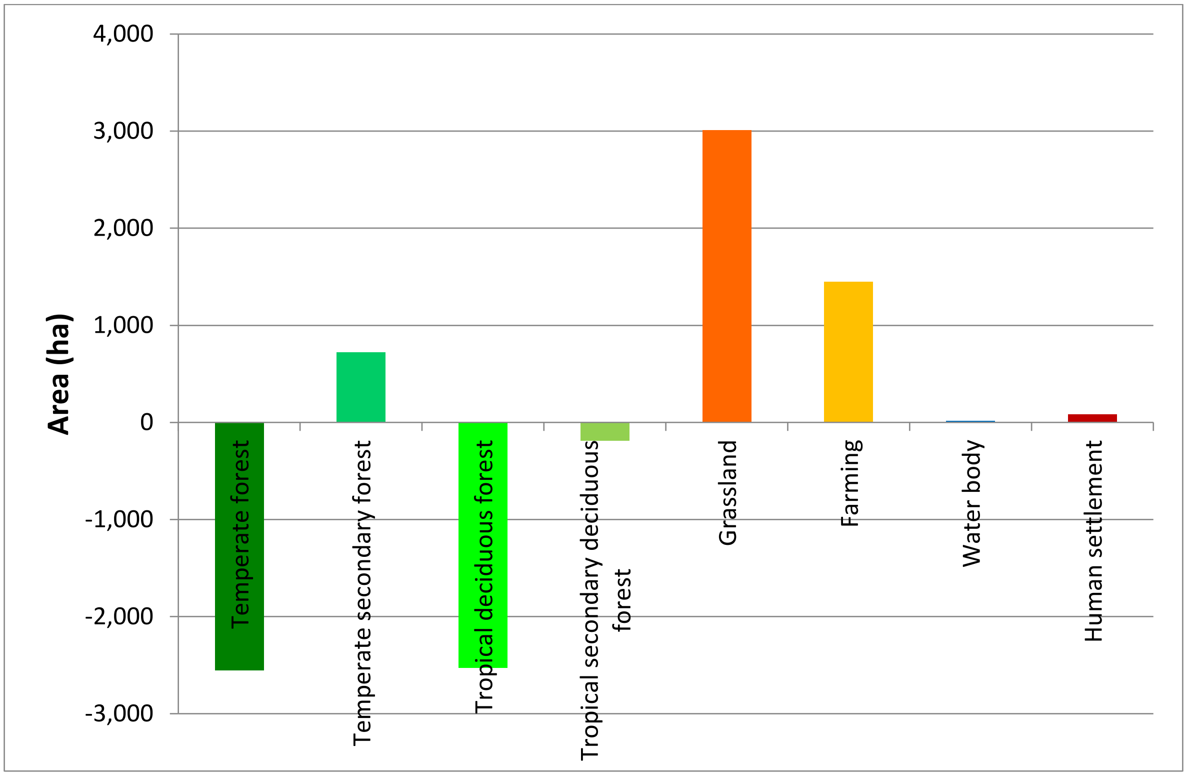

Figure 5. Net change of area by type of land use in the Sierra Nanchititla Natural Reserve, between 1986 and 2017.

4. Discussion

The knowledge and monitoring of land cover is basic information in territorial management processes and a fundamental aspect for the management of protected natural areas. Mexico has recorded in the last decades important changes in land use – land cover, mainly the loss of important areas of natural vegetation (Mas *et al*., 2009). The protected natural areas (PNAs) are not immune to this issue, although conservation strategies at the national level are largely based on these areas (Figueroa and Sánchez-Cordero, 2008, García-Frapolli *et al*., 2009). The loss and deterioration of natural vegetation is mainly due to a historical lack of financial resources, human resources and effective management plans (Blackman *et al*., 2015). The intensity and characteristics of the land use change processes in the PNAs of Mexico are quite variable (Velázquez *et al*., 2002), that depend, among other factors, on the regional environmental, socioeconomic and cultural characteristics, extension of the

PNAs, the historical period in which they were decreed, as well as the modality or category to which each corresponds.

The land use in the Sierra Nanchititla Natural Reserve (SNNR) has had moderate to significant alterations in the last three decades. The processes of change of use affected approximately 15% of the total protected natural area (0.48% per year), which can be considered moderate in comparison with that reported for other PNAs, such as the Sierra de Lobos, in Guanajuato, where the change in Land use covered 28.8% of its territory between 1970 and 2007 (0.77% per year, Muñoz-Villalobos *et al*., 2011). However, the change rate of the SNNR was higher compared to the Nevado de Toluca National Park (now Flora and Fauna Protection Area), where during the period from 1972 to 2000, the areas affected by changes in land use involved 11.8% (0.42% per year, Maass *et al*., 2006). According to Figueroa and Sánchez-Cordero (2008), in 69 PNAs of Mexico, for which the changes in land use were evaluated, these fluctuated among 0 and 72%, between the years 1993 and 2002.

The SNNR is the second most extensive and the most important PNA in terms of biological diversity in the State of Mexico, Mexico (Monroy-Vilchis *et al*., 2011; Monroy-Vilchis *et al*., 2011b), however, the current land use data, as well as the transformation dynamics in the SNNR are incompatible with the official figure of protected natural area, considering its role in the biodiversity protection and in the ecosystems maintenance, since only 35.28% of the reserve currently has natural vegetation in relatively good condition. However, the current land use data as well as the transformation dynamics in the RNSN are incompatible with the official figure of protected natural area, considering its role in the protection of biodiversity and in the preservation of ecosystems, since only 35.28% of the reserve support natural vegetation well preserved.

According to the management plan of the SNNR, the core zone was delimited considering the potential habitat of registered felines, taking into account their role as umbrella species (GEM, 2009, Monroy-Vilchis *et al*., 2011). This core zone covers the highest areas, in the central part of the reserve, so the dominant vegetation is pine and oak forests. However, by 2017, native vegetation only covered 44.75% of the surface, while 25.33% was secondary vegetation. Within the core area, croplands (5.37%) and induced grasslands (18.13%) were also identified.

The fragmentation of areas with natural vegetation is not a recent phenomenon, as can be seen in the 1986 map of land use, as legal and illegal logging have been happening since before the reserve was declared (Ramírez *et al*., 2010), although there is no adequate spatial information to make comparisons. The continuity of the temperate forest is greater than the continuity of the tropical deciduous forest because the first one is located predominantly in the highest and inaccessible areas of the reserve and because the transformation of the tropical deciduous forest to cultivated land is favored in areas with a lower slope.

Anthropogenic influence is the main cause of land use change in the SNNR, as evidenced by the proportion of areas covered by crops and grasslands (36.74%). The predominant economic activities are self-consumption agriculture and livestock, the latter is the main factor of coverage change, because it usually generates higher income than agriculture (Ramírez *et al*., 2010).

The human settlements in the SNNR represented 0.39% of the reserve area in 1986 and 0.51% in 2017, which reflects a low population density (18.24 inhabitants / km2 in comparison with the density at the state level of 679.39 inhabitants. / Km2) (INEGI, 2010), which is related to the high emigration rate of this region. The municipality of Luvianos, State of Mexico, coincides spatially in 73.44% with the polygon of the protected natural area, the population of this municipality was 28,213 and 27,860 inhabitants for the years 2005 and 2015, respectively, that is, it registered a decrease in absolute terms of 353 inhabitants in that period. The National Population Council (CONAPO) (2012) reports an index of migratory intensity for Luvianos of 7.02, which places it in the first place at the state level and at the 144th place nationwide. However, despite the reduction in the number of inhabitants in the region, the change in land use continues, since the main productive activities remain the same, extensive farming and livestock. The negative environmental impact of both activities is enhanced due to the slash-and-burn practice, which is carried out to transform the forest into crops or grazing areas. This practice has been one of the main causes of forest fires in the reserve. On the other hand, the pronounced slope that occurs in most of the SNNR, as well as the lack of agricultural aptitude of the soil, lead to a change in the cultivation areas in periods of approximately 3 years (shifting agriculture), which increases the rates of landscape transformation (Monroy-Vilchis *et al*., 2011).

The use of remote sensing and geographic information systems technologies was a reliable method for the inventory and analysis of spatio-temporal changes in land use in the SNNR. Its application is feasible when information is required from specific periods of time at fine scales (Jaiswal *et al*., 1999, Koomen and Stillwell, 2007, Diallo *et al*., 2009, Afify, 2011, Setiawan and Yoshino, 2011, Butt *et al*., 2015, Rawat and Kumar, 2015, Abuelaish and Camacho, 2016, Rujoiu-Mare and Mihai, 2016, Haque and Basak, 2017). The inventory generated constitutes a basic input for natural resources management and for scientific research in the SNNR, it can be taken as a reference or baseline for future monitoring of changes in the protected natural area and, at the same time, it provides information for carrying out other physical-geographical studies, environmental analysis and territorial planning.

Acknowledgements

This work was supported by the National Council of Science and Technology (CONACyT) through the scholarship granted to Francisco Reyna Sáenz (268135) and by the Autonomous University of the State of Mexico. A great recognition to the Geo-spatial Analysis Laboratory of the Institute of Geography of the National Autonomous University of Mexico for the facilities provided during the research stay in that institution.

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VII. Discusión general

La depredación de ganado por grandes carnívoros en México está asociada a indicadores de manejo (70.59%) y, en segundo lugar, a factores antrópicos y ambientales (29.41%). Estos resultados demuestran la importancia de la dimensión humana en la manifestación de este fenómeno y la necesidad de incorporar datos complementarios a las variables descriptoras del paisaje donde ocurren los eventos de depredación por carnívoros, usualmente manejadas en el análisis de esta problemática (Graham *et al*., 2005; Kolowski & Holekamp, 2006; Cascelli & Murray, 2007; Marchini y Macdonald, 2012; Dickman *et al*., 2014; Harihar *et al*., 2014). El trabajo de investigación también muestra que el análisis integrado de las variables de gestión ambiental, antrópica y pecuaria al analizar los conflictos entre humanos y la vida silvestre facilita el diseño de los programas de manejo (Bagchi y Mishra, 2006). Este enfoque de estudio concuerda con los postulados teóricos de la biología de la conservación que resaltan la necesidad de incorporar el componente social, tanto en el desarrollo de estudios ambientales, como en la planeación en materia ambiental (Primack *et al*., 2001).

Las acciones de mitigación de esta problemática propuestas en este trabajo, son consistentes con las propuestas derivadas de otros estudios en diversas partes del mundo (Ogada *et al*., 2003; Chávez y Zarza, 2009; Kissling *et al*., 2009; Rosas-Rosas *et al*., 2010; Zarco-González *et al*., 2013; Harihar *et al*., 2014; Schulz *et al*., 2014; Yirga *et al*., 2014; Alexander *et al*., 2015), es decir, coinciden en señalar que las pérdidas de ganado por depredación pueden ser minimizadas básicamente implementando cambios en las prácticas de manejo de ganado y por medio de mejoras en la infraestructura.

La variabilidad espacial es inherente a las interacciones entre humanos y vida silvestre y en particular a la depredación de ganado, como lo demuestran los modelos espaciales de riesgo, en los cuales se identifican gradientes de riesgo de depredación en el territorio a partir de los casos registrados y de la variabilidad espacial de los atributos del paisaje asociados a dichos eventos (Miller, 2015; Cox y Gaston, 2018; Margulies y Karanth, 2018). Este fenómeno tiene lugar en sitios con características ambientales, sociales, económicas y de manejo de ganado diferenciadas geográficamente, donde ciertas propiedades de las variables espaciales tenderán a ser más determinantes que otras (Zarco-Gonzalez *et al*., 2013). Identificar estas diferencias es un aspecto fundamental para desarrollar una política nacional para la mitigación de la depredación, que considere las particularidades de cada región de tal forma que las políticas y estrategias estén orientadas tanto a sus condiciones como a problemáticas particulares y que sea posible dirigir de manera más apropiada los limitados recursos de los programas de fomento ganadero y conservación ambiental.

En total 9,699.26 ha, que representan el 14.8% de la Reserva Natural Sierra Nanchititla, tuvieron algún tipo de transformación de cobertura el suelo entre 1986 y 2017. Una superficie de 8,643.73 ha se transformaron de vegetación natural a coberturas antrópicas o bien de vegetación de bosque y selva baja a vegetación secundaria de bosque o selva (13.23% del área total de la reserva). La mayor disminución en el área corresponde al bosque templado y a la selva tropical caducifolia con porcentajes de -3.91 y -3.87, respectivamente, con relación al área total. Los mayores incrementos se registraron en pastizales y áreas de cultivo con 4.61 y 2.22% respectivamente. La evaluación de cambio de cobertura del suelo permite deducir que antes del primer año de referencia (1986) tuvieron lugar importantes cambios de cobertura, basados en la fragmentación de la vegetación, la existencia de vegetación secundaria y de usos antrópicos en ese año. Asimismo, la dinámica observada en el periodo analizado permite conocer que los cambios de cobertura del suelo continúan y que, si bien hay pérdidas y ganancias en prácticamente todas coberturas, las mayores pérdidas corresponden a áreas con vegetación natural.

La presencia de eventos de depredación está muy relacionada con las áreas donde se registraron cambios de cobertura. 5 de los 11 eventos de depredación registrados en la RNSN están dentro o a menos de 500 metros de áreas deforestadas y 10 de los 11 están dentro o a menos de 1000 metros de áreas deforestadas. Lo anterior evidencia la estrecha relación entre las actividades antrópicas representadas por la expansión de zonas de cultivo y pecuarias, con las áreas de conflicto entre depredadores y humanos a causa de la depredación de ganado.

La presente investigación realiza un aporte complementario a los estudios existentes a nivel nacional principalmente en términos del tipo de información analizada, así como de la identificación de particularidades regionales en la distribución de este tipo de conflicto entre humanos y carnívoros. La generación de conocimiento más detallado en esta temática es posible con la disponibilidad de mayor cantidad y calidad de información, especialmente para el desarrollo de estudios locales o regionales a escalas cartográficas mayores que ayuden a definir acciones más concretas.

VIII. Conclusión general

Los eventos de depredación de ganado en México están asociados a variables de carácter ambiental, antrópico y de manejo de ganado. En este caso de estudio, 76.5% de las variables asociadas a los casos de depredación para las tres especies de carnívoros, corresponde a variables de manejo de ganado y antrópicas.

La zonificación de los eventos de depredación permitió definir propuestas diferenciadas regionalmente, lo cual podría hacer más factible y eficiente el diseño e implementación de un plan de gestión de esta problemática en el país.

El inventario de cobertura del suelo de la RNSR generado constituye un insumo básico para el manejo de los recursos naturales y para la investigación científica en la reserva, principalmente como una referencia o línea base para el monitoreo futuro de los cambios en el área. Al mismo tiempo, proporciona información para llevar a cabo otros estudios físico-geográficos, de análisis ambiental y ordenamiento territorial.

Diversas características ambientales, antrópicas y de manejo de ganado inciden en la ocurrencia de la depredación por grandes carnívoros, lo cual hizo posible la regionalización del territorio de acuerdo a los factores asociados a los eventos de depredación, así como la regionalización de propuestas de mitigación.

Por otro lado, la influencia antrópica a causa de la fragmentación del paisaje y cambios en la cobertura de suelo está asociada al fenómeno de depredación de ganado por carnívoros y en este sentido su análisis en los estudios nacionales, regionales y locales en México proporcionará mayores elementos para la explicación y atención de este problema de conservación de la fauna silvestre.

IX. Referencias bibliográficas

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