UNIVERSIDAD DE CIENCIAS Y ARTES DE CHIAPAS

INSTITUTO DE CIENCIAS BIOLÓGICAS

TESIS

Diversidad de la comunidad de mamíferos medianos y grandes en paisajes fragmentados y conservados en dos Áreas Naturales Protegidas en Chiapas, México

QUE PARA OBTENER EL GRADO DE:

Doctor en Ciencias en Biodiversidad y Conservación de Ecosistemas Tropicales

PRESENTA

JENNER RODAS TREJO

Tuxtla Gutiérrez, Chiapas **Agosto de 2025**

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JENNER RODAS TREJO

DIRECTOR

DR. SERGIO LÓPEZ MENDOZA
Instituto de Ciencias Biológicas
Universidad de Ciencias y Artes de Chiapas

ASESORES

DR. CÉSAR TEJEDA CRUZ
Instituto de Ciencias Biológicas
Universidad de Ciencias y Artes de Chiapas

DR. CARLOS TEJEDA CRUZ
Facultad de Medicina Verterinaria y Zootecnia
Universidad Autónoma de Chiapas

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C. Jenner Rodas Trejo
CVU: 206503
Candidato al Grado de Doctor en Ciencias en Biodiversidad y Conservación de Ecosistemas Tropicales
Instituto de Ciencias Biológicas
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RESUMEN

La tesis constituye un exhaustivo análisis sobre cómo los atributos del paisaje y las actividades humanas influyen en la estructura y composición de las comunidades de mamíferos terrestres medianos y grandes en la Reserva de la Biosfera Selva El Ocote (REBISO) y el Área de Protección de Recursos Naturales La Frailescana.

La investigación se estructura en siete capítulos. En el capítulo inicial, el autor establece el marco teórico, destacando la importancia ecológica de los mamíferos medianos y grandes como reguladores de cadenas tróficas, dispersores de semillas y modificadores del paisaje. Además, expone la problemática de la fragmentación del hábitat en Chiapas y formula las preguntas de investigación, hipótesis y objetivos que guían el estudio.

El segundo capítulo presenta una revisión sistemática de la literatura sobre los efectos de los atributos del paisaje en mamíferos terrestres medianos y grandes estudiados mediante fototrampeo entre 2010 y 2023. Este meta-análisis revela un incremento significativo en el número de publicaciones sobre la temática, particularmente en ecosistemas tropicales de América, Asia y África. La revisión identifica que la riqueza de especies, ocupación y abundancia relativa son las variables de respuesta más comúnmente estudiadas, mientras que los disturbios humanos y la cantidad de hábitat disponible constituyen las métricas de paisaje más evaluadas.

El tercer capítulo describe brevemente "Camelot", una herramienta desarrollada para el manejo y procesamiento de imágenes de cámaras trampa utilizando inteligencia artificial, mientras que el cuarto capítulo evalúa el potencial de ChatGPT como herramienta innovadora para la búsqueda de información sobre mamíferos silvestres, demostrando una alta precisión (88%) en conocimiento específico de especies, con un desempeño destacado en taxonomía (100%) e historia natural (90%), aunque presentó limitaciones en información sobre estatus de conservación (56%) y conocimiento general de mamíferos silvestres (73.54%).

En los capítulos quinto y sexto, se presentan los resultados empíricos del estudio. Para la REBISO, se documentaron 20 especies de mamíferos medianos y grandes, identificándose dos ensamblajes distintos: uno asociado a zonas mejor conservadas como "El Encajonado" con mayor presencia de especies especialistas como *Puma concolor*, y otro vinculado a áreas con mayor influencia humana, dominado por especies generalistas como *Didelphis spp*. El análisis multivariado de nicho (OMI) identificó a *P. concolor* como la especie con mayor especialización, mientras que *Nasua narica* mostró el comportamiento más generalista.

En La Frailescana, se registraron 19 especies, incluyendo algunas amenazadas como *Tapirus bairdii* y *Panthera onca*. La investigación reveló que la distancia a cuerpos de agua emergió como un factor crítico en la estructuración espacial de la comunidad, afectando negativamente tanto la abundancia como la riqueza de especies. Las respuestas a la infraestructura humana variaron entre especies: *P. tajacu*, *U. cinereoargenteus* y *O. virginianus* fueron más abundantes lejos de asentamientos humanos, mientras que la respuesta a caminos rurales mostró patrones más complejos, con algunas especies como *O. virginianus* utilizándolos como corredores de movimiento y otras como *L. wiedii* evitándolos.

El séptimo capítulo sintetiza las conclusiones generales, destacando la importancia de considerar múltiples factores al evaluar la distribución de mamíferos en áreas protegidas. La investigación demuestra que, tanto en la REBISO como en La Frailescana, la estructura de las comunidades está determinada por una compleja interacción entre factores naturales (altitud, cobertura forestal, proximidad a cuerpos de agua) y antropogénicos (asentamientos humanos, caminos).

Los hallazgos tienen importantes implicaciones para la conservación, enfatizando la necesidad de mantener la conectividad entre fragmentos de hábitat, proteger elementos críticos del paisaje como cuerpos de agua, implementar zonas de amortiguamiento efectivas alrededor de asentamientos humanos y establecer corredores biológicos que faciliten el movimiento de especies. La tesis proporciona así una base científica sólida para el desarrollo de estrategias de conservación más efectivas en paisajes tropicales fragmentados, considerando tanto los requerimientos específicos de las especies como el mantenimiento de elementos críticos del paisaje que facilitan su persistencia en ambientes modificados por humanos.

PALABRAS CLAVE: Mamíferos medianos y grandes, Fragmentación del hábitat, Cámaras trampa, Conservación de biodiversidad, Paisajes tropicales.

ABSTRACT

The doctoral thesis, constitutes a comprehensive analysis of how landscape attributes and human activities influence the structure and composition of terrestrial mammal communities in the Selva El Ocote Biosphere Reserve (REBISO) and the La Frailescana Natural Resource Protection Area.

The research is structured into seven chapters. The first chapter establishes the theoretical framework, highlighting the ecological importance of medium- and large-sized mammals as trophic regulators, seed dispersers, and landscape modifiers. It also addresses the issue of habitat fragmentation in Chiapas and formulates the research questions, hypotheses, and objectives guiding the study.

The second chapter presents a systematic literature review on the effects of landscape attributes on medium- and large-sized terrestrial mammals studied through camera trapping between 2010 and 2023. This meta-analysis reveals a significant increase in the number of publications on the subject, particularly in tropical ecosystems of the Americas, Asia, and Africa. The review identifies species richness, occupancy, and relative abundance as the most commonly studied response variables, while human disturbances and habitat availability constitute the most evaluated landscape metrics.

The third chapter briefly describes "Camelot", a tool developed for managing and processing camera trap images using artificial intelligence, whereas the fourth chapter assesses the potential of ChatGPT as an innovative tool for retrieving information on wild mammals.

The fifth and sixth chapters present the empirical results of the study. In REBISO, 20 species of medium- and large-sized mammals were documented, identifying two distinct assemblages: one associated with well-preserved areas such as El Encajonado, where specialist species like *Puma concolor* were more prevalent, and another linked to human-influenced areas, dominated by generalist species like *Didelphis spp*. The Outlying Mean Index (OMI) niche analysis identified *P. concolor* as the most specialized species, while *Nasua narica* exhibited the most generalist behavior.

In La Frailescana, 19 species were recorded, including some threatened species such as *Tapirus bairdii* and *Panthera onca*. The study revealed that distance to water bodies emerged as a critical factor in shaping community spatial structure, negatively affecting both species abundance and richness. Species responses to human infrastructure varied: *Pecari tajacu*, *Urocyon cinereoargenteus*, and *Odocoileus virginianus* were more abundant farther from human settlements, while responses to rural roads showed more complex patterns. Some species, such as O. virginianus, used roads as movement corridors, whereas others, like *Leopardus wiedii*, avoided them.

The seventh chapter synthesizes the general conclusions, emphasizing the importance of considering multiple factors when assessing mammal distribution in protected areas. The research demonstrates that in both REBISO and La Frailescana, community structure is determined by a complex interaction between natural factors (altitude, forest cover, proximity to water bodies) and anthropogenic factors (human settlements, roads).

The findings have significant conservation implications, highlighting the need to maintain habitat connectivity, protect critical landscape elements such as water bodies, implement effective buffer zones around human settlements, and establish biological corridors that facilitate species movement. The thesis thus provides a solid scientific foundation for developing more effective conservation strategies in fragmented tropical landscapes, considering both the specific requirements of species and the preservation of key landscape elements that support their persistence in human-modified environments.

KEY WORDS: Medium and large-sized mammals, Habitat fragmentation, Camera trapping, Biodiversity conservation, Tropical landscapes

CAPÍTULO I

INTRODUCCIÓN

1.1 Introducción general

Los mamíferos desempeñan un papel crucial en el mantenimiento de la estructura y función de los ecosistemas tropicales (Lacher et al., 2019). Estas especies actúan como reguladores de las cadenas tróficas, controladores de poblaciones de presas, dispersores de semillas y modificadores del paisaje, lo que las convierte en componentes esenciales para la estabilidad ecológica (Estrada et al., 2017; Oliveira & Wellington, 2017; Lacher et al., 2019). Sin embargo, su conservación se ve amenazada por la creciente fragmentación y pérdida de hábitat, impulsada principalmente por la expansión agrícola, la ganadería y el desarrollo urbano (Gibson et al., 2011; Newbold et al., 2015). En particular, los ecosistemas tropicales, que albergan una gran diversidad de mamíferos, están experimentando tasas alarmantes de deforestación y degradación, lo que pone en riesgo la viabilidad de muchas poblaciones (Gibson et al., 2011; Laurance et al., 2014).

En México, Chiapas se destaca como uno de los estados con mayor biodiversidad, ocupando el segundo lugar en riqueza de especies de mamíferos a nivel nacional, albergando una amplia variedad de mamíferos, muchos de los cuales son endémicos o se encuentran en peligro de extinción (Lorenzo et al., 2017). Sin embargo, esta riqueza biológica se enfrenta a presiones crecientes debido a la transformación del paisaje. La Selva El Ocote y La Frailescana, dos de las Áreas Naturales Protegidas más importantes de la región, no son ajenas a estos desafíos. A pesar de su estatus de protección, estas áreas han experimentado una pérdida significativa de cobertura forestal y un aumento en la fragmentación debido a actividades humanas como la agricultura, la ganadería y la extracción de recursos forestales (SEMARNAT, 2001; CONANP, 2019). Estas transformaciones han generado un mosaico de hábitats que varían en su grado de conservación, lo que afecta de manera diferencial a las comunidades de mamíferos.

En Chiapas, La REBISO y La Frailescana protegen más de 218,000 hectáreas de ecosistemas diversos (CONANP, 2019). Sin embargo, ambas reservas experimentan una intensa transformación del paisaje debido a las crecientes presiones antropogénicas por las actividades humanas como la agricultura, la ganadería y la extracción de recursos forestales, lo que ha generado una acelerada pérdida de cobertura vegetal y la fragmentación de los ecosistemas (CONANP, 2019), lo que compromete su capacidad de mantener poblaciones viables de mamíferos terrestres. Estas áreas protegidas presentan una compleja topografía y un mosaico ambiental que incluye bosques primarios, vegetación secundaria y zonas perturbadas, proporcionando un escenario ideal para evaluar los impactos de la modificación del paisaje en la distribución de especies. Además, estas reservas cumplen una función estratégica como corredores biológicos al conectar otras áreas protegidas como La Sepultura y El Triunfo, facilitando la dispersión de especies (Fahrig, 2003; Hanski, 2015).

Estudios previos en otras regiones tropicales han demostrado que la fragmentación del hábitat puede tener efectos profundos en la diversidad y composición de las comunidades de mamíferos. Por ejemplo, en la Amazonía brasileña, la pérdida de cobertura forestal ha llevado a una disminución en la abundancia de especies especialistas, como los grandes felinos, mientras que las especies generalistas, como los marsupiales y algunos roedores, han aumentado su presencia en áreas perturbadas (Michalski & Peres, 2005; Benchimol & Peres, 2015). Estos cambios en la estructura comunitaria no solo afectan a las especies individuales, sino que también pueden alterar las interacciones ecológicas y los procesos ecosistémicos (Terborgh et al., 2008).

La expansión de actividades agrícolas, ganaderas y el crecimiento de asentamientos humanos representan una de las principales amenazas para la biodiversidad global, especialmente en ecosistemas tropicales, al transformar paisajes continuos en mosaicos fragmentados (Haddad et al., 2015; Barlow et al., 2016). Este proceso genera el aislamiento de poblaciones silvestres, lo que aumenta el riesgo de extinción para muchas especies (Fahrig, 2003; Hanski, 2015). Los mamíferos medianos y grandes, debido a sus amplios requerimientos espaciales, densidades poblacionales naturalmente bajas y susceptibilidad a presiones antropogénicas, son particularmente vulnerables a estas transformaciones (Ceballos et al., 2017; Lacher et al., 2019). Además, estos grupos taxonómicos desempeñan roles ecológicos fundamentales como reguladores de cadenas tróficas, dispersores de semillas y modificadores del paisaje, por lo que su declive puede desencadenar efectos en cascada que alteran la dinámica ecosistémica en su conjunto (Jones & Safi, 2011; Lacher et al., 2019).

En este contexto, las Áreas Naturales Protegidas (ANP) juegan un papel clave en la conservación de los mamíferos, al proporcionar refugios relativamente estables en paisajes fragmentados (Watson et al., 2014). Sin embargo, las diferencias en su nivel de manejo, conectividad y presión antropogénica pueden influir en los patrones de diversidad y ocupación de las especies. La Reserva de la Biosfera Selva El Ocote (REBISO) y el Área de Protección de Recursos Naturales La Frailescana (La Frailescana), ambas ubicadas en Chiapas, México, representan dos sistemas con distintos grados de conservación y distintos niveles de influencia humana. Comprender cómo estas diferencias afectan la estructura comunitaria y la selección de hábitat de los mamíferos medianos y grandes es fundamental para diseñar estrategias de conservación más eficaces en paisajes fragmentados. A pesar de los esfuerzos de conservación, persisten vacíos de conocimiento sobre cómo los factores ambientales como la altitud, cobertura forestal, disponibilidad de agua y antropogénicos como cercanía a asentamientos humanos, carreteras, zonas agrícolas y pecuarias, interactúan para moldear la distribución y diversidad de los mamíferos en estos ecosistemas (Imre & Derbowka, 2011; Ferreguetti et al., 2019).

Las respuestas de los mamíferos medianos y grandes a estos cambios en el paisaje varían considerablemente según la ecología de cada especie. Mientras que los mamíferos especialistas, como los grandes carnívoros (*Panthera onca*, *Puma concolor*) y algunas especies dependientes de hábitat conservado, suelen ser altamente sensibles a la pérdida de cobertura forestal y al aislamiento de hábitats debido a sus requerimientos de extensas áreas continuas para el mantenimiento de sus funciones ecológicas, las especies generalistas, como *Nasua narica* y *Didelphis* spp., muestran una mayor plasticidad ecológica y pueden adaptarse mejor a paisajes modificados (Espinoza-García et al., 2014; Zanin et al., 2014; Oliveira et al., 2019; De la Torre et al., 2019; Cruz-Salazar et al., 2020; Amiot et al., 2021).

Estos cambios en la estructura comunitaria pueden alterar las dinámicas ecosistémicas al modificar las interacciones tróficas y los roles funcionales de las especies. La disminución de especies especialistas puede llevar a un aumento en la abundancia de generalistas, lo que puede afectar la composición y funcionalidad del ecosistema. Aunque estos procesos han sido documentados en otras regiones tropicales, en Chiapas los estudios se han concentrado en la Selva Lacandona (Arroyo-Rodríguez et al., 2013; Garmendia et al., 2013; Muench &

Martínez-Ramos, 2016; Porras et al., 2016), dejando un vacío de conocimiento sobre cómo la fragmentación, pérdida de hábitat y las actividades humanas influyen en las comunidades de mamíferos en la Sierra Madre de Chiapas.

La Reserva de la Biosfera Selva El Ocote y el Área de Protección de Recursos Naturales La Frailescana constituyen laboratorios naturales excepcionales para el análisis de los impactos del paisaje en las comunidades de mamíferos del sureste de México. Su relevancia científica se fundamenta en múltiples aspectos: funcionan como refugios críticos para la fauna silvestre, albergan ecosistemas de alta diversidad biológica, poseen características biogeográficas particulares que las distinguen regionalmente, desempeñan un papel fundamental como corredores de conectividad biológica, y enfrentan desafíos significativos derivados de las presiones antropogénicas que las convierten en modelos ideales para estudios de fragmentación y conservación (SEMARNAT, 2001; CONANP, 2019).

El análisis de los efectos del paisaje sobre las comunidades de mamíferos medianos y grandes en estas áreas protegidas resulta fundamental para comprender los mecanismos mediante los cuales la fragmentación y conectividad del hábitat influyen en la biodiversidad de la Sierra Madre de Chiapas. A pesar de su relevancia ecológica, existe un vacío de conocimiento sobre el efecto sistemático de la estructura del paisaje y las actividades antropogénicas en estas comunidades de mamíferos, limitando el desarrollo de estrategias de manejo basadas en evidencia científica.

Esta investigación evaluó llenar este vacío de conocimiento al evaluar los efectos del paisaje y la influencia humana sobre la estructura y composición de las comunidades de mamíferos medianos y grandes en ambas ANP. A través del fototrampeo y el análisis de gradientes ambientales y antropogénicos, se identificaron patrones de diversidad, que incluyen la riqueza y composición de especies, abundancia relativa, estructura de las comunidades considerando dominancia y rareza de especies, así como el recambio entre sitios con diferentes condiciones del paisaje. El análisis de estos patrones permitió entender cómo se distribuyen las especies en relación con los gradientes estudiados y evaluar las diferencias en la diversidad entre sitios con distintos grados de conservación.

Los resultados permitieron identificar los factores críticos que influyen en la biodiversidad, sino también entender cómo las especies responden diferencialmente a la alteración del paisaje en función de sus características ecológicas. En particular, los hallazgos ayudan a identificar especies indicadoras de la calidad del hábitat y a diseñar estrategias de conservación adaptadas a cada grupo funcional. Además, permite determinar qué áreas son prioritarias para la protección de especies especialistas y desarrollar planes de manejo que equilibren la conservación con las actividades productivas locales, promoviendo el uso sostenible del territorio. Finalmente, los resultados pueden establecer una base para el monitoreo a largo plazo de estas comunidades de mamíferos, facilitando la evaluación continua de las estrategias de conservación implementadas.

1.2 Preguntas de investigación

1) ¿Cómo se estructuran las comunidades de mamíferos medianos y grandes en áreas con diferentes grados de conservación en la Reserva de la Biosfera Selva El Ocote y el Área de Protección de Recursos Naturales La Frailescana?

2) ¿Qué factores ambientales y antropogénicos determinan los patrones de diversidad y distribución de mamíferos medianos y grandes en estas áreas naturales protegidas?

3) ¿ Cómo responden las diferentes especies a los factores ambientales y antropogénicos en términos de su ocupación y selección de hábitat?

1.3 Hipótesis

H1. Estructura de las comunidades:

- Las áreas mejor conservadas presentarán mayor riqueza y diversidad de especies en comparación con las zonas perturbadas.

La composición de especies diferirá significativamente entre ambientes, donde:

- Las zonas conservadas estarán caracterizadas por la presencia de especies sensibles como depredadores tope y especies especialistas de hábitat.
- Las zonas perturbadas estarán dominadas por especies generalistas y especies tolerantes a la presencia humana.

H2. Factores determinantes de los patrones de diversidad:

Los factores ambientales y antropogénicos influirán de manera diferencial en la distribución de las especies, donde:

- La riqueza y abundancia de especies se correlacionará positivamente con la cobertura forestal y la cercanía a cuerpos de agua.
- La diversidad de especies disminuirá con la proximidad a asentamientos humanos y caminos principales.

H3. Respuestas específicas y selección de hábitat:
Las especies mostrarán diferentes grados de especialización de nicho y respuestas a los gradientes ambientales basadas en sus características ecológicas:

- Las especies de mayor tamaño corporal y los carnívoros mostrarán mayor especificidad de hábitat, prefiriendo áreas con mayor cobertura forestal y alejadas de influencia humana.
- Las especies medianas presentarán mayor plasticidad ecológica, pudiendo utilizar tanto hábitats conservados como modificados.
- La ocupación y abundancia relativa de especies especialistas disminuirá conforme aumenta el grado de perturbación antropogénica.

1.4 Objetivo general

Evaluar los efectos de los atributos del paisaje y la influencia de las actividades humanas sobre la estructura, composición y patrones de diversidad de las comunidades de mamíferos medianos y grandes en la Reserva de la Biosfera Selva El Ocote y el Área de Protección de Recursos Naturales La Frailescana, Chiapas.

1.4.1 Objetivos específicos

- Realizar una revisión y análisis del conocimiento sobre los efectos de los atributos del paisaje en mamíferos terrestres no voladores medianos y grandes, a través de estudios realizados con cámaras trampa.

- Analizar la estructura y composición de las comunidades de mamíferos medianos y grandes en áreas con diferentes grados de conservación.

- Identificar los factores ambientales y antropogénicos que determinan los patrones de diversidad y distribución de mamíferos.

- Caracterizar las respuestas específicas de las especies a los gradientes ambientales y antropogénicos.

CAPÍTULO II

Efectos de los atributos del paisaje en mamíferos terrestres no voladores medianos y grandes: una revisión sistemática de los estudios de cámaras trampa (2010-2023)

Discover Animals

Review

Effects of landscape attributes on medium- and large terrestrial non-volant mammals: a systematic review of camera trap studies (2010–2023)

Jenner Rodas-Trejo[1,2] · **Sergio López**[1,3] · **Cesar Tejeda Cruz**[3] · **Jaime R. Rau**[4] · **Carlos Tejeda Cruz**[5]

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Abstract

Human-driven transformations of terrestrial landscapes are causing unprecedented habitat loss, degradation and fragmentation, with particularly severe consequences for medium- and large-sized terrestrial mammals. Landscape ecology offers critical insights into how wildlife populations respond to changes in habitat configuration, quantity, quality and connectivity. This review addresses two primary objectives: (1) to systematically synthesize scientific evidence from 2010 to 2023 on the effects of landscape attributes on the distribution, abundance, and behavior of medium- and large-sized terrestrial mammals, pinpointing the most influential metrics and variables; and (2) to evaluate the response patterns of various species and functional groups to diverse landscape matrices and anthropogenic transformations. The landscape effects explored focused on natural habitat fragmentation affecting functional connectivity, reduction in available habitat, changes in spatial patch configuration, intensification of human activities in the surrounding matrix, and edge effects arising from the transition between natural and anthropized habitats. These landscape attributes significantly influenced species richness (28.45% of studies), occupancy patterns (25.63%), and population abundance (12.39%) of terrestrial mammals. Camera traps served as the primary methodological tool for data collection in these studies, enabling systematic assessment across various spatial and temporal scales. A total of 180 articles from scientific databases were analyzed, with most studies conducted in the Americas, Asia, and Africa, predominantly in tropical and subtropical biomes. Research primarily occurred in native forests (77.17%) and areas with agricultural activities (42.39%), with 68.89% focusing on mammal communities broadly. Commonly utilized landscape metrics were associated with human disturbances and habitat quantity. This review emphasizes the need to comprehend landscape effects on mammal conservation, as species exhibited varied responses to landscape transformation, with some demonstrating ecological flexibility while others faced adverse consequences.

Keywords Camera traps · Terrestrial mammals · Habitat fragmentation · Landscape ecology

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✉ Jenner Rodas-Trejo, jenner.rodas@unach.mx; Sergio López, sergio.lopez@unicach.mx; Cesar Tejeda Cruz, cesar.tejeda@unicach.mx; Jaime R. Rau, jrau@ulagos.cl; Carlos Tejeda Cruz, tejedac@unach.mx | [1]Programa de Doctorado en Ciencias en Biodiversidad y Conservación de Ecosistemas Tropicales, Instituto de Ciencias Biológicas, Universidad de Ciencias y Artes de Chiapas, Libramiento Norte Poniente 1150, 29039 Tuxtla Gutiérrez, Chiapas, México. [2]Escuela de Estudios Agropecuarios Mezcalapa, Universidad Autónoma de Chiapas, C.P. 29625 Copainalá, Chiapas, México. [3]Laboratorio de Ecología Evolutiva, Instituto de Ciencias Biológicas, Libramiento Norte Poniente 1150, 29039 Tuxtla Gutiérrez, Chiapas, México. [4]Laboratorio de Ecología, Departamento de Ciencias Biológicas y Biodiversidad, Universidad de Los Lagos, Campus Osorno, Casilla 933, Osorno, Chile. [5]Facultad de Medicina Veterinaria y Zootecnica, Universidad Autónoma de Chiapas, C.P. 29060 Tuxtla Gutiérrez, Chiapas, Mexico.

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1 Introduction

Landscapes are heterogeneous physical spaces whose characteristics result from the interaction of biophysical and socioeconomic components [1]. In these spaces, the arrangement of elements and landscape structure is determined primarily by natural changes and those caused by human activities [2, 3]. Currently, owing to human activities, terrestrial landscapes are experiencing unprecedented transformations, leading to habitat loss, degradation, and fragmentation on a global scale [4–6].

These landscape alterations have severe effects on wildlife, and their survival largely depends on factors such as landscape composition, the availability of habitat resources within the landscape structure, and species adaptability and resilience to new habitat matrices [7–10]. Understanding how habitat configuration, quantity, quality, and connectivity influence wildlife populations has become a central research theme in landscape ecology, critical for predicting species responses to ongoing environmental change [11].

Studies on the effects of landscape on wildlife employ a multilevel approach that examines both the landscape scale (amount and type of habitat, human pressure) and the patch scale (vegetation structure, size, and shape) to understand how habitat amount, structural complexity, and spatial configuration—particularly fragmentation and connectivity—affect various aspects of species, such as their presence, richness, abundance, and distribution [12–17].

Medium- and large-sized terrestrial non-volant mammals are particularly vulnerable to fragmentation due to their extensive space requirements, mobility, and dependence on well-preserved habitats, making them key indicators of landscape health and biodiversity loss. Attributes such as habitat loss, reduced connectivity, and edge effects disrupt their access to resources, alter movement patterns, and increase exposure to human-induced pressures like hunting and competition with invasive species, often leading to declines in distribution, abundance, and reproductive success [4, 8, 18, 19]. These studies have provided insights into the effects of fragmentation and identified the attributes with the greatest impact on these mammals, generating valuable information to guide area management and achieve conservation objectives [20].

Research on these landscape effects has been enriched by tools like camera traps, which enable detailed data collection on mammal distribution, behavior, and population dynamics across spatial and temporal scales in fragmented habitats [21–23]. Analytical advances, such as occupancy models, further enhance our ability to assess how landscape changes influence species beyond simple presence or absence [10, 24]. However, the primary focus remains understanding the ecological consequences of habitat transformation, with technology serving as a means to deepen insights into these processes rather than an end in itself.

This review has two main objectives: (1) to systematically synthesize the scientific evidence from the period 2010–2023 regarding the effects of landscape attributes on the distribution, abundance, and behavior of medium- and large-sized terrestrial mammals, identifying the most influential metrics and variables; and (2) to assess response patterns of different species and functional groups to various landscape matrices and anthropogenic transformations, with an emphasis on studies employing camera traps as a methodological tool. This approach not only provides an updated synthesis of the current body of knowledge but also helps to systematize emerging patterns, identify key variables, and enhance the understanding of how landscape attributes influence medium- and large-sized terrestrial mammals across different spatial scales and ecological regions. This review identifies patterns in geographic coverage, research topics, response variables, land use, and landscape metrics, while evaluating the effectiveness of camera traps and the impact of human intervention at the landscape level. It helps to identify priority areas for future research and guides more effective conservation strategies to tackle fragmentation and landscape transformation.

2 Materials and methods

2.1 Data sources and search strategy

The systematic review was conducted through an exhaustive search of scientific articles published between 2010 and 2023. Searches were carried out using consolidated academic electronic databases, including EBSCO, Google Scholar, ScienceDirect, and Web of Science. In addition, artificial intelligence-powered tools such as ResearchRabbit and Semantic Scholar were used to complement and refine the search results. These AI-based tools were specifically employed to enhance literature discovery through intelligent citation mapping, automated paper recommendations based on semantic similarity, and identification of relevant studies that might have been missed through traditional keyword searches. The compilation was strictly limited to peer-reviewed articles published in academic journals in the English language, thereby excluding grey literature, theses, books, and conference abstracts.

The search strategy was constructed through the systematic combination of three groups of key terms: (1) study base: "landscape," "land use," "landscape change," "fragmentation," "forest fragments," "habitat," "habitat use," and "habitat loss"; (2) study object: "mammal," "terrestrial mammal," "medium and large mammals"; and (3) data collection method: "camera trap," "camera trapping," and "infrared triggered camera." These terms were combined using Boolean operators to optimize the retrieval of relevant publications.

Specific inclusion criteria were applied to select publications analyzing: (a) occupancy, diversity, richness, composition, community structure, populations, and species of medium- and large-sized terrestrial mammals in conserved, deforested, fragmented, disturbed, urbanized environments, and/or biological corridors; (b) landscape use, avoidance, and/or preference by mammal communities, populations, and species in the previously mentioned environments; and (c) the effects of landscape, patch, and/or habitat attributes on communities, populations, and species of medium- and large-sized terrestrial mammals.

Articles that did not focus on landscape and/or fragmentation studies were systematically excluded, including those limited to reporting diversity, new species records, activity patterns, inventories, resource selection, or diet without a landscape-level context. This filtering process ensured the inclusion of studies with methodological designs capable of assessing the effects of landscape attributes on medium- and large-sized terrestrial mammals through camera trapping.

All selected articles were systematized in a structured database based on the criteria defined in Table 1, organizing the information into three main groups: general information and content, study design and approach, and analytical metrics and variables. This structure enabled a robust and multidimensional characterization of the existing literature on the topic (Table 1) [15, 25–29].

Table 1. Groups and Categories Included in the Analysis of the Articles.

2.2 Group 1: general information and content

The articles were classified by year, the journals in which they were published, and spatial scale (the continents, countries, and biomes where the research was conducted), consulting the Ecoregions2017©Resolve site (https://ecoregions.appspot.com). For each journal in which the selected articles were published, we recorded its Journal Impact Factor (JIF) based on the most recent values available in the Journal Citation Reports (Clarivate Analytics). This allowed us to evaluate not only the frequency of publication across journals but also their relative scientific influence. The study scale was determined as (a) local (those studies that covered only one region), (b) national (those that considered at least three provinces or regions of a country), (c) transnational (those that covered more than two countries on the same continent), and (d) intercontinental (those that conducted studies on more than one continent).

To understand collaboration patterns among researchers in the field, a co-authorship network analysis was performed. All authors from the 180 selected publications were recorded, and co-authorship relationships were identified when two or more authors collaborated on a publication. The network analysis was conducted using the bibliometrix package, which is

Table 1 Groups and categories included in the analysis of the articles

Groups	Categories
General Information and Content	Journal and year of publication Countries, continents, and biomes where the research was conducted Bibliometric analysis Scale of the study: local, national (> 3 provinces of a country), transnational (> 2 countries within the same continent), intercontinental (> 2 continents) Research topics
Study Design and Approach	Object of study Number of detected species reported Level at which the study was conducted: landscape, fragmentation, landscape-fragmentation
Analysis Metrics and Variables	Response variables used Landscape metrics, fragmentation metrics, and detection covariates integrated into the analysis Land use where the studies were conducted Work inside or outside Protected Natural Areas

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specifically designed for bibliometric and scientometric analysis [30]. Additionally, author productivity over time was assessed by tracking publication patterns from 2010 to 2023, with particular attention given to researchers who contributed multiple publications. Author metrics included the total number of publications and the temporal distribution of their research output.

To group publications into research topics, an analysis of the hypotheses and objectives of each article was conducted and classified as follows: (1) climate change; (2) distribution and occurrence of communities, populations, and species of medium and large terrestrial mammals in different environments, vegetation types, and land use; (3) effect of habitat, landscape, and fragment characteristics on communities, populations, and species of medium and/or large terrestrial mammals; (4) effects of anthropogenic activities on communities, populations, and species of medium and large terrestrial mammals in different environments; (5) current status of communities, populations, and species of medium and large terrestrial mammals in different environments, habitat conditions, and protected natural areas (PNA); (6) factors influencing the occupancy of communities, populations, and species in conserved and/or fragmented environments; (7) activity patterns of species in different environments, habitats, landscapes, and/or fragments; and (8) connectivity and use of biological corridors. Each article could contain one or more research topics.

2.3 Group 2: study design and approach

To characterize the study subjects, the focus of each article was considered and grouped into three categories: focal species, when the study centered on a single species; multiple species, when all recorded species were considered; and trophic guilds, when the study targeted a specific functional group [28]. In addition, the taxonomic composition of the mammals recorded across studies was characterized by compiling all species reported. For each species, the order, family, and scientific name were documented, along with the frequency with which each was reported across studies. The most frequently recorded species were identified. Furthermore, their geographic distribution by continent and conservation status, based on the International Union for Conservation of Nature (IUCN) Red List, were also recorded.

The level of analysis was classified as: a) landscape, for studies analyzing elements at the landscape scale; b) fragments, for those focusing on specific remnant elements; and c) landscape fragmentation, for studies addressing both spatial levels.

2.4 Group 3: analysis metrics and variables

Considering ecological objectives, response metrics were classified into eight variables: abundance (primarily considering the relative abundance index (RAI)), activity patterns, community structure, density, diversity, occupancy, detection probability, and species richness [26, 29, 31]. Detection covariates, landscape metrics, and fragmentation metrics were classified into 23 subcategories, focusing on a set of metrics widely addressed in the literature [15, 32–34] (see Table 2).

Table 2. Classification of landscape metrics, fragments and detection covariates included in the analyses of the articles.

To quantify land use, the characteristics of the vegetation types and anthropogenic activities described at the study sites were considered. The vegetation types were grouped into (1) Native forests, (2) Degraded forests, (3) Wetlands and riparian areas, (4) Native grasslands, (5) Secondary forests, and (6) Shrub vegetation. Human activities were summarized as follows: (7) agriculture, (8) monoculture plantations, (9) introduced pastures for livestock, (10) urban and developed areas, (11) livestock, and 12) mining and energy.

The studies conducted inside and outside protected natural areas were counted. A chi-square analysis was performed to determine if there were significant differences between them. The number of species reported in the studies by continent was counted, and the means and standard deviations were obtained. All analyses were performed in R 2022.02.3 software [35].

3 Results

3.1 General information and content

The search yielded 314 scientific publications, 180 of which met the inclusion criteria and were included in this study. Of these, 66.11% (n = 119) were published in the past 6 years (Fig. 1 and supplementary material S1).

The reviewed articles were published in 73 scientific journals, with 10 of them accounting for 45.55% (n = 83) of all publications. The most frequent journals were Biological Conservation (7.22%, n = 13), PLOS ONE (6.67%, n = 12), Mammalian Biology (6.11%, n = 11), and both Oryx and Landscape Ecology (5.00%, n = 9 each). In contrast, 44 journals featured only a

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Table 2 Classification of landscape metrics, fragments and detection covariates included in the analyses of the articles

Clasificación	Code	Category	Description
Human disturbance	Hum_dist	Landscape metrics	Elements of the landscape that impact or have been impacted by human activities such as tourism, hunting, human settlements [81]
Hábitat amount	Hab_amo	Landscape metrics	Proportion of primary and secondary forest. The hypothesis predicts that species richness at a habitat site increases with the amount of habitat in the "local landscape" defined by an appropriate distance around the site, without distinctive effects of the habitat patch size in which the site is located [11, 13]
Abiotic factors	Abi_fact	Landscape metrics	Abiotic factors involved in the characterization of a given ecosystem, such as altitude, topography, slope, among others (Nakashima et al. 2020)
Matrix the Patch	Mat_P	Patch metrics	Indicates the types of habitat of the patches included in a study. Patches refer to preserved vegetation or secondary forest [15]
Spatial configuration of the landscape	Spa_confL	Landscape metrics	Elements that constitute the quantitative landscape (Parsons et al. 2016)
Landscape impact	Land_imp	Landscape metrics	Proportion of areas where human and natural activities occur that impact the landscape [22]
Hábitat type	Hab_ty	Landscape metrics	Indicates the main habitat type included in a study, referring to preserved vegetation or secondary forest [15]
Matrix type	Mat_ty	Landscape metrics	Represents the primary driver of fragmentation in a study. The categories are urban, agriculture, livestock, and seminatural (e.g., burning, flooding) [15, 73]
Landscape size	Land_siz	Landscape metrics	Composition and size of each landscape element
Interspecific interactions	Intr_rel	Detection covariates	Directly or indirectly examine interspecific interactions (e.g., predator−prey, competition, mutualism) [22, 29]
Isolation	Iso	Patch metrics	Distance to the nearest forest patch [73]. Isolation is due to landscape resistance exerted on the remaining habitats by the surrounding nonhabitat matrix [32]
Camera	Camera	Detection covariates	Evaluates the success of capture due to the different operational capabilities and characteristics of camera models (Penjor et al. 2021)
Patch area	Area_P	Patch metrics	Represents the contiguous area of a remaining habitat patch, measured in hectares [15]
Protected areas	PA	Landscape metrics	Considered public property and management land, protected from private urbanization (size of the protected area, type of protected area, etc.) (Massara et al. 2017, [37])
Domestic mammals	Dom_mam	Detection covariates	Presence of domestic animals in the study area (Parsons et al. 2016, Massara et al. 2017)
Basal area of trees/saplings	Basal_ar	Patch metrics	Basal area of small trees/sprouts within the patch estimated per hectare, applies to lianas, shrubs, etc. [6]
Intraspecific characteristics	Intr_char	Detection covariates	Species characteristics such as reproductive rate, home range, body mass
Shape	Shape	Patch metrics	Habitat fragmentation measured by the patch shape index, explains an increase in the length of the habitat patch edge; more circular areas have less edge effect [73]
Number of patches	Num_P	Landscape metrics	Indicates the number of habitat patches evaluated within a study [15]
Density of forest edges	Dens_forEd	Landscape metrics	Total density of forest—nonforest edge in the landscape (km/ha) [6]
Density of forest patches	Dens_forP	Landscape metrics	Density of forest patches in the landscape (no./km^2) [6], (Pfeifer et al. 2017)
Time since fragmentation or disturb	Time_dist	Landscape metrics	Time elapsed since the loss of primary or secondary forest (Semper-Pascual et al. 2021)
Mean patch size	Mean_sizP	Landscape metrics	Average size of all forest patches in the landscape (ha) [6]

single article. The 20 most represented journals are illustrated in Supplementary Figure S2a. Additionally, when considering both the number of publications and the Journal Impact Factor (JIF), Biological Conservation, Ecological Indicators, and Conservation Biology emerged as the most influential sources in the reviewed literature (Supplementary Figure S2b).

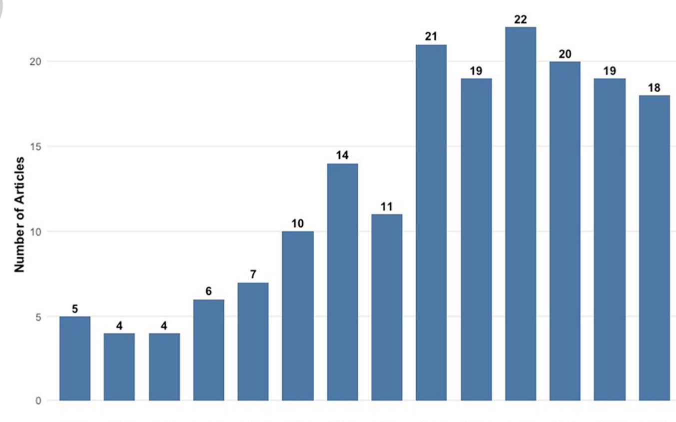
The analysis of co-authorship networks revealed distinct collaboration clusters among researchers in the field of terrestrial mammal studies (Fig. 2). The network visualization shows several well-defined research groups, with the largest clusters appearing in red, orange, and blue nodes. These represent established collaborative teams that have published multiple papers together. Smaller clusters and isolated pairs (represented by pairs of connected nodes distant from the main clusters) indicate more limited collaboration networks or emerging research teams.

Examination of author productivity over time identified several consistently productive researchers in the field (Fig. 3). Authors including Cruz P., Rovero F., and Iezzi M.E. showed sustained research output across multiple years, with peaks of productivity observed primarily between 2016 and 2020. The pattern of publication suggests an intensification of research activity in this period, coinciding with the overall increase in publications noted in Fig. 1. Several authors, such as Carbone C. and Rovero F., demonstrated ongoing productivity extending into 2023, which may indicate sustained research programs.

The studies were conducted across five continents (114 in America, 30 in Asia, 24 in Africa, nine in Europe, and three in Oceania) and in 54 countries (18 in America, 15 in Africa, 14 in Asia, six in Europe, and one in Oceania), with five countries accounting for 50.00% (n = 89). The six countries with the highest contributions were Brazil, with 41 studies; Argentina, with 17; the United States, with 14; and Malaysia 12 and Mexico 10 (Fig. 4). The most common scale of the studies was local, focusing on a single region within a country (95.56%; n = 172); four studies were national (2.22%); four were transnational, two were in America and one was in Asia; and three were continental, encompassing America, Europe, Asia, and Africa (2.22%). Thirteen biomes were represented, with Tropical and Subtropical Moist Broadleaf Forests accounting for 47.16% (n = 83), Tropical and Subtropical Grasslands, Savannas, and Shrublands accounting for 17.06% (n = 30), Temperate Broadleaf and Mixed Forests accounting for 12.50% (n = 22), and Mediterranean Forests, Woodlands, and Scrub accounting for 5.11% (n = 9).

Research topics were included 272 times, with the topics "Effects of anthropogenic activities on populations of medium and large terrestrial mammals in different environments" and "Effects of habitat, landscape, and fragment characteristics on populations of medium and large mammals" identified in 67 articles (24.63%) and 61 publications (22.43%), respectively. The "Distribution and occurrence of populations of medium and large terrestrial mammals in different environments, vegetation types, and land use" was the third most recorded topic (20.59%; n = 56); the topic "Current status of communities and/or populations of medium and large terrestrial mammals in different environments, habitat conditions, and protected natural areas (PNAs)" was the fourth most common topic (10.66%; n = 29); and the topic "climate change" was recorded in only 1.47% (n = 4) of the publications (see Fig. 5).

Fig. 1 Number of articles published per year



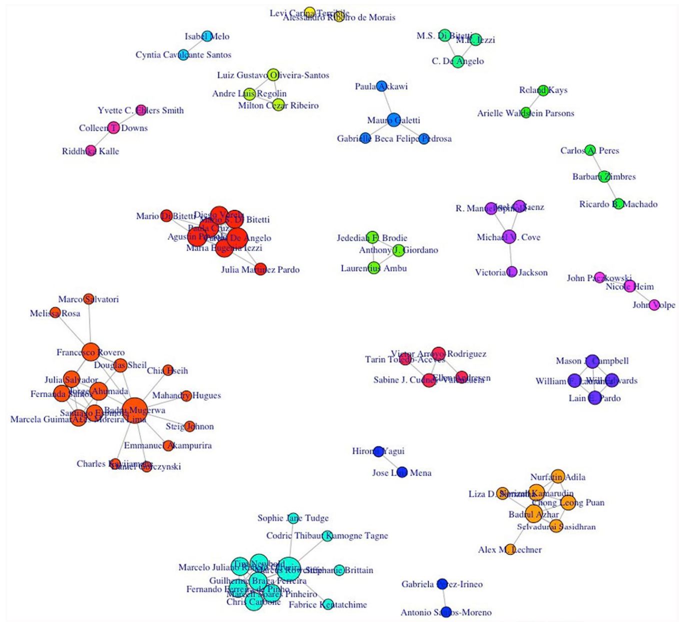


Fig. 2 Co-authorship network in studies of terrestrial mammals. Nodes represent individual authors, and connections indicate collaborations in publications. Colors identify different groups or clusters of collaboration

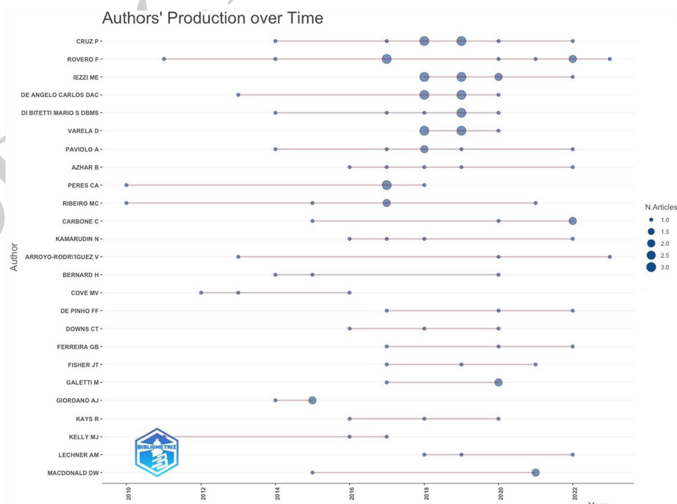
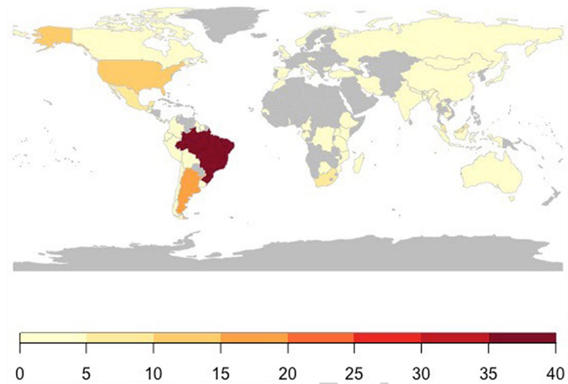


Fig. 3 Author productivity over time (2010–2023). The size of the circles represents the number of published articles (N.Articles), while the horizontal position indicates the year of publication

Fig. 4 Number of articles published by country



3.2 Study design and approach

Regarding species/community approach, 68.89% (n = 124) of the studies focused on the mammal community as a whole, while 15.00% (n = 27) targeted specific trophic guilds, primarily carnivores and herbivores. Additionally, 29 studies (16.11%) examined 40 individual species, with *Panthera onca*, *Vulpes vulpes*, and *Puma concolor* being the most frequently studied, each appearing in three studies. Camera traps were the predominant sampling method, employed exclusively in 90.00% (n = 162) of the studies, followed by a combination of camera traps and track searches in 7.22% (n = 13). Other methods, such as interviews, direct observations, and DNA sampling, were used in 2.77% (n = 5) of the studies. Research was conducted primarily at the landscape level (n = 140; 77.77%), with fewer studies focusing on the fragment level (n = 28; 15.56%) and the landscape fragmentation level (n = 12; 6.67%).

A total of 523 wild species and eight domestic species were recorded across the 180 studies analyzed. Twenty-five taxonomic orders were identified, with the most represented being Carnivora (31.45%, n = 167), Artiodactyla (19.77%, n = 105), Rodentia (14.88%, n = 79), and Primates (13.75%, n = 73). At the family level, the most frequently documented

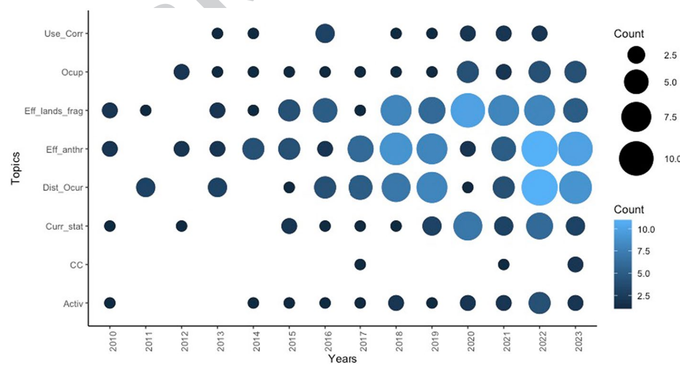


Fig. 5 Number of research topics recorded per year. Connectivity and use of biological corridors (Use_Corr), Factors influencing species occupancy in conserved and/or fragmented environments (Ocup), Effect of habitat, landscape, and fragment characteristics on populations of medium and large mammals (Eff_lands_frag), Effects of anthropogenic activities on populations of medium and large terrestrial mammals in different environments (Eff_anthr), Distribution and occurrence of populations of medium and large terrestrial mammals in different environments, vegetation types, and land use (Dist_Ocur), Current status of communities and/or populations of medium and large terrestrial mammals in different environments, habitat conditions, PNAs (Curr_stat), climate change (CC), activity patterns in different environments, habitats, landscapes, and/or fragments (Activ)

were Bovidae (11.68%, n = 62), Cercopithecidae and Sciuridae (both with 7.34%, n = 39), followed by Mustelidae (6.97%, n = 37) and Felidae (6.78%, n = 36) (Supplementary Material S3).

Species distribution varied by continent: the Americas recorded 169 species, Africa 178, and Asia 186. Among the 30 most frequently recorded species, 29 were found in the Americas, with *Mellivora capensis* being the only species native to another continent (Africa). The felids *Leopardus pardalis* and *P. concolor* were the most frequently reported species (Supplementary Figure S4a). In Africa, the most commonly recorded species were *M. capensis*, *Atilax paludinosus*, and *Potamochoerus larvatus*, while in Asia, the most frequently documented were *Sus scrofa*, *Prionailurus bengalensis*, and *Paradoxurus hermaphroditus* (Supplementary Figures S4b,c,d).

In terms of conservation status, only eight of the recorded species were not listed under any threat category according to the IUCN Red List. Asia had the highest number of species classified under some level of risk (180), followed by Africa (169) and the Americas (158). Nine species were classified as Critically Endangered (CR), while the majority (336 species) were listed as Least Concern (Fig. 6; Table 3).

3.3 Analysis metrics and variables

The response variables were presented 355 times in the articles and focused primarily on two of the eight response variables, species richness (28.45%, n = 101) and occupancy (25.63%, n = 91), which accounted for the highest number of records and have shown an increasing trend since 2016, followed by the abundance variable (12.39%, n = 44). The fourth response variable was community structure (9.86%, n = 35), whereas detection probability, diversity, activity patterns, and density were the variables with the lowest records, with values of 9.01% (n = 32), 7.89% (n = 28), 5.35% (n = 19), and 1.41% (n = 5), respectively (Fig. 7).

Landscape, fragmentation metrics, and detection covariates were integrated into the studies' analyses 808 times. Landscape metrics appeared 435 times, with "human disturbance" covariates, which include human activities, distances to settlements, population density, and hunting pressure, being mentioned 152 times, and "habitat amount", which includes the proportions of conserved and secondary vegetation cover, was mentioned 87 times (Fig. 6a). Patch metrics appeared in 202 instances, with the most important covariate being the "Matrix the patch," which includes counts of palms, trees, and shrubs, among others, with 101 mentions, followed by "Isolation", with 33 (Fig. 7a). The detection covariates appeared 153 times, with "Abiotic factors," which include altitude, temperature, precipitation, and season of the year, among others, mentioned 92 times, followed by "Interspecific relationships," which integrates the frequency of appearance and abundance of mammals (Fig. 8a).

Fig. 6 Sankey Diagram Showing the Relationship Between Families, Orders, Conservation Status, and Continental Distribution of Mammals

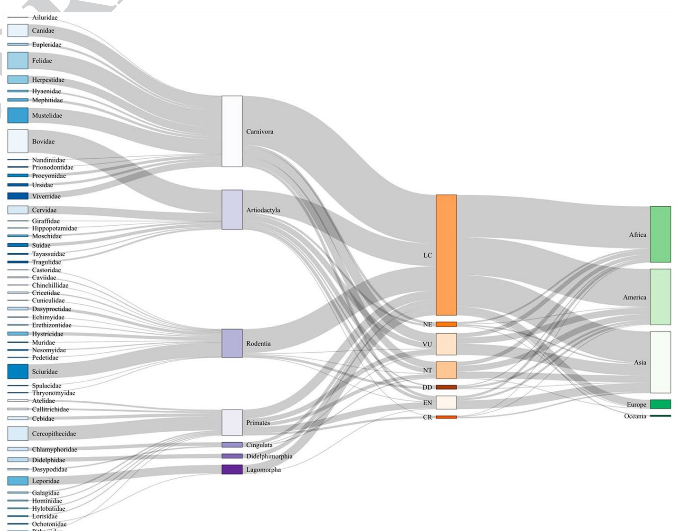


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Table 3 Distribution of Species by Conservation Status and Continent

	Africa	America	Asia	Europe	Oceania
CR	1	2	6	0	0
EN	9	9	27	0	0
VU	19	19	29	0	0
NT	14	18	18	1	1
LC	126	110	100	20	11
DD	3	6	2	0	0
NE	6	5	4	2	0

Some species were counted more than once, as they were recorded on more than one continent

CR Critically Endangered, *EN* Endangered, *VU* Vulnerable, *NT* Near Threatened, *LC* Last Concern; *DD* Data Deficient, *NE* Not Evaluated

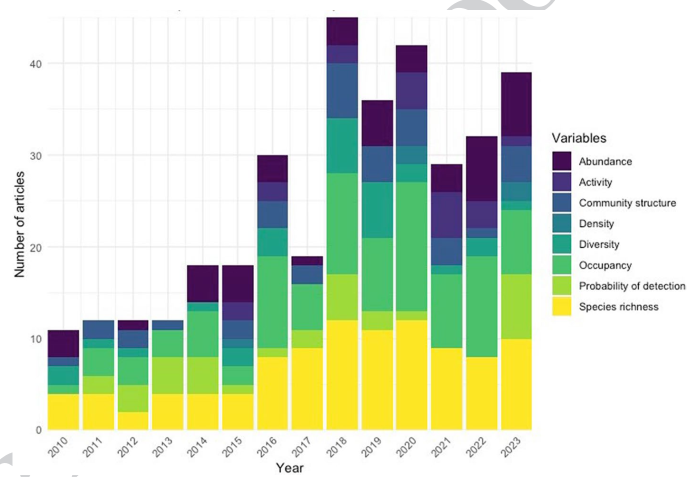

Fig. 7 Number of annual publications of the response variables on which the ecological objectives of the publications were based

Land use was defined based on the described location where the camera traps were placed to detect species, considering human activities and vegetation types. The studies focused on Native Forest (n = 142, 77.17%), which encompasses vegetation in its original state, followed by Grasslands (n = 86, 46.74%), Wetlands and Riparian Forests (n = 26, 14.13%), and Secondary Forests (n = 20, 10.87%) (Fig. 7b). Human activities included sites with agriculture (n = 78, 42.39%), in particular maize and rice cultivation, followed by monoculture plantations (n = 44, 23.91%), such as oil palm and forestry plantations such as pine and eucalyptus, and cattle pastures (n = 30, 16.30%) (Fig. 8b).

The published studies that conducted sampling within PNA accounted for 55.56% (n = 100), with no significant differences found compared with those conducted outside them ($X^2 = 2.222$, df = 1, p value = 0.136).

4 Discussion

4.1 General information

This review provides an overview of published articles addressing the effects of landscape and fragmentation on populations of medium- and large-sized terrestrial mammals, using camera traps as the primary sampling method. The analysis encompasses information on research topics, response variables, land use, and the most commonly evaluated landscape and fragmentation metrics; geographic coverage; species and guild focus; and study design details. This review

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Fig. 8 **a** Landscape metrics, fragmentation metrics and detection covariates that were integrated into the analyses in the research work. **b** Vegetation types and human activities where the samples were collected

underscores the importance of camera traps as a widely used and essential tool for assessing how habitat variables and the structure of both natural and anthropogenic landscapes influence the status, composition, distribution, and activity patterns of medium- and large-sized terrestrial mammal populations and communities [28, 36, 37].

4.2 Trends and contributions of camera trap studies to understanding landscape effects on mammals (2010–2023)

The results of this review reveal a increase in the use of camera traps as a primary tool for studying medium- and large-sized terrestrial mammals over the period analyzed. Among the 180 included studies, a temporal trend is observed, progressing through three phases: an initial establishment phase (2010–2013) with a modest but steady output, a development phase (2014–2017) with moderate growth, and a consolidation phase (2018–2023) during which 66.11% (n = 119) of studies were published. This growth has been largely driven by advances in camera trap technology—including miniaturization and improved image quality—along with lower costs, the development of specialized statistical packages, open-source software, geographic information systems (GIS), and access to satellite imagery and land-use maps, all of which have enhanced landscape-level analyses [26, 27, 38–40]. Methodologically, camera trap studies have shifted from basic descriptive metrics to more sophisticated analyses. While early research focused on species richness and relative abundance, recent years have seen a rise in the use of occupancy models (25.63%, n = 91) and community structure analyses (9.86%, n = 35), which incorporate imperfect detection and allow for more robust spatial inferences [26, 29]. Thematic trends show a similar progression. Earlier studies emphasized species distribution and occurrence (20.59%, n = 56), whereas more recent work increasingly evaluates the impacts of anthropogenic activities (24.63%, n = 67) and landscape characteristics and fragmentation (22.43%, n = 61), reflecting a growing alignment with conservation priorities [31].

The widespread adoption of camera trapping—used exclusively in 90.00% (n = 162) and as a complementary method in 7.22% (n = 13) of studies—is justified by its ability to detect elusive species, operate continuously in diverse ecosystems, minimize disturbance, and provide standardized data for multiple species [26]. These qualities have been especially valuable in tropical and subtropical regions, where 64.22% of the studies were conducted.

The diversity of publication platforms, including 72 journals, highlights the methodological acceptance of camera trapping across environmental sciences. Ten journals accounted for nearly half of the articles (46.67%, n = 84), with Biological Conservation (7.22%), PLOS ONE (6.67%), Mammalian Biology (6.11%), and Oryx (5.00%) among the most frequent. This distribution reflects the relevance of camera trap studies to conservation biology, landscape ecology, and related disciplines. Together, these trends demonstrate how camera traps have evolved from an emerging tool into a central method for studying landscape effects on mammalian biodiversity [29]. This methodological consolidation has increased both the quantity and quality of available scientific evidence, supporting more refined analyses and conservation planning in human-modified landscapes. The exclusive use of camera traps as the sole sampling method in 90% of the publications highlights the widespread adoption of this technique, as demonstrated in previous reviews documenting the adoption and growth of camera trap use in wildlife research [29, 41].

The bibliometric analysis of scientific production reveals a significant concentration of publications between 2015 and 2020, with prominent contributions from authors such as Di Bitetti, De Angelo, Paviolo, and Rovero, who have maintained consistent productivity. The co-authorship network highlights well-structured collaborative clusters, particularly in South America, Africa, and Asia, where strong regional institutional partnerships have formed. Examples include the South American group led by Di Bitetti and the East African cluster associated with Rovero. However, the network also reveals limited integration between regions, with weaker connectivity observed in Europe and Oceania, potentially reflecting both geographic underrepresentation and institutional or linguistic barriers. The presence of "bridge" authors, such as Rovero and Peres, underscores their strategic role in linking research efforts across continents. These findings emphasize the importance of strengthening international collaborations to enhance the geographic and taxonomic scope of mammal research, particularly in biodiversity-rich regions that remain underrepresented in the scientific literature. Promoting more inclusive and diverse scientific networks is essential to achieving a global understanding of mammal ecology and to informing comprehensive conservation strategies.

4.3 Content

In terms of the number of articles per continent and country, America, specifically South America (Brazil and Argentina), stands out for its scientific output. This contrasts with findings by [25, 27, 34] that North America has produced the most research, both to evaluate camera traps as a data collection tool and to understand trends in the use of landscape spatial metrics. The increase in publications in South America may be due to the reduction in equipment costs, access to information, and the formation of research networks. [29], in a study on trends in camera trap applications by thematic composition, taxonomy, and geography, reported the highest frequency of studies in South America, North America, Asia, and southern Africa, whereas the Middle East, western Australia, and northern Africa presented the lowest number of published articles, which aligns with the results of this study.

The preferred study environments identified were tropical and subtropical biomes, specifically Tropical and Subtropical Moist Broadleaf Forests and Tropical and Subtropical Grasslands, Savannas and Shrublands, which are found in North, Central, and South America; Central and Southern Africa; and Southern Asia. This preference is likely due to the high levels of endemism, habitat complexity, and mammalian richness in these biomes, as well as the significant threats they face from land-use changes due to human activities and climate change, which is supported by the high number of species recorded in Asia, Africa, and the Americas [42–44]. Therefore, it is imperative to continue generating knowledge on the dynamics and adaptations of terrestrial mammal populations in changing landscapes. Although some studies have conducted analyses across multiple continents and countries, most have focused on local studies, allowing for finer-scale analyses of landscapes and their components, since habitat disturbances generally occur at local levels; thus, generalizable patterns derived from coarse-scale metrics may not be applicable at finer scales [45].

The transformation, loss, and fragmentation of natural habitats by human activities are considered the greatest threats to biodiversity and significant causes of species extinction [19, 46]. Therefore, one of the main conservation challenges is understanding how wild species respond to the landscape matrix and land-use changes to ensure their survival over time and space [5, 8, 47]. In this context, it is not surprising that the main objectives addressed in the studies focused on evaluating the "Effects of anthropogenic activities on populations of medium and large terrestrial mammals in different environments," the "Effect of habitat, landscape, and fragment characteristics on populations of medium and large mammals," and the "Distribution and occurrence of populations of medium and large terrestrial mammals in different environments, vegetation types, and land use," seeking to understand how these factors influence variables such as richness, occupancy, abundance, diversity, and activity of mammals.

4.4 Study design and approach

One of the main advantages of camera traps is their ability to collect data that can be used to address multiple questions for multiple species [48]. The ability of camera traps to generate information on a wide spectrum of species in numerous habitats simultaneously allows the acquisition of robust data that provide insights into variables of interest such as

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species richness, diversity, occupancy, resource selection, habitat use, and activity patterns in the landscape, whether for focal species or species groups [21, 26, 40, 41, 49]. In this review, the 68.89% (n = 124) of the articles focused on multispecies studies aimed at protecting the biodiversity and communities of entire mammals, while some studies targeted groups, mainly carnivores, and fewer focused on specific species. Conservation efforts targeting multiple species are generally more efficient than single-species strategies, where the objective is to maintain biodiversity and ecosystem functions [50]. However, it is essential to consider that generalizing may be less effective in conserving a particular species or group than a specifically designed strategy, as the ability to protect viable populations can be achieved only through detailed population analyses. Therefore, it is crucial to consider conservation objectives, habitat selection, and whether the impact of human-induced stress factors varies significantly among species [51, 52]. Most focal species in the reviewed articles were indicator species, such as predators, mesopredators, and large mammals, which aligns with the findings of [27], who noted that these species are selected because of their extensive habitat area requirements, relatively low population densities, charismatic nature, and significant susceptibility to human influence; thus, their conservation benefits other species and habitats [53].

Mammal species richness is concentrated in tropical regions worldwide, as evidenced by the geographic distribution of the 523 wild species recorded in this study, highlighting the high biodiversity found in tropical and subtropical areas, with Asia (186 species) and Africa (178) leading in diversity, followed by the Americas (169) [54, 55]. In Asia and Africa, the high richness of orders such as Carnivora, Artiodactyla, and Rodentia is closely linked to the complexity of habitats like tropical rainforests and savannas. These ecosystems have served as key arenas for the diversification of large predators and herbivores, driven by the availability of trophic resources and the structural heterogeneity of the landscape. In Africa, for example, the evolutionary expansion of bovids (Artiodactyla) coincided with the evolution of spiny plants in eutrophic savannas, reflecting a coevolution between herbivores and plant defenses [56]. In contrast, the tropical forests of southern Asia have functioned as "cradles" of diversity for multiple orders, while arid savannas and steppes have fostered adaptations in Artiodactyla and rodents [57]. These patterns underscore how the interaction between geodiversity, climate, and ecological pressures (e.g., herbivory, competition) has shaped unique assemblages across both continents—Africa stands out for its megafauna adapted to open environments, whereas Asia harbors high functional diversity associated with altitudinal gradients and monsoonal regimes [57].

In the Americas, mammal species richness follows a distinct tropical pattern, with notable concentrations in the Neotropics, from southern Mexico to the Amazon Basin and the Andes, characterized by extraordinary phylogenetic and functional diversity [54, 58]. Environmental heterogeneity has promoted speciation, with the Amazon and the eastern slopes of the Andes acting as epicenters of diversity. Geological events such as the formation of the Isthmus of Panama facilitated the Great American Biotic Interchange, shaping current faunal composition through asymmetric migration and extinction events. Unlike Africa and Asia, which are renowned for their megafauna, the Americas stand out for hosting relict Gondwanan lineages such as the Microbiotheria marsupials, as well as unique historical processes such as the prolonged isolation of South America during the Cenozoic, which created a natural laboratory for mammalian diversification [55].

The predominance of species such as *L. pardalis*, *P. concolor*, *P. onca*, *Tapirus terrestris* and *Myrmecophaga tridactyla* reflects both the wide natural distribution of these taxa and the conservation efforts targeting keystone species within ecosystems, particularly top predators. This taxonomic prevalence can be attributed to regional ecological characteristics and evolutionary processes [59, 60]. The adaptability of many felid species with *Puma yagouaroundi* and generalist mammals with *Sus scrofa*, *Canis latrans* and *Procyon lotor* to fragmented landscapes has enabled their persistence in human-modified matrices, such as agricultural areas or forest edges [61–63].

The presence of clusters of threatened species is concentrated in regions experiencing high-impact human activities and, to some extent, follows species richness patterns. Threatened species are distributed across the globe, with the highest concentrations found in the tropical regions of the Americas, Africa, and Asia [64]. The high proportion of at-risk species in Asia (186), Africa (178) and the Americaa (169), including nine Critically Endangered (CR) species, underscores the urgency of implementing conservation strategies in landscapes transformed by human activities [44, 64]. The IUCN category analysis reveals an alarming scenario: nine species are classified as CR, 45 as Endangered (EN), and 67 as Vulnerable (VU), indicating that approximately 19% of the studied species face some level of threat. The geographic distribution of these species aligns with biodiversity hotspots under intense anthropogenic pressure, such as the tropical forests of Southeast Asia, the Amazon, and equatorial Africa.

The concentration of studies in the Americas and the limited representation of Europe (n = 7) and Oceania (n = 3) reveal significant geographic gaps that may underestimate the diversity and ecological responses of mammals in underrepresented regions. To address these limitations, future research should expand geographic and taxonomic coverage,

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integrate complementary methods, and evaluate the long-term responses of threatened species in human-modified landscapes.

4.5 Analysis metrics and variables

In a review for the estimation of abundance in unmarked animals, [65] reported that the main variables were relative abundance indices (RAI), followed by occupancy and, finally, species richness. In this review, most studies focused on estimating species richness, occupancy, and abundance variables. The analysis of these variables provides a basis for detecting population changes over time and space, thereby allowing for the testing of hypotheses about how wildlife mammal communities and populations respond to landscape modifications and human influence [31].

The concept of species richness, represented as the number of species in a given area and time period, is the most frequently employed measure of biodiversity, allowing for inferences about community structure. However, its measurement in extensive regions or with diverse taxa requires significant investment in sampling effort [66]. Unlike our results, [25], in a review of the use of camera traps in habitats, taxa, and study types, reported that studies on species richness constituted only 10%, although a growing trend was noted, similar to the trend observed by [26], which might be due to economic and rapid results. The metric was primarily used to compare community composition between sites impacted by human activities versus conserved sites or those under some conservation scheme and was estimated conjointly with occupancy and, second, with species abundance measurements.

Studies estimating occupancy have experienced growth associated with theoretical advancements in models for their implementation [29, 67], as reflected in the review, with an increase since 2015. Occupancy refers to the proportion of area, fragments, or sites occupied by a species, accounting for the detection probability over the estimates of species presence [68]. The results allowed inference of habitat use, landscape effects, and disturbances (e.g., logging, agriculture, livestock) at the level of a single species or community. Notably, one of the research topics identified in the articles was the estimation of factors influencing species occupancy in conserved and/or fragmented environments, with the goal of validating occupancy models.

The detection probability was presented as a response variable in 32 studies (17.78%), reflecting the increasing methodological sophistication in the field. This variable is essential for correcting inherent biases in occupancy and abundance studies, especially when camera traps are used [69]. The importance of detection probability lies in its ability to distinguish between the true absence of a species and non-detection due to methodological or environmental factors [70]. In our review, we observed that researchers frequently incorporated this variable into their occupancy and abundance models, indicating a widespread awareness of the importance of addressing imperfect detectability in wildlife studies. The increased use of detection probability as a response variable can be attributed to the development of more robust analytical frameworks, such as hierarchical occupancy and abundance models [71]. These models allow researchers to separate ecological processes (e.g., true occupancy or abundance) from observation processes (the probability of detecting a species when present). This separation is crucial for obtaining unbiased estimates of the parameters of interest and understanding how landscape factors affect not only species presence, but also our ability to detect them.

While camera traps have made significant technological advancements, one of their main limitations is the inability to identify unmarked individuals, making it difficult to ascertain whether multiple detections involve different individuals or the same one. This limitation complicates abundance estimation [65, 72]. Because of this methodological constraint, [26] note that many researchers opt to estimate occupancy models or relative abundance indices (RAI). In the reviewed articles, abundance referred primarily to the RAI calculation per species, which indicates the number of detections per 100 traps/days, assuming a positive linear relationship with local real abundance [37]. However, it is important to note that this index may be biased by variability in detectability, meaning that it does not always accurately reflect the real abundance of the studied species [69]. The RAI results were complemented with information on habitat preferences and landscape influences on medium and large terrestrial mammal populations and were used to infer differences in abundance between sites or fragments.

In terms of community structure, this response variable provides a more comprehensive view of how landscape attributes affect mammal communities as a whole beyond the specific responses of individual species. Our analysis revealed that researchers used this variable to examine how changes in the landscape alter species interactions, community composition, and trophic networks [73–75]. Community structure is typically evaluated via diversity indices, community similarity analyses, and multivariate ordination techniques [76, 77]. The focus on community structure reflects a shift toward a more holistic understanding of landscape ecology, with the recognition that species do not respond to habitat changes in isolation but rather are part of complex interaction networks [1, 78]. This approach is particularly valuable in the context of habitat fragmentation and land-use change, where impacts on one species can have cascading effects on the entire community [79].

In the case of the activity patterns variable, it referred to spatial concurrence and not the interaction between species (e.g. predator–prey) and was used to infer habitat preferences. On the other hand, with regard to the density variable, [25] in 414 papers from 1994 to 2011, found that the density variable was the most used, while in this review it was found only in four articles. This may be because with camera traps, density is primarily calculated for individuals with distinguishable markings [62], and most of the studies focused on the mammal community in general.

Natural environmental changes due to anthropogenic factors such as agriculture, livestock farming, pollution, and urbanization have affected up to 95% of the Earth's surface, directly impacting wildlife [80]. Therefore, a significant area of conservation research seeks to understand the influence of these factors on faunal species and predict responses to establish management strategies [45, 81].

Understanding how medium- and large terrestrial mammal species persist and adapt to modifications of natural habitats was the main conservation objective of the articles. Studies have shown that mammal species respond differently to anthropogenic landscape matrices [82]. In this context, surveys have been conducted in various types of ecosystems, vegetation, and anthropogenic disturbances, which are categorized into two groups: (a) native and secondary forests, and (b) areas impacted by human activities.

Native forests primarily include tropical rainforests, Atlantic forests, mangroves, deciduous and semideciduous forests, wetlands and riparian forests, encompassing savannahs, steppes, native grasslands, and prairies, which are considered threatened habitats due to human activities. Conservation efforts aim to gather information for their preservation [72–76]. Surveys in conserved and secondary forests were regularly conducted to compare mammal structure and abundance with those of sites subjected to human disturbances, as well as to understand how habitat remnants preserve mammal populations.

On the other hand, areas impacted by human activities refer primarily to those associated with agriculture involving monocultures, livestock farming, and urban zones. Research has focused mainly on oil palm, sugarcane, pine, and eucalyptus plantations; cattle ranching; and urban development, as these activities are considered the major causes of the conversion of natural habitats into anthropogenic landscapes [80, 82, 83, 86].

The articles generally highlighted the impact of anthropogenic landscapes on mammal species composition compared with native forests, showing that most species respond negatively and emphasizing the importance of conserving habitat remnants to maintain ecological processes [22, 88, 89]. Another relevant aspect was the documentation of the ecological flexibility of certain species to land-use change and those that are habitat specialists [90–92].

Landscapes are spatial mosaics of biophysical and socioeconomic components that interact, are compositionally diverse, and are spatially heterogeneous [93], influencing ecological processes and affecting species. Under this assumption, landscape metrics were adopted as components to explain these relationships [34]. Currently, hundreds of metrics are used to measure landscape patterns through many applications, but their use is not free from scrutiny [94]. These metrics are mainly classified into two categories: those that measure landscape composition and those that assess its spatial configuration, the latter being applicable both at the landscape and fragment scale. Researchers employing these metrics have focused on identifying the elements that influence mammal populations under different land use conditions, considering structural aspects that indicate spatial relationships (continuity and adjacency) between landscape elements (for example, forest fragments) and the functional aspect which refers to the landscape characteristics that facilitate or impede the movement of species between habitat patches [94].

The application of metrics to integrate them into analyses and contrast them with variables was highly diverse. The metrics most frequently used were those corresponding to human disturbances, incorporating those that, owing to productive or recreational human activities, limit or facilitate mammal movement. Most of the measurements of these metrics are based on distances calculated through geographic information systems (GIS), which are enabled by advances in computational technology; free access to satellite images with very high spatial, temporal, and spectral resolutions, which allows for the interpretation of complex datasets; the detection and monitoring of changes in vegetation and biodiversity over time; and the detection of rapid, large-scale changes [38–40].

Fragmentation is understood as a large expanse of habitat transformed into a series of smaller fragments of total area, which are isolated from each other by a matrix of habitats different from the original one [12]. Many studies have focused on analyzing habitat loss and fragmentation and their effects on species [16]. Currently, there is a scientific debate questioning whether the characteristics of the fragment (such as its size and isolation) are truly important as predictors of species richness, suggesting that these effects could simply be explained by total habitat loss in the landscape [13, 14, 16]. Owing to this situation, it is inferred that habitat quantity was the most commonly used landscape metric in

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analyses as a predictive covariate over those referring to fragments. A consideration for habitat-related metrics is that they must be well defined, considering that the spatial extent is appropriate for the species studied and the resolution at which the values are taken [94]. In most articles, metrics are calculated via remote sensing methods, not considering internal site aspects that are considered to complement the information and obtain more precise data when seeking to respond to landscape effects on mammal populations.

One of the most common measures for biodiversity protection is the creation of PNA, which serve as refuges for wildlife [82]. Approximately half of the studies aimed at evaluating mammal populations within PNAs intend to assess whether these wildlife refuges fulfill their function and to detect possible threats.

Finally, it is imperative to acknowledge the inherent limitations of this systematic review. Despite conducting an extensive search across multiple academic databases, it is plausible that relevant studies were inadvertently omitted. Notably, the methodological constraint of including only peer-reviewed articles published in English likely resulted in the exclusion of pertinent research disseminated in other languages, as well as studies published in specialized or regional journals with limited indexing in the selected databases. Furthermore, variability in terminology—whereby studies may have utilized alternative descriptors for analogous concepts—could have impeded comprehensive retrieval, particularly when key terms were absent from titles, abstracts, or keywords. Divergences in scientific nomenclature across geographic regions and academic traditions may have further contributed to these omissions.

A pronounced geographic bias was also identified, with a disproportionate concentration of studies originating from the Americas and Asia, whereas regions such as Europe, Oceania, the Middle East, and North Africa remain markedly underrepresented. This imbalance may constrain the global applicability of synthesized patterns and limit a holistic understanding of landscape effects across diverse biogeographic realms.

Additionally, substantial methodological heterogeneity was evident among the included studies, encompassing variations in experimental design, sampling duration, camera trap models and deployment densities, and the selection and application of landscape metrics. Such heterogeneity complicates direct cross-study comparisons and may have influenced the interpretation and synthesis of findings.

5 Conclusions

A increase in the volume of publications was documented over the past six years (2018–2024), alongside a broadening spectrum of journals disseminating these findings, indicative of an escalating scholarly interest in the impacts of landscape alterations on mammalian populations. This surge is largely attributable to technological advancements, notably in camera trap methodologies and the refinement of sophisticated analytical frameworks.

The recorded studies were primarily concentrated in South America, North America, and Asia, with particular emphasis on tropical and subtropical biomes. This distribution reflects both the rich biodiversity inherent to these regions and the urgent conservation needs driven by rapid landscape transformations.

Most studies focus on entire mammalian communities, providing a more comprehensive view of the landscape's effects on biodiversity. However, these findings underscore the need for more studies focused on individual species to better understand specific responses.

Among response variables, species richness, occupancy, and abundance were most frequently examined, furnishing pivotal insights into mammalian responses to habitat modifications. The progressive adoption of occupancy modeling reflects methodological advancements that incorporate imperfect detection, thereby bolstering the robustness and reliability of inferences. AQ3

Metrics associated with anthropogenic disturbances and habitat availability were identified as the most frequently addressed variables in the studies, highlighting the importance of integrating landscape composition and spatial configuration into conservation initiatives.

Collectively, this review highlights the pivotal influence of landscape attributes on medium- and large-sized terrestrial mammal populations. However, substantial knowledge deficits remain, particularly regarding long-term ecological effects, interspecific interactions, and responses to environmental drivers such as climate change.

Future studies should prioritize long-term research, expand geographic coverage to underrepresented regions, and incorporate interdisciplinary approaches that consider both ecological and socioeconomic drivers of landscape change. Additionally, it is crucial that future research translates into more effective conservation and landscape management strategies to protect mammalian biodiversity in an increasingly anthropized world. AQ4

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CAPÍTULO III

Camelot: Una herramienta intuitiva para el manejo y procesamiento de imágenes de cámaras trampa utilizando inteligencia artificial

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Camelot: Una herramienta intuitiva para el manejo y procesamiento de imágenes de cámaras trampa utilizando inteligencia artificial

Jenner Rodas-Trejo[1,*]

(1) Programa de Doctorado en Ciencias en Biodiversiad y Conservación de Ecosistemas Tropicales, Instituto de Ciencias Biológicas, Universidad de Ciencias y Artes de Chiapas, Tuxtla Gutiérrez, Chiapas, 29039, México. Escuela de Estudios Agropecuarios Mezcalapa, Universidad Autónoma de Chiapas, 29625, Copainalá, Chiapas, México.

Autora de correspondencia*: J. Rodas-Trejo [jenner.rodas@unach.mx]

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Las cámaras trampa son una herramienta ampliamente utilizada en la investigación de la fauna silvestre, ayudando a los científicos a responder preguntas ecológicas (Gómez et al. 2016). Las cámaras trampa generan una gran cantidad de imágenes, que resulta en grandes volúmenes de datos, planteando desafíos técnicos al procesarlos, requiriendo gran inversión de tiempo y esfuerzo (Tabak et al. 2022). En la actualidad, con el empleo de la Inteligencia Artificial, se ha transformado la forma en que se procesan imágenes (Schneider et al. 2020). Para ello, se han creado diferentes plataformas y programas que ofrecen herramientas para la gestión de imágenes, sintetización de información y generación de bases datos. Una herramienta interesante que ha integrado Inteligencia Artificial y cámaras trampa es el software Camelot. La finalidad de esta nota es mostrar la aplicación práctica de Camelot, destacando sus funcionalidades clave y utilidad, ilustrado a través de un caso de estudio enfocado en el análisis de riqueza, abundancia y Patrones de Actividad Diaria de mamíferos medianos y grandes.

¿Qué es Camelot?

Camelot es un software gratuito con una interfaz intuitiva que facilita la gestión de imágenes de cámaras trampa, ofreciendo un siguiente paso natural al filtrado automático de imágenes que ofrece la Inteligencia Artificial del modelo MegaDetector, y así agilizar el flujo de trabajo semi-automatizado en el filtrado de imágenes que contiene fauna o personas (Vélez et al. 2022).

Estructura y flujo de trabajo de Camelot

Para mostrar el flujo de trabajo de Camelot tomaremos como ejemplo un estudio sobre la diversidad mastofaunística en un Área Natural Protegida en el sur de México. En el estudio se colocaron 12 cámaras trampa en tres sitios con un total de 1368 días.

La raíz de estructura de datos de Camelot está comprendida por cuatro elementos base que contienen la información sobre el proyecto, sitios y estaciones de muestreo, datos de las cámaras trampa, metadatos de las imágenes y especies (**Fig. 1**).

1. **Información del proyecto (*Surveys*):** El primer paso es incluir nombre y descripción del proyecto. Posteriormente se configura el tiempo de independecia de registros de individuos de la misma especie (utilizamos 60 min), forma de identificar a las especies (nombre científico), además de campos de avistamiento que vienen de forma predeterminada como la forma para clasificar el sexo (Female, Male) y el estadío de vida (Adult, Juvenile). Es posible ingresar otros campos, como el nombre de individuos identificados por patrones de manchas.
2. **Sitios de muestreo (*Sites*):** Los sitios de muestreo representan las áreas donde se colocan las estaciones de muestreo y se establecen según criterios del investigador. Por ejemplo, en el caso de estudio se muestrearon dos sitios, en cada uno se colocaron seis estaciones de muestreo, uno en zona conservada del Área Natural Protegida (Conservado) y el otro en zonas ganaderas (Perturbado). En cada sitio se le colocó el nombre, localización, ciudad, estado, país y superficie comprendida.
3. **Cámaras trampa (*Cameras*):** En este apartado se integran el nombre (ejemplo, CT1, CT2), la marca y modelo de cada cámara trampa. Una o dos cámaras trampa ubicadas en un mismo lugar constituyen una estación de muestreo.
4. **Especies (*Species*):** Camelot a diferencia de otros programas no tiene integrada una base de datos de especies, por lo que los nombres científicos se agregan de forma manual. La base de datos ingresada puede ser utilizada en otros proyectos e ir agregando nuevas especies cuando sea necesario.

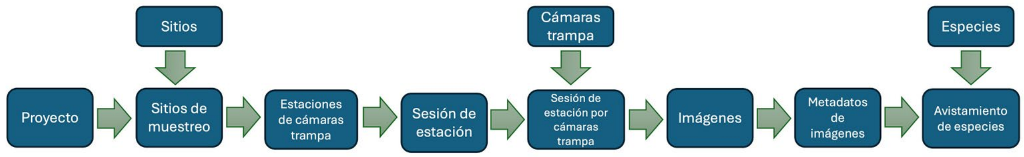


Figura 1. *Esquema de la estructura y flujo de trabajo de Camelot. La estructura se conforma por un Proyecto que contiene Sitios de muestreo, que incluyen la información de las cámaras trampa y el listado de especies. El flujo de trabajo inicia con información del Proyecto, luego se especifican los Sitios de muestreo que contienen la información de las Estaciones de cámaras trampa. En cada estación, se integran las Sesiones por cámara trampa, esto genera Imágenes que contienen los Metadatos de los Avistamientos de las especies.*

Figure 1. *Schematic of Camelot's structure and workflow. The structure is made up of a Project containing Sampling Sites, which include the camera trap information and the list of species. The workflow starts with the Project information, then the Sampling Sites containing the information from the Camera Trap Stations are specified. At each station, the Sessions per camera trap are integrated, this generates Images that contain the Metadata of the Sightings of the species.*

Con la información integrada en los cuatro elementos base, ingresamos en "*Manage camera trap stations*" y damos agregar cámara trampa (*Add camera trap*). En esta sección seleccionamos uno de los sitios (ejemplo, Conservado), nombramos a la estación de muestreo (ejemplo, C1), colocamos la fecha de inicio de actividad de la cámara trampa, las coordenadas de ubicación en decimales y la relacionamos con alguna de las cámaras trampa (ejemplo, CT1). Además, se puede ingresar información de altitud, distancia de colocación de la cámara trampa sobre el suelo, a caminos, ríos y a asentamientos humanos próximos, información que se utiliza para diferentes análisis (**Fig. 2**).

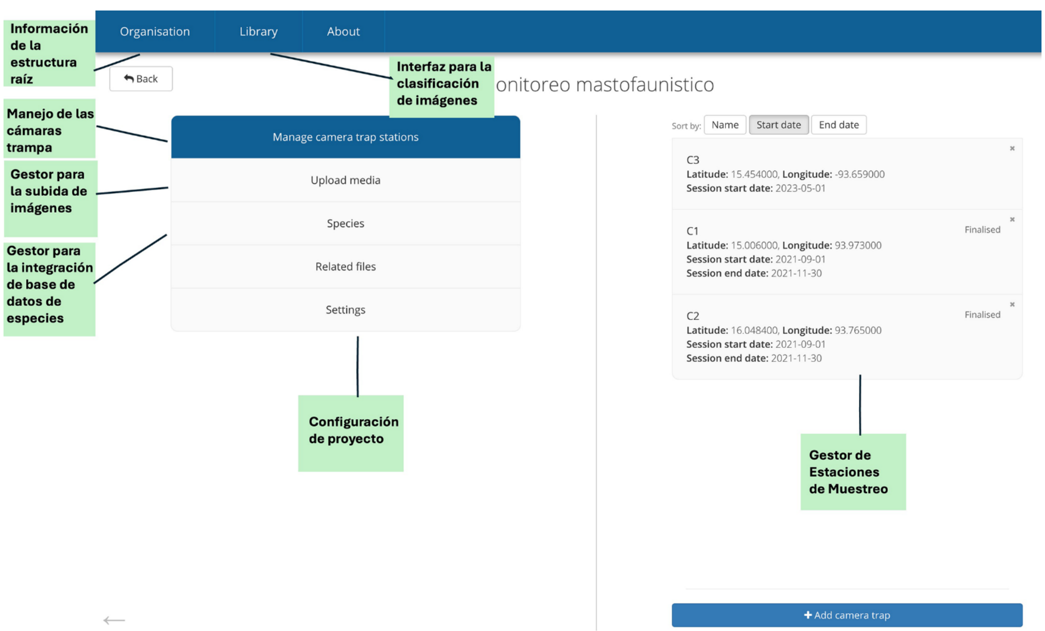


Figura 2. *Gestor para la integración de la base de datos de especies; Configuración de proyecto; Gestor de las Estaciones de muestreo; Interfaz para la clasificación de imágenes; Información de la estructura raíz; Manejo de las cámaras trampa; Gestor para la integración de la base de datos de especies.*

Figure 2. *Species database integration manager; Project configuration; Sampling stations manager; Image classification interface; Root structure information; Camera trap management; Species database integration manager.*

Para subir las imágenes a Camelot ingresamos a cada una de las estaciones de muestreo (ejemplo, C1), colocamos la fecha de recogida de la cámara trampa e ingresamos si fue retirada, perdida o si sigue activa en campo. En "*Upload media*" seleccionamos a la estación de muestreo y arrastramos las imágenes. En caso de haber un error, por ejemplo, que las fechas de muestreo de la cámara trampa no coincidan con los metadatos de las imágenes, el programa dará una advertencia. Camelot no presenta límite de cantidad de datos que puede admitir, y su rendimiento para la carga de imágenes y otras funciones depende de la memoria física de la computadora. Por ejemplo, para el manejo de 100 000 imágenes se requiere un mínimo de memoria física de 4096 MB.

Ya con las imágenes subidas nos trasladamos hacia *"Library"*. En esta interfaz se clasifican y etiquetan las imágenes. Seleccionamos el proyecto y la estación de muestreo. En cada imagen o grupos de imágenes se selecciona *"Identify selected"* y se agrega la información de la especie como el nombre científico, cantidad de individuos, sexo y estadío de vida (**Fig. 3**). Camelot permite la selección de varias fotografías a la vez para su identificación, lo que hace que el procesamiento sea más ágil y sencillo.

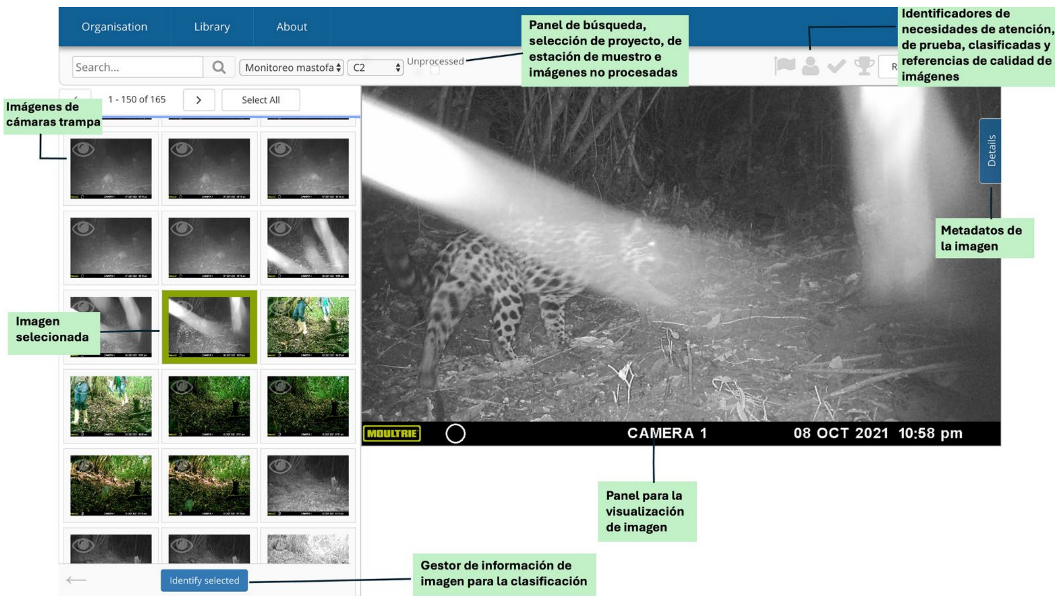


Figura 3. *Panel para la visualización de la imagen; Gestor de información de la imagen para la clasificación; Panel de búsqueda; Metadatos de la imagen, I'dentificadores de necesidades de atención, de prueba, clasificadas y referencia de calidad de imágenes.*

Figure 3. *Image display panel; Image information manager for classification; Search panel; Image metadata, care needs identifiers, test, classified and image quality reference.*

Informes analíticos

Camelot incluye un módulo analítico que proporciona informes con exportación de datos en archivos CSV. Por lo que, una vez finalizado el proceso de etiquetado, en la interfaz inicial se presiona "*Reports*", con lo que accedemos al menú que genera informes predeterminados entre los que se encuentran:

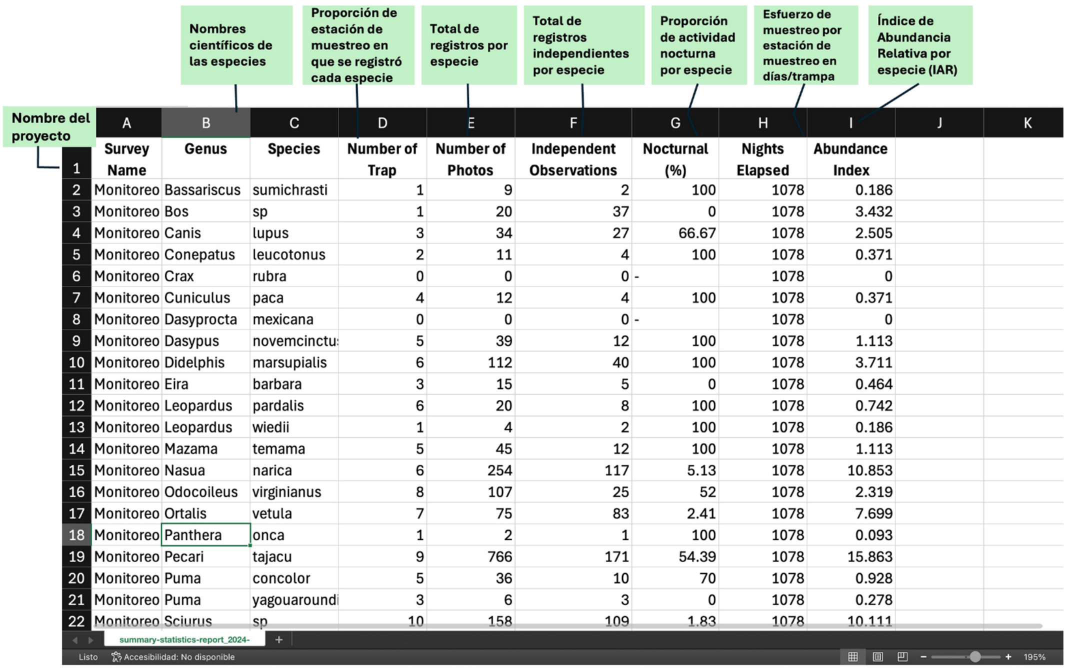
Matriz de detección para ajustar modelos de ocupación y con el programa PRESENCE (https://www.mbr-pwrc.usgs.gov/software/doc/presence/presence_doc.html)

Base de datos para trabajar con el paquete camtrapR de R (Niedballa et al. 2016).

Resúmenes estadísticos por proyecto, sitio, estación de muestreo, cámara trampa y especie

A diferencia de otros pogramas, Camelot no anida la información de los sitios de muestreo y cámaras trampa dentro del proyecto, lo que da flexibilidad a la hora de elegir variables relativas a la ocupación/abundancia de las especies y su detectabilidad.

En el caso del estudio, se requirieron los datos de abundancia, número de especies por estación de muestreo, sitio y proyecto, además de los horarios de actividad de especies con más de 50 registros. En "*Reports*" se descargó "*effort-summary-report*" que proporciona los datos de esfuerzo de muestreo en días/trampa y el número de especies diferentes registrada por sitio (Riqueza). Posteriormente se descargaron: "*summary-statistics-report*" que contiene información estadística de todo el proyecto y "*survey-site-statistics"* que contiene información estadística de cada sitio (**Fig 4**). En ambos reportes se pueden observar a nivel de proyecto, sitio o estación de muestreo las especies observadas, el número de estaciones y veces que fue registrada cada especie. Además, proporciona la información de la actividad nocturna, del esfuerzo de muestreo y el Índice de Abundancia Relativa (IAR) calculado como registros independientes/días-trampa*100.



	A	B	C	D	E	F	G	H	I
1	Survey Name	Genus	Species	Number of Trap	Number of Photos	Independent Observations	Nocturnal (%)	Nights Elapsed	Abundance Index
2	Monitoreo	Bassariscus	sumichrasti	1	9	2	100	1078	0.186
3	Monitoreo	Bos	sp	1	20	37	0	1078	3.432
4	Monitoreo	Canis	lupus	3	34	27	66.67	1078	2.505
5	Monitoreo	Conepatus	leucotonus	2	11	4	100	1078	0.371
6	Monitoreo	Crax	rubra	0	0	0	-	1078	0
7	Monitoreo	Cuniculus	paca	4	12	4	100	1078	0.371
8	Monitoreo	Dasyprocta	mexicana	0	0	0	-	1078	0
9	Monitoreo	Dasypus	novemcinctu	5	39	12	100	1078	1.113
10	Monitoreo	Didelphis	marsupialis	6	112	40	100	1078	3.711
11	Monitoreo	Eira	barbara	3	15	5	0	1078	0.464
12	Monitoreo	Leopardus	pardalis	6	20	8	100	1078	0.742
13	Monitoreo	Leopardus	wiedii	1	4	2	100	1078	0.186
14	Monitoreo	Mazama	temama	5	45	12	100	1078	1.113
15	Monitoreo	Nasua	narica	6	254	117	5.13	1078	10.853
16	Monitoreo	Odocoileus	virginianus	8	107	25	52	1078	2.319
17	Monitoreo	Ortalis	vetula	7	75	83	2.41	1078	7.699
18	Monitoreo	Panthera	onca	1	2	1	100	1078	0.093
19	Monitoreo	Pecari	tajacu	9	766	171	54.39	1078	15.863
20	Monitoreo	Puma	concolor	5	36	10	70	1078	0.928
21	Monitoreo	Puma	yagouaroundi	3	6	3	0	1078	0.278
22	Monitoreo	Sciurus	sp	10	158	109	1.83	1078	10.111

Figura 4*. Ejemplo de reporte final, que incluye datos clave para cada especie registrada. El reporte incluye nombres científicos, proporción de estaciones con registros, total de registros, registros independientes, actividad nocturna, esfuerzo de muestreo e índice de abundancia relativa (IAR).*

Figure 4. *Example of final report, including key data for each species recorded. The report includes scientific names, proportion of stations with records, total records, independent records, nocturnal activity, sampling effort, and relative abundance index (RAI).*

Para comparar los Patrones de Actividad Diaria entre dos especies de interés, se descarga el reporte "*CamtrapR Record Table*" y se realiza el análisis con el paquete camtrapR de R (Niedballa et al. 2016) (**Fig 5**). Como ejemplo seleccionamos las especies *Nasua narica* y *Pecari tajacu* que presentan más de 50 registros por lo cual utilizamos el estimador "Dhat4" (Meredith y Ridout 2021).

```
library(camtrapR)

Data_mam <- read.csv("record-table_2024-05-31_2008.csv", header = T)

#Se selecciona el reporte "CamtrapR Record Table" de Camelot y se carga al script

activityOverlap(recordTable = Data_mam, speciesA = "Pecari tajacu", speciesB = "Nasua narica", speciesCol = "Species", recordDateTimeCol = "DateTimeOriginal", recordDateTimeFormat = "ymd HMS", addLegend = TRUE, legendPosition = "topleft", pngMaxPix = 1000, add.rug = TRUE, overlapEstimator = c("Dhat4"))

#Se seleccionan al reporte y especies Pecari tajacu y Nasua narica, además del estimador "Dhat4" utilizado cuando ambas muestras son mayores a 50 registros
```

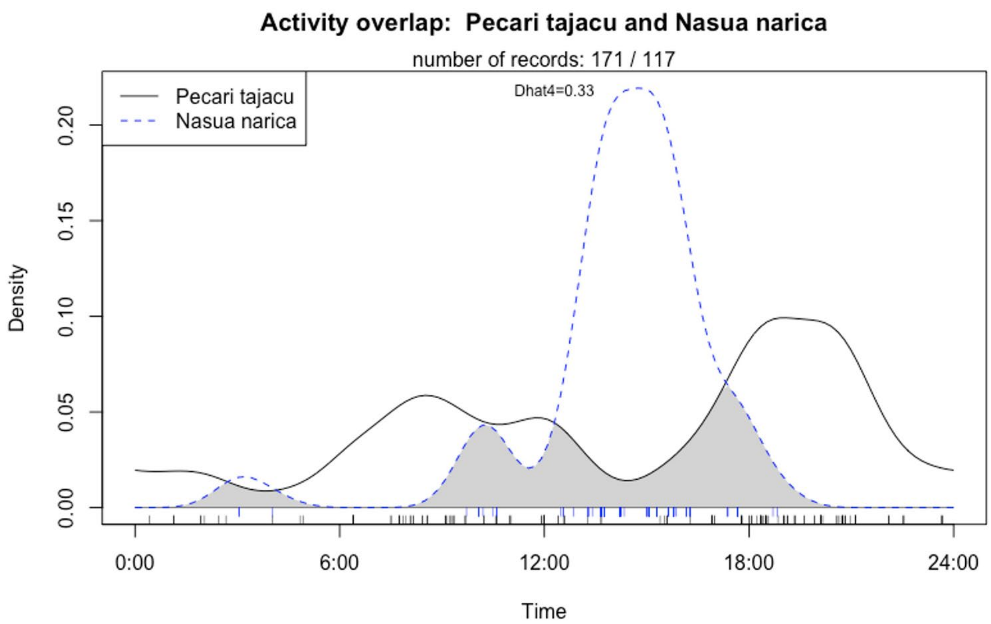


***Figura 5**. Ejemplo de superposición temporal de los patrones diarios de actividad para Nasua narica y Pecari tajacu. Se muestra la superposición temporal entre las especies que está representada por el área sombreada. El coeficiente de superposición (Dhat4) varía de "0" sin superposición a "1" con superposición completa.*

***Figure 5.** Example of temporal overlap of daily activity patterns for Nasua narica and Pecari tajacu. The temporal overlap between species is shown and is represented by the shaded area. The overlap coefficient (Dhat4) varies from "0" with no overlap to "1" with complete overlap.*

Desventajas

Entre las desventajas que presenta Camelot a diferencia de otras plataformas, es que no realiza directamente el reconocimiento de especies, ni encuadra al animal, ni genera informes personalizados para otros programas o paquetes de R como unmarked (Kellner et al. 2023) o spOccupancy (Doser et al. 2022). Además, la importación masiva de datos puede ser complicada para usuarios nuevos y algunas tareas, como la carga y búsqueda de imágenes, pueden volverse lentas a medida que aumenta el tamaño del conjunto de datos.

Finalizando

Camelot reduce notablemente el tiempo de etiquetado, preparación de bases datos y generación de reportes. Si bien no se ha evaluado el rendimiento de Camelot, el modelo MegaDetector (https://saul.cpsc.ucalgary.ca/timelapse/pmwiki.php?n=Main.DownloadMegadetector) que utiliza presenta un rendimiento entre el 87 al 99% en el filtrado de imágenes. En el ejemplo presentado y por experiencia en el uso de otros programas como Wild.ID (https://github.com/ConservationInternational/Wild.ID) y Timelapse2 (https://saul.cpsc.ucalgary.ca/timelapse/pmwiki.php?n=Main.Download2), Camelot redujo notablemente el tiempo de etiquetado y en la preparación de reportes para los análisis. Para más información sobre su uso se puede consultar https://camelot-project.readthedocs.io/en/latest/

Disponibilidad de datos

La revisión abierta de la nota está disponible en: https://github.com/ecoinfAEET/Notas_Ecosistemas/issues/55

Los datos y código asociados a la nota están en: https://github.com/Jennerodas/Ejemplo_Camelot

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CAPÍTULO IV

Evaluación del potencial de ChatGPT como herramienta innovadora en la búsqueda de información sobre mamíferos silvestres

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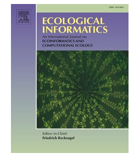

Assessment of ChatGPT's potential as an innovative tool in searching for information on wild mammals

Jenner Rodas-Trejo [a,b], Paola Ocampo-González [a,*]

[a] Universidad Autónoma de Chiapas, Escuela de Estudios Agropecuarios Mezcalapa, Carretera Chicoasén-Malpaso, km 24+300, Código postal 29625 Copainalá, Chiapas, Mexico

[b] Programa de Doctorado en Ciencias en Biodiversiad y Conservación de Ecosistemas Tropicales, Instituto de Ciencias Biológicas, Universidad de Ciencias y Artes de Chiapas, Libramiento Norte Poniente 1150, Colonia Lajas Maciel, Tuxtla Gutiérrez, Chiapas 29039, Mexico

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ABSTRACT

In November 2022 OpenAI launched ChatGPT, an Artificial Intelligence model capable of processing, retrieving, and organizing large amounts of data and identifying patterns, thereby generating text on various topics and contexts. In recent months ChatGPT has gained wide attention and adoption in the academic and scientific fields, so its use is being widely evaluated and discussed. In this connection, an evaluation of the performance of ChatGPT was carried out on the accuracy of the answers on general knowledge about wild mammals and the specific knowledge of 30 species. A descriptive study was carried out using three chats where twenty-one questions on general knowledge and three questions on specific knowledge were asked. The questions considered information on the taxonomy, natural history, and conservation status of each species, as well as concepts and indices commonly used in the study of wild mammals. The answers were compared with scientific literature and a value was assigned to later obtain the percentage of precision. The results showed a high precision in the specific knowledge of the species, with an average of 88 % correct answers. Precision varied by species, with species scoring close to 100 % and others scoring as low as 65 %. The taxonomy question had 100 % correct answers, the natural history questions 90 %, and the conservation status question 56 %. In the precision of the general knowledge answers in the study of wild mammals, a moderate precision of 73.54 % was obtained. The study shows that ChatGPT has high precision, so it can be a helpful tool in the search for information in research on wild mammals. On the other hand, concerns are raised about its applicability in the academic field, due to the risk of producing unreliable or biased results and generating inaccurate or misleading content, so it is important to take into account the limitations and risks associated with its use. It is suggested that further research and insight into accuracy be done to explore the full potential of ChatGPT.

1. Introduction

More than 6495 species of mammals have been identified in the world, of which approximately one-fifth are considered threatened or extinct for different reasons including habitat loss and degradation, hunting, climate change, pollution, and diseases (Bowyer et al., 2019; Burgin et al., 2018; Powers and Jetz, 2019). Therefore, the research and study of wild mammals constitutes a fundamental task to understand and preserve biological diversity in ecosystems (Safran et al., 2013). However, with the use of the Internet this task can be challenging due to the large amount of dispersed and constantly updated information. Currently, the use of Artificial Intelligence (AI) facilitates this work because large amounts of data can be quickly processed and patterns and relationships that may be difficult for humans to detect are identified (Kooli, 2023), providing new opportunities for the study of biodiversity, including research on wild mammals, such as the organization and identification of species recorded by photo-trapping (Leorna and Brinkman, 2022).

With the evolution of AI, a new era in chatbot-based education and research has been generated that is growing rapidly, having widespread adoption and considerable influence in academia, as new systems such as ChatGPT provide user interfaces that help to identify and extract relevant information to improve understanding (Morera, 2024), in this context, chatbots have emerged as a promising alternative to facilitate

* Corresponding author.
E-mail address: paola.ocampo@unach.mx (P. Ocampo-González).

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the obtaining and organization of knowledge (Zhai, 2023).

Since its public launch by OpenAI (OpenAI, L.L.C., San Francisco, CA, USA) in November 2022, ChatGPT has generated widespread attention, however, its application is associated with several challenges and limitations (Khan et al., 2023; Kooli, 2023; Sallam et al., 2023). ChatGPT is a type of AI applicability that uses deep learning techniques, the model represents a conversational chatbot that is trained on a vast corpus of text data based and developed on a type of neural network architecture, allowing it to understand and respond to a wide range of natural language input, adjusting to perform specific tasks, such as answering questions, translating languages, and generating text (Agathokleous et al., 2023; Rahman and Watanobe, 2023). Its ability to understand and respond to natural language input makes it a versatile tool that can be applied to various fields, such as education, ecology, medicine, among other science disciplines (Byeon and Kwon, 2023; Khan et al., 2023; Biswas, 2023), so in recent months works have been published seeking to evaluate the capabilities of ChatGPT (Hisan and Amri, 2023).

Among the benefits of the ChatGPT application in education and research, its function as an efficient translator in several languages that preserves the context of the translated text is mentioned, as well as its ability to generate reviews and summaries of literature, write programming codes and analyze large data sets (Sallam et al., 2023). Therefore, ChatGPT is currently being used by researchers in the summary, analysis, and generation of academic texts, in the detection of gaps in research, analysis of statistical data, in the discovery of new patterns, among other applications (Khan et al., 2023). Despite the benefits mentioned, there are concerns about the applicability of ChatGPT in academia that must be considered, such as the risk that it may be misused or manipulated to produce unreliable or biased results, perpetuate existing biases and discrimination in research and education, fraud in research, as well as producing misleading or inaccurate content (Kooli, 2023; Sallam et al., 2023).

Taking into account that the full potential of ChatGPT has not yet been explored and that growth in its potential is expected, as well as a significant increase in its use in the academic and research sector, in this paper, we present an evaluation of the potential and usefulness of ChatGPT as an innovative tool in the search for information on wild mammals and its performance in the accuracy of the answers in the general and specific knowledge of wild mammals. Likewise, the advantages and disadvantages that this tool presents in the study of mammals are analyzed.

2. Materials and methods

A descriptive study was conducted in June 2023 using ChatGPT (default model) from OpenAI (OpenAI, L.L.C., San Francisco, CA, USA) to answer specific questions of 30 species, and general questions and concepts about wild mammals to evaluate the accuracy of the answers. This work is assisted by an interactive interaction with ChatGPT and not another chatbot system since it is currently the system that has the most interest around the world (Hisan and Amri, 2023).

2.1. Species selection and classification

30 species of mammals with distribution in Mexico were arbitrarily selected, including wild terrestrial, flying, and aquatic mammals. The species were classified as "Moderately documented" and "Extensively documented" based on the number of bibliographic references that the search for each species in Google Scholar yielded. Species with more than 10,000 bibliographic references were classified as "Extensively documented" and those with fewer references as "Moderately documented" (Table 1). Taking into account that ChatGPT is a system designed for language processing tasks, serving as a search engine, answering questions, completing sentences, and generating specialized text in different disciplines (Agathokleous et al., 2023; Aljanabi and ChatGPT, 2023), two assumptions were generated in relation to the amount of information that exists on the Internet and can be used by ChatGPT to generate the answers: a).- that the more information that existed on a species, the greater the accuracy it would have in the answers b).- The more information, the less accuracy in the answers due to the dispersion of information.

Table 1
List of species by scientific name and common name, including classification based on a Google Scholar search for the number of articles in which the species appears (Extensively documented >10,000 and moderately documented ⟨10,000) and their risk category according to the International Union for Conservation of Nature (IUCN). LC = Least Concern; NT = Near Threatened; VU=Vulnerable; EN = Endangered; CR = Critically Endangered.

No	Specie	Common name	IUCN	Bibliographic references
1	*Panthera onca*	Jaguar	NT	Extensively documented
2	*Leopardus wiedii*	Margay	NT	Moderately documented
3	*Leopardus pardalis*	Ocelot	LC	Extensively documented
4	*Herpailurus yagouaroundi*	Jaguarundi	LC	Moderately documented
5	*Procyon lotor*	Northern Raccoon	LC	Extensively documented
6	*Canis latrans*	Coyote	LC	Extensively documented
7	*Urocyon cinereoargenteus*	Grey Fox	LC	Moderately documented
8	*Eira barbara*	Tayra	LC	Extensively documented
9	*Mustela frenata*	Long-tailed Weasel	LC	Moderately documented
10	*Dasyprocta mexicana*	Mexican Agouti	CR	Moderately documented
11	*Dasyprocta punctata*	Central American Agouti	LC	Moderately documented
12	*Tapirus bairdii*	Baird's Tapir	EN	Moderately documented
13	*Pecari tajacu*	Collared Peccary	LC	Extensively documented
14	*Tayassu pecari*	White-lipped Peccary	VU	Extensively documented
15	*Cuniculus paca*	Agouti	LC	Moderately documented
16	*Trichechus manatus*	Caribbean Manatee	VU	Extensively documented
17	*Lontra longicaudis*	Neotropical Otter	NT	Moderately documented
18	*Desmodus rotundus*	Vampire Bat	LC	Extensively documented
19	*Diphylla ecaudata*	Hairy-legged Vampire Bat	LC	Moderately documented
20	*Diaemus youngi*	White-winged vampire bat	LC	Moderately documented
21	*Artibeus jamaicensis*	Jamaican Fruit-eating Bat	LC	Moderately documented
22	*Leptonycteris yerbabuenae*	Lesser Long-nosed Bat	NT	Moderately documented
23	*Didelphis marsupialis*	Common opossum	LC	Extensively documented
24	*Alouatta pigra*	Yucatán Black Howler Monkey	EN	Moderately documented
25	*Odocoileus virginianus*	White-tailed deer	LC	Extensively documented
26	*Leptonycteris nivalis*	Greater Long-nosed Bat	EN	Moderately documented
27	*Coendou mexicanus*	Mexican tree porcupine	LC	Moderately documented
28	*Ursus americanus*	American black bear	LC	Extensively documented
29	*Bassariscus astutus*	Ringtail	LC	Moderately documented
30	*Didelphis virginiana*	Virginia opossum	LC	Extensively documented

To determine the level of knowledge according to their risk category, the species were grouped based on the IUCN classification (2022). It is expected that threatened species will score higher, as they are generally more extensively studied (Bird et al., 2020; Boakes et al., 2010).

2.2. Question implementation and use of ChatGPT

Twenty-one questions were formulated to evaluate general knowledge of wild mammals and three questions to evaluate specific knowledge for each species that covered the items taxonomy, natural history, and national and international protection status (Appendix A). The research steps and questions were predefined to avoid the influence of reading ChatGPT results.

The questions were asked in three independent chats with new accounts, on different computers and locations, using the website https://chat.openai.com on the free version 3.5 of the application, with a knowledge cutoff date of January 2022. The use of multiple computers aimed to evaluate the consistency of ChatGPT under different conditions.

In ChatGPT, a chat was opened to ask general questions about the study of wild mammals and a chat to ask questions for each of the 30 species. In each case, the same questions were asked on the three computers. The questions in the chat were asked using correct syntax and spelling to avoid confusion. To prevent updates from influencing ChatGPT's responses, the questions were asked on the same days. For the taxonomic classification of the species, we used the IUCN classification (2022). When the questions were correct but incomplete, ChatGPT was asked to expand the answer so that it could be evaluated.

Within the general knowledge questions, in the case of species with the same genus such as *Leopardus wiedii* and *Leopardus pardalis*; *Dasyprocta punctata* and *Dasyprocta mexicana*, as well as in species with similar feeding habits such as *Desmodus rotundus*, *Diphylla ecaudata*, and *Diaemus youngi*, ChatGPT was asked to indicate the morphological, geographical distribution, and dietary differences between them. To evaluate theoretical knowledge and the ability to apply specific methods and tools in the study of wild mammals, questions were posed related to concepts, methods, and analyses used in ecological research of wild mammals. These questions covered key aspects such as diversity, occupancy, activity patterns, and sampling design.

2.3. Evaluation of the answers

The answers were divided into general knowledge of wild mammals and specific knowledge by species, with 21 elements to be evaluated in general knowledge and 18 elements in knowledge by species (Table 2). A database was formulated for each one taking the correct answers obtained with the opinion of experts and with a review of literature and websites with precise specialized information on wild mammals such as Aranda (2012); Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (2023); The International Union

Table 2
Items, elements, and number of elements of general knowledge and knowledge by species into which the answers were divided.

Items general knowledge	Elements	Number of elements
Wild mammal species	Number of species in America Number of species in Mexico	2
Bat species	Number of species in Mexico	1
Wild cat species	Number and name of species in America Number and name of species in Mexico Names of the species of wild cats that exist in the American continent. Names of the species of wild cats that exist in Mexico.	4
Difference between Species	*Leopardus wiedii* and *Leopardus pardalis.* *Dasyprocta punctata* and *Dasyprocta mexicana.* *Desmodus rotundus*, *Diphylla ecaudata* and *Diaemus youngi*	7
Relative abundance, real abundance, sampling effort and its calculation in camera trapping	Relative abundance relative to true abundance and how it is calculated Sampling effort calculation	2
Alpha, beta and gamma diversity and diversity indices used in the study of wild mammals and	Differences between alpha, beta and gamma diversity Define diversity indices	2
Activity pattern of wild mammals	Calculation of the activity pattern of wild mammals and package used in R	1
Biodiversity analysis with vegan package	Biodiversity analysis with vegan package	1
Occupancy models	Occupancy models, how they are expressed in mathematical terms and assumptions of the occupancy models	1
Total		21

Items knowledge for each species	Elements	Number of elements
Taxonomy	Kingdom Phylum Class Order Family Genus Specie	7
Natural History	Common name Morphology Diet Habitat Behavior Geographical distribution Lifecycle Reproduction	8
National and international protection status	UICN CITES NOM-059-SEMARNAT-2010	3
Total		18

for Conservation of Nature's Red List of Threatened Species (IUCN) (2022); *GBIF Secretariat: GBIF Backbone Taxonomy* (2023), among others. They were subsequently compared with the answers given by ChatGPT (Appendix B).

The analysis of ChatGPT's responses regarding species-specific knowledge was based on a binary rating system, with "1" assigned to correct answers and "0" to incorrect ones, applied consistently to both extensive and concise questions.

Application by Question Type:

1. Taxonomy

- Evaluation of seven elements: Kingdom, Phylum, Class, Order, Family, Genus, and Species
- Each correct element: 1 point
- Maximum score: 7 points per species

2. Natural history

- Evaluation of eight elements: Common Name, Morphology, Diet, Habitat, Behavior, Geographic Distribution, Life Cycle, and Reproduction
- Score of "0" if there is an error in any part of the element
- Example:

Species: *Panthera onca.*
Correct common names: Jaguar, American Jaguar.
If "Ocelot" (incorrect) is mentioned, the score for this element is "0".

3. Conservation status

- Evaluation of three categories: IUCN, CITES, NOM-059-SEMARNAT-2019
- Each correct category: 1 point
- Example:

IUCN: "Near Threatened".
CITES: "Appendix I".
NOM-059-SEMARNAT-2019: "Subject to Special Protection".

This rating method allowed for an objective and consistent evaluation of ChatGPT's responses, encompassing detailed information such as taxonomy, precise data like conservation status, and extensive responses like natural history. The results were obtained by calculating the percentage of correct answers from the total of the three chats; for example, to have an accuracy of 100 % per species, 54 correct answers would be obtained (18*3). Subsequently, the results of the classification scores of the species with "Moderately documented" and "Extensively documented" information were compared with the non-parametric Wilcoxon test.

To evaluate general knowledge of wild mammals, if the answer was considered to be completely correct it was scored with "3", if the answer was considered to be almost correct it was scored with "2", when the answer was partially correct it was scored as "1", and "0" if the answer was completely incorrect, so each question could have a maximum of nine points. The scoring was based on the opinions of two mastozoologists and the number of errors in specific data.

The criteria for assigning scores to the responses were as follows:

1. Completely correct response (3 points)

- The response contains all the requested information.
- There are no factual errors.
- The information is accurate and up-to-date.

2. Almost correct response (2 points)

- The response contains most of the requested information.
- There may be minor errors or omissions that do not significantly impact the overall accuracy.
- At least 80 % of the provided information is correct.

3. Partially correct response (1 point)

- The response contains some correct elements but also significant errors or omissions.
- Between 40 % and 80 % of the provided information is correct.
- The response may be incomplete but still contains relevant and accurate information.

4. Incorrect response (0 points)

- The response contains serious errors or completely irrelevant information.
- Less than 40 % of the provided information is correct.
- The response does not address the question, provides misleading or outdated information.

For example, for the number and names of feline species inhabiting the Americas, "0" errors corresponded to "3" points, "1" error to "2" points, "3" errors to "1" point, and more than three errors to "0" points.

The general result was given from the percentage of the score obtained in all the answers, so to obtain 100 % a score of 189 must have been obtained (63 points multiplied by the three chats).

To establish a degree of accuracy for the responses, the percentages were classified into high, medium, and low precision. Percentages greater than 80 % were considered high, 60 % to 79 % medium, and less than 60 % low. To evaluate the coherence of responses in the three different chats, a Kruskal-Wallis test was conducted to determine if there were significant differences for the same question in species-specific knowledge and questions related to general knowledge of wild mammals. This, in turn, helped us validate the appropriate number of sessions needed to conduct the performance evaluation of ChatGPT.

3. Results

3.1. Accuracy in species-specific knowledge

A high accuracy was obtained with 88.27 % ± 6.97 in specific knowledge for all species, where the average score of correct answers per species was 47.67 ± 3.76, with a maximum of 53 and a minimum of 35 (Table 3). Twenty-six species presented a high accuracy, three species presented medium and one species presented low precision. One species obtained 98.15 % accuracy, 14 presented between 96.30 % and 90.74 %, eleven between 88.89 % and 81.48 %, three between 79.63 and 77.78 %, and one 64.81 %. Question one, referring to the taxonomy of the species, obtained a total of 100 % correct answers for the 30 species. Question two, referring to natural history, obtained 90.14 %. Question three, referring to the conservation status, was the lowest with 55.93 % correct answers.

The species classified as Moderately documented obtained an average accuracy in knowledge of 47.11 ± 3.10 correct answers with a maximum of 52 and a minimum of 42. Seven species obtained between 96.30 % and 90.74 % correct answers, seven species between 88.89 % and 81.48 %, and three species between 79.63 and 77.78 %. The species classified as Extensively documented obtained an average of 48.38 ± 4.52 correct answers with a maximum of 53 and a minimum of 35. One species obtained 98.15 % correct answers, seven between 96.30 % and 90.74, four between 88.89 % and 85.19 %, and one with 64.81 %. No statistically significant differences were found between the species classified as Moderately documented and Extensively documented by the number of articles in Google Scholar ($W = 74$, p-value $= 0.1166$).

Table 3
Results in percentage and score in accuracy in knowledge by species.

No	Specie	Species-specific knowledge accuracy (%)	Score
1	*Panthera onca*	98.15	53
2	*Procyon lotor*	96.30	52
3	*Urocyon cinereoargenteus*	96.30	52
4	*Didelphis virginiana*	96.30	52
5	*Canis latrans*	94.44	51
6	*Tapirus bairdii*	94.44	51
7	*Herpailurus yagouaroundi*	92.59	50
8	*Mustela frenata*	92.59	50
9	*Didelphis marsupialis*	92.59	50
10	*Leopardus wiedii*	90.74	49
11	*Leopardus pardalis*	90.74	49
12	*Eira barbara*	90.74	49
13	*Pecari tajacu*	90.74	49
14	*Lontra longicaudis*	90.74	49
15	*Leptonycteris yerbabuenae*	90.74	49
16	*Cuniculus paca*	88.89	48
17	*Desmodus rotundus*	88.89	48
18	*Odocoileus virginianus*	88.89	48
19	*Coendou mexicanus*	88.89	48
20	*Artibeus jamaicensis*	87.04	47
21	*Ursus americanus*	87.04	47
22	*Trichechus manatus manatus*	85.19	46
23	*Diphylla ecaudata*	85.19	46
24	*Bassariscus astutus*	85.19	46
25	*Leptonycteris nivalis*	83.33	45
26	*Diaemus youngi*	83.33	45
27	*Alouatta pigra*	79.63	43
28	*Dasyprocta mexicana*	77.78	42
29	*Dasyprocta punctata*	77.78	42
30	*Tayassu pecari*	64.81	35

3.2. General knowledge accuracy of wild mammals

A medium accuracy was obtained in general knowledge in the study of wild mammals with 73.54 % correct answers, since of the 189 answers, ChatGPT answered 139 correctly. The average score per question between the three chats was 6.62 ± 2.65. Only the question regarding the number of mammal species in the American continent did not obtain any score, while in nine questions all the answers given by ChatGPT were correct, obtaining the maximum score of 9 points. With respect to each response individually, nine presented high knowledge accuracy, four presented medium knowledge accuracy, and eight presented low knowledge accuracy.

3.3. Evaluation of species knowledge according to their risk category

The 30 species were placed into five risk categories: 20 species in Least Concern (LC), four in Near Threatened (NT), two in Vulnerable (VU), three in Endangered (EN), and one in Critically Endangered (CR). Three categories had high knowledge: NT (92.59 % ± 3.70; 50.00 ± 2.0), LC (89.63 % ± 4.86; 48.40 ± 2.62), and EN (85.80 % ± 7.71; 46.33 ± 4.16). Two categories had medium knowledge: CR (77.78 %; 42) and VU (75.00 % ± 14.40; 40.52 ± 7.78) (Table 4). The smallest number of bibliographic references were found in species with the highest risk.

3.4. Evaluation of response consistency across different sessions and devices

For the question related to taxonomy (C1), all three chats presented maximum average values relative to the maximum possible value ($n = 7$). For questions related to the natural history of species (C2; $n = 8$) and general knowledge of wild mammals (C4; n = 3), the difference between the average values relative to the maximum possible value was less than 1. For the national and international protection status (C3), the greatest difference was 1.4 relative to the maximum possible value ($n = 3$) (Fig. 1). No statistically significant differences were found between the three chats for each of the items: C1 (H = NaN; p = NA); C2 (H = 2.2088; $p = 0.3314$); C3 (H = 0.98197; $p = 0.612$); and C4 (H = 0.73839; $p = 0.6913$).

4. Discussion

Due to its ability to generate human-like text and answer complex questions, a few months after its release ChatGPT became one of the fastest growing and accepted applications in the history of the Internet (Frosolini et al., 2023). With the daily use of ChatGPT, developers have been taking advantage of the large amount of data generated in these interactions and have created language models closely adjusted to the language, tone, style, specific needs, and preferences of each user. This has allowed them to generate responses more personalized and precise in different disciplines (Aljanabi and ChatGPT, 2023). Currently there is a wide discussion about the use, scope, limitations, and applications of ChatGPT both in daily life and in education and academia, which is why the number of articles testing its efficiency has increased significantly in recent months (Frosolini et al., 2023; Mehnen et al., 2023).

Various studies have focused on testing the use of different chatbots, mainly ChatGPT, as a support tool in searching for specialized information and evaluating their efficiency and performance (Dhanvijay et al., 2023; Liu et al., 2023). Therefore, in the present study, we evaluated the potential and utility of ChatGPT as a tool for searching information about wild mammals and its performance in providing accurate responses on general and specific knowledge of wild mammals. The results generally revealed a good performance of ChatGPT in answering questions related to species-specific knowledge and general knowledge of wild mammals.

4.1. Accuracy in species-specific knowledge

ChatGPT presented high accuracy in species-specific knowledge with percentages greater than 80 % in 85 % of the species, showing a good understanding of the questions and optimal performance in the answers. The question related to taxonomy obtained 100 % of the total answers for the 30 species, this may be due to the fact that the taxonomic changes of the species are less variable and that there are international agreements in the classification of the species (Enghoff, 2009), so the variation and changes in the information is less. Although it was expected that question two, regarding natural history, would be the one that

Table 4
Results of the analysis on the accuracy of knowledge of wild mammal species, considering their IUCN risk category, frequency of bibliographic references, and species-specific knowledge accuracy. The distribution of the studied species across different risk categories is presented, along with the proportion of species classified as “Extensively documented” or “Moderately documented” based on the number of references in Google Scholar. Additionally, the scores obtained from ChatGPT responses, the average percentage accuracy, and the qualitative classification of accuracy (high, medium, low) are included.

Risk Category	Species	Extensively documented (%)	Moderately documented (%)	Score	Average (%)	Accuracy
LC	20	50	50	48.40 ± 2.62	89.63 ± 4.86	High
NT	4	25	75	50.00 ± 2.00	92.59 ± 3.70	High
VU	2	100	0	40.50 ± 7.78	75.00 ± 14.40	Medium
EN	3	0	100	46.33 ± 4.16	85.80 ± 7.71	High
CR	1	0	100	42.00	77.78	Medium

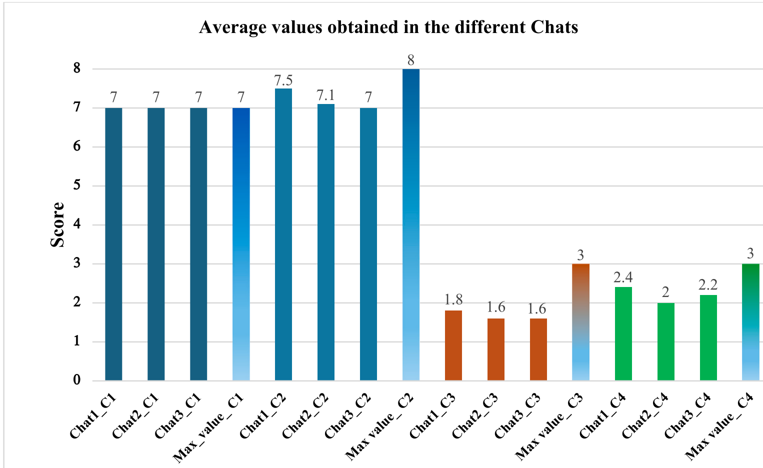

Fig. 1. This figure presents the average values and the maximum value for each of the three chats on questions about species-specific knowledge and general knowledge of wild mammals. C1, C2, C3, and C4 represent different items. C1 = Taxonomy; C2 = Natural history; C3 = National and international protection status; C4 = General knowledge. Chat1, Chat2, and Chat3 represent the different sessions and devices. Max_value = Maximum value that the item reaches.

presented the most errors due to the dispersion and greater amount of existing information, the weakness occurred in the question about the international and national conservation status of the 30 species, failing mainly in the Mexican national regulation where confusion occurred between the risk categories of NOM-059-SEMARNAT-2019 with the risk categories of the IUCN and a lack of information that ChatGPT itself recognized. This may be because the information in NOM-059-SEMARNAT-2019 is more specific and is presented in a document with an update to 2019 (SEMARNAT, 2019) with few references in scientific literature according to Google Scholar. Meanwhile, information on the natural history of the species is present in a large amount of specialized literature, on web pages, and is widely reported in articles. This fact demonstrates, on the one hand, that there is a high capacity to collect and summarize data efficiently by ChatGPT (Fatani, 2023), and on the other hand, that it presents certain flaws in the search for specific information (Mehnen et al., 2023).

The results indicate that there is no statistical difference between the number of bibliographic references consulted in Google Scholar and the accuracy of knowledge of the species, so in this case the ability of ChatGPT to respond correctly does not seem to depend on the number of bibliographic references, since it obtained more than 85 % accuracy in species with the highest and lowest number of bibliographic references, verifying its ability to summarize and discriminate information.

The errors presented in question two, which included the natural history of the species, were: a) confusion in common names of species, b) errors in geographical distribution in which countries and regions were omitted, or confused; c) mistakes in the description of morphology, specifically in the weight and body size of the species, in the measurement of wingspan in the case of bats, and in the differentiation between species or subspecies, d) discrepancies in gestation time, feeding habits, and population size in the case of bats. We consider most of the errors that occurred "normal" to a certain point, since they were in very specific data, where the information consulted for some species is varied, dispersed, confusing, and with constant updates. Another aspect to consider is the confusion that can occur between species, as occurred between the White-lipped Peccary (*Tayassu pecari*) and the Collared Peccary (*Pecari tajacu*), two species from the same family and with similar habits, in which ChatGPT mentioned aspects such as common name, morphology, habitat, and conservation status for the White-lipped Peccary with information from the Collared Peccary.

The risk classification of a species directly influences the available knowledge for each species, which is based on the number of published articles. Therefore, it was expected that there would be differences in the accuracy of species-specific knowledge according to their risk category (Bird et al., 2020; Cazalis et al., 2023). In this case, similar to the number of publications, the accuracy of species-specific knowledge in ChatGPT does not seem to depend on the risk category. However, it is important to note that this is not conclusive due to the difference in the number of selected species included in each category.

Since the quantity and quality of information available for a species vary based on several factors such as the taxonomic group they belong to, whether they are threatened, their risk category, geographic region, and whether they are in protected areas, among others (Boakes et al., 2010; Cazalis et al., 2023; Donaldson et al., 2017), it is necessary to conduct further studies to evaluate how these and other factors affect ChatGPT's ability to generate accurate responses about the knowledge of mammals.

4.2. General knowledge accuracy of wild mammals

ChatGPT presented a moderate accuracy in the general knowledge of wild mammals with 73.54 % correct answers, failing in particular questions such as those referring to the number and name of mammal species that live in America and Mexico, giving incorrect data, omitting or confusing species. This suggests certain failures of ChatGPT in the search for specific information, as mentioned by King (2023), that in its current state, sometimes the text generated by ChatGPT tends to contain incorrect statements. On the other hand, as presented in the accuracy in knowledge by species, ChatGPT demonstrated great ability to analyze and summarize specific information that can be confusing, by correctly indicating morphological, geographical, behavioral, and feeding habits differences between species of the same genus, such as the case of *Leopardus wiedii* with *Leopardus pardalis*, and between species of hematophagous bats. Hence the need to know the way in which chatbots collect and provide the information requested by users to know its origin and guarantee its reliability.

In specific questions about the definition of concepts used in the study of diversity such as alpha, beta, and gamma diversity concepts, calculation of the relative abundance index, as well as the definition of the concept of occupancy models and their expression in mathematical terms through their probability functions and assumptions in phototrapping studies, ChatGPT performance was remarkable with over 77 %

of the information correct. This suggests that ChatGPT can be used as a quick reference source; however, given that the information provided by ChatGPT is not always 100 % accurate, it should be verified and reviewed by the user before using it, to ensure the accuracy and reliability of the information (Aljanabi and ChatGPT, 2023; Kooli, 2023; Lubiana et al., 2023).

An outstanding aspect of the answers issued by ChatGPT was in relation to the mention and definition of the most used indices in diversity, as well as the description, use of packages, and generation of codes in R for the analysis of diversity and activity patterns of species, since in both cases 100 % correct answers were obtained. These results support what was mentioned by Lubiana et al. (2023), who highlighted the usefulness of ChatGPT in bioinformatics studies due to its ability to work with libraries in R; by building script logic, and making them more explicit by adding explanatory comments, renaming variables for clarity, and overcoming syntax challenges; in assisting in writing specific functions; suggesting new data visualization and presentation techniques.

4.3. Consistency and variability in ChatGPT's responses

The variability in ChatGPT's responses poses significant challenges for its consistency and reliability (Liang et al., 2024). This variability can be attributed to several key factors, including the quality and quantity of training data, the formulation of the question, and the context of the conversation (Dhanvijay et al., 2023; Nazir and Wang, 2023; Ray, 2023). Based on this, we sought to mitigate the variations in the responses provided by the model by using new accounts and the same version of the model on three different devices, and by formulating identical questions.

The variability was observed in how ChatGPT presented the text in the responses, as ChatGPT sometimes varied the responses to the same questions between chats, both in content and in the way the information was delivered, which can lead to inconsistency in the presentation of answers and potentially cause confusion (Tenhundfeld and ChatGPT, 2023). While the way that ChatGPT presented responses varied, the accuracy and inaccuracies of the answers were consistent, as seen by the comparable ratings that all three chats displayed across the board (Fig. 1). This consistency is comparable to what was found in a study assessing how well ChatGPT 3.5, ChatGPT 4, and Bard models performed when solving mathematical problems. There, both ChatGPT models generated comparable answers for the same problems throughout three separate sessions (Plevris et al., 2023). Likewise, a study assessing ChatGPT's legitimacy discovered that ChatGPT 3.5 and ChatGPT 4 produced replies that were consistent (Elkhatat, 2023).

In a conversation with ChatGPT, the model interprets the input, applies its learnt patterns, and produces a response based on its comprehension of the text. The response is produced by taking a sample from a probability distribution throughout the potential word vocabulary; thus, the responses' forms can vary (Wang et al., 2023). Furthermore, the responses produced by ChatGPT are largely dependent on the training data because the model lacks real-time access to the internet and current events, and its expertise and information are derived from the data it was trained with (Nazir and Wang, 2023; Plevris et al., 2023). These two characteristics of the model can explain why ChatGPT varied in the responses but was consistent in the information presented. Our results do not ensure that ChatGPT is consistent in presenting responses across multiple devices, so it is necessary to conduct studies increasing the number of devices and sessions, as well as to evaluate the effect of factors influencing response variability, such as asking the same question with different contexts.

Among the disadvantages mentioned in the literature is the ability of ChatGPT to give erroneous information when it does not have the information or when asking for data after the training cut-off date, since this limits its answers and tends to make up information or give inaccurate information (Asirvatham and Asirvatham, 2024; Thirunavukarasu et al., 2023). This could be corroborated in questions such as the international and national conservation status of the 30 species and in questions about the natural history of wild mammals, where ChatGPT gave erroneous or made up data, rarely stating that it did not have the information. In general, a chatbot rarely admits it does not know the answer and does not express confidence in its solution (Plevris et al., 2023). Therefore, continuously improving the training data is essential to increase the model's consistency. ChatGPT's lack of knowledge on certain topics can be solved by allowing it to consult information on the Internet, just as other chatbot models (Asirvatham and Asirvatham, 2024).

As a consideration in the use of ChatGPT, we must take into account the way in which the questions are asked since the answer and the way in which ChatGPT processes and delivers the information will depend on that, since by providing more context, details, and specific objectives, a more precise answer is more likely to be generated (Lubiana et al., 2023). The formulation of the question, including its clarity and context, significantly impacts the variability of ChatGPT's responses. Ambiguous or broad questions generate inconsistent responses, while specific and well-structured questions produce more precise and coherent answers (Lecler et al., 2023; Ray, 2023). The lack of context when presenting the questions, along with using a new account, could have affected the responses provided. When making inquiries to ChatGPT from a new account or in the absence of prior conversational context, the responses may be more generic or less tailored to the specific topic (Nazir and Wang, 2023). Therefore, it is recommended that information obtained from ChatGPT be always corroborated by reliable sources.

4.4. Considerations, advantages, and disadvantages of using ChatGPT as a tool in the search for information on wild mammals

Thanks to the Internet, today there is greater spread and access to specialized information, which has allowed substantial progress in science. It is enough to type a topic in academic search engines for hundreds or thousands of results to be generated. Although this represents an advantage, in many cases the search and concentration of information on a topic becomes difficult, which is why ChatGPT appears as a possible solution to this problem, since the use of ChatGPT is recognized in the efforts to collect and summarize data efficiently (Rahman and Watanobe, 2023).

One of the biggest disadvantages found is the lack of bibliographic references in the information provided by ChatGPT, which is why many authors have included ChatGPT as author or co-author of information (Hisan and Amri, 2023). However, because ChatGPT generates responses through a variety of data sources with which it was trained, credit should be given to the authors, so failure to cite the information sources runs the risk of cheating and plagiarism in the use of information (Frosolini et al., 2023). Likewise, it is mentioned that ChatGPT generates completely fictitious bibliographic references or has errors in authorship or year of publication, deceiving those who consult the information by giving missing or wrong references (Spennemann, 2023).

Among the advantages found in the use of ChatGPT in the search for information on wild mammals, we can mention that there is a notable performance in the correct answers obtained in the present work, showing the ability to extract, analyze, and summarize large amounts of information that on many occasions might be confusing or difficult to obtain. Considering its usefulness in quickly obtaining accurate information mainly on species and concepts used in the study of mammals, ChatGPT makes time and human effort more efficient, and can replace traditional information search engines. Chatbots such as ChatGPT can represent a valuable tool in ecological research, as they can be trained with specific information about ecology and can be useful in simplifying scientific texts, streamlining processes, assisting in decision making, providing new tools and techniques to analyze and simulate ecological systems that favor the generation of new knowledge, and can be used as a support instrument for the learning of concepts and the execution of research in biological education (Byeon and Kwon, 2023; Haghighi et al., 2023; Morera, 2024).

5. Conclusions

The results obtained in both the accuracy of species-specific knowledge and the accuracy of general knowledge of wild mammals by ChatGPT indicate that ChatGPT can be used in the study and research of wild mammals as a complementary tool in the search and analysis of relevant information providing a quick and accessible source of scientific information.

It is important to consider the limitations of ChatGPT, such as its dependence on the information available up to the date of its training and the possibility of providing incorrect or incomplete answers, also, and very importantly, the lack of bibliographic references. Thus, caution is required when using this technology, since its accuracy may vary depending on the subject and the availability of data with which it was trained. Therefore, it is recommended to use ChatGPT as a complementary tool, always verifying the accuracy of its answers with reliable and specialized sources. Likewise, it is important to take into account the ethical aspects in the use of the information provided by ChatGPT.

Although ChatGPT has some limitations, its ability to provide accurate and detailed information is notable, which is why it shows to be a promising tool in the search for information on wild mammals. Its ability to provide accurate answers in knowledge by species can be very useful in species identification, taxonomic research, and basic information gathering. Furthermore, the ability to ask multiple questions in different chats and get quick and accessible answers makes it a convenient and efficient tool in terms of human effort, replacing traditional information seekers.

The information on various aspects of the ecology, conservation, and natural history of wild mammal species generated by ChatGPT does not seem to depend on the amount of scientific information that exists about each of them; however, it is necessary to know the sources and the way in which ChatGPT processes the answers to guarantee their veracity and give corresponding credits to the researchers who generate the information with which ChatGPT is trained.

Collaboration between wild mammal experts and AI developers is critical to improve the accuracy and reliability of ChatGPT. Constant feedback and updating the model with new data and scientific findings are necessary to ensure its usefulness and relevance in the field of study.

This work is based on the information generated by ChatGPT in version 3.5, which is limited by the ability to generate answers to the training date, so it is important to evaluate the paid version ChatGPT-4 or other chatbots that have the quality of searching for current information on the Internet.

Finally, this study provides an initial assessment of the accuracy of ChatGPT in general and species-specific knowledge of wild mammals. These results lay the foundations for future research that will optimize the use of this tool in the study of biodiversity, thus contributing to the conservation, generation of knowledge, and effective management of wild mammals.

Author contributions

All authors made equal contributions to this work, and the manuscript underwent review by each of them.

CRediT authorship contribution statement

Jenner Rodas-Trejo: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Paola Ocampo-González:** Writing – review & editing, Investigation.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (default model) from OpenAI (OpenAI, L.L.C., San Francisco, CA, USA) in order only to answer general and specific questions about wild mammals as part of the methodology of this paper to assess the accuracy of responses generated by this tool, therefore, were not edited.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data can be accessed in the Supporting Information section. The data and the codes created in the research are available at: https://github.com/Jennerodas/mammals_ChatGPT/tree/main

Appendix A. Prompts

Prompts used to evaluate species-specific knowledge and general knowledge of wild mammals in ChatGPT.

General questions

1. How many species of mammals exist in the American continent?
2. How many species of mammals exist in Mexico?
3. How many species of bats exist in Mexico?
4. How many species of wild cats exist in the American continent?
5. How many species of wild cats exist in Mexico?
6. Tell me the names of the species of wild cats that exist in the American continent.
7. Tell me the names of the species of wild cats that exist in Mexico.
8. Tell me what are the morphological differences between *Leopardus wiedii* and *Leopardus pardalis*.
9. Tell me what are the differences in behavior between *Leopardus wiedii* and *Leopardus pardalis*.
10. Tell me what are the morphological differences between *Dasyprocta punctata* and *Dasyprocta mexicana*.
11. Tell me the differences in geographic distribution between *Dasyprocta punctata* and *Dasyprocta mexicana*.
12. Tell me what are the morphological differences between *Desmodus rotundus*, *Diphylla ecaudata* and *Diaemus youngi*.
13. Tell me what are the differences in feeding habitat between *Desmodus rotundus*, *Diphylla ecaudata* and *Diaemus youngi*.
14. Tell me the differences in geographic distribution between *Desmodus rotundus*, *Diphylla ecaudata* and *Diaemus youngi*.
15. What is the relative abundance of species, what relationship does it have with their real abundance and how is it calculated in a study carried out through camera traps?
16. How is the sampling effort calculated in a population study of wild mammals carried out through camera traps?
17. What is it and what are the differences between alpha, beta and gamma diversity? Give an example of each in a community of wild mammals.
18. Mention and define the most widely used indices of diversity in the study of wild mammals and give an example of each one.
19. How is the activity pattern of wild mammals calculated in a study of camera traps in R, what is the package used, what data should be taken and write me a code
20. What Biodiversity Analysis can be performed with the R vegan package
21. It explains what occupancy models are, how they are expressed in mathematical terms through their probability functions, and

what are the assumptions of occupancy models for a study of wild mammals through camera trap sampling.

Questions by species (18 elements)

1. Tell me the taxonomy of *Panthera onca* including Kingdom, Phylum, Class, Order, Family, Genus and Species (seven elements).
2. Tell me the natural history of *Panthera onca* including Common Names, Morphology, Diet, Habitat, Behavior, Geographic Distribution, Life Cycle and Reproduction (eight elements).
3. Tell me the protection status of *Panthera onca* that includes IUCN, CITES and NOM-059-SEMARNAT-2019 (three elements).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoinf.2024.102810.

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CAPÍTULO V

Evaluación de los efectos de los atributos del paisaje en la riqueza de mamíferos terrestres medianos y grandes dentro de una Reserva de la Biosfera de Bosque Tropical

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RESEARCH

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Assessing the effects of landscape attributes in medium and large terrestrial mammal richness inside a tropical rainforest biosphere reserve

Jenner Rodas-Trejo · María Gómez-Tolosa · Eduardo J. Naranjo · Sergio López

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Abstract The landscape's structure significantly impacts how communities assemble due to the environment filtering and the limitation of dispersal processes. Human activities can enhance or alter these factors, resulting in changing environments and isolated animal populations. In studying this, we used 39 camera trap stations during 102 continuous days in preserved and disturbed areas to assess medium and large terrestrial mammals in the Selva El Ocote Biosphere Reserve in Chiapas, Mexico (REBISO). We identified various groups of mammals and the factors influencing their presence and distribution through VIF, Clustering, RDA, NDMS, ANOSIM multivariate, and niche decomposition (OMI) analyses. The redundancy analysis (RDA) indicated that the most significant variables were altitude, distance to main roads and settlements, and forest cover. The optimal multivariate indicator (OMI) analysis accounted for 88.75% of the variability in niche structure. It revealed that *Puma concolor* exhibited the highest level of specialization (marginality = 2.96), while *Nasua narica* displayed the most generalist behavior (marginality = 0.26). Natural elements and human impact played a crucial role in the species' distribution, resulting in patterns in two distinct conditions: one characterized by preserved natural environments and the other affected by significant human impact. Notably, 63% of the species were common in both regions. For instance, *Cuniculus paca* positively correlated with distance to main roads and altitude, whereas *Leopardus pardalis* negatively responded to proximity to settlements. This study emphasizes the importance of maintaining habitat connectivity to preserve terrestrial mammal species.

Keywords Connectivity · Environment conservation · Species distribution · Mammal assemblages · Human impact · Landscape metrics · Selva El Ocote Biosphere Reserve

J. Rodas-Trejo
Programa de Doctorado en Ciencias en Biodiversidad y Conservación de Ecosistemas Tropicales, Instituto de Ciencias Biológicas, Universidad de Ciencias y Artes de Chiapas, Libramiento Norte Poniente 1150, C.P. 29039 Tuxtla Gutiérrez, Chiapas, México
e-mail: jenner.rodast@e.unicach.mx

M. Gómez-Tolosa
Instituto de Ciencias Biologicas, Universidad de Ciencias y Artes de Chiapas, Libramiento Norte Poniente 1150, C.P. 29039 Tuxtla Gutiérrez, Chiapas, México
e-mail: malugomeztolosa@gmail.com

E. J. Naranjo
Departamento de Conservación de La Biodiversidad, El Colegio de La Frontera Sur, Carretera Panamericana y Periférico Sur S/N, Barrio de María Auxiliadora, San Cristóbal de Las Casas, C.P. 29290 Chiapas, México
e-mail: enaranjo@ecosur.mx

S. López (✉)
Laboratorio de Ecología Evolutiva, Instituto de Ciencias Biológicas, Libramiento Norte Poniente 1150, C.P. 29039 Tuxtla Gutiérrez, Chiapas, México
e-mail: sergio.lopez@unicach.mx

Introduction

According to the known population trends of mammals, over half of the species are presently experiencing a decline (Brodie et al., 2021). The decline of large wildlife is happening both locally and globally. This reduction significantly affects numerous ecosystem processes and services, highlighting the intricate web of life we are a part of. The impact of this selective removal of animals based on their size can create a domino effect on the ecosystems (Young et al., 2014). Most nations worldwide acknowledge that human activities are causing the degradation of the Earth's ecosystems and the extinction of genes, species, and biological functions at an alarming rate. This realization raised concerns about the impact of reduced biological diversity on ecosystem performance and their ability to supply the goods and services necessary for human well-being (Cardinale et al., 2012).

Svenning et al. (2024) demonstrated that only 11 out of 57 species of megaherbivores (mean body mass ≥ 1000 kg) survived through 1000 AD, and now, these species are endangered again (Young et al., 2015). Growing human populations and the consequent demand for natural resources have severely affected biodiversity. The conversion of large land areas for human use has resulted in many natural environments being included in these areas. Land use changes, particularly driven by agricultural and urbanization expansion, are the major causes of species and ecological trait loss in tropical environments (Magioli et al., 2021; Resende et al., 2024). The reduction of biodiversity levels, especially of large-sized fauna, is a drastic consequence of habitat loss and fragmentation (Dirzo et al., 2014; Foley et al., 2005; Haddad et al., 2015; Pereira et al., 2024; Tollefson, 2019), reducing resource availability and landscape connectivity (Fahrig, 2003). This causes the isolation of wild populations, leading to changes in species abundance and composition and alterations to ecological processes (Vuyiya et al., 2014).

Several studies, including Stoner et al. (2007) and Barlow et al. (2016), confirmed the harmful effects of human disturbances on specialists. Oliveira and Wellington (2017) report that terrestrial mammal species richness and diversity are higher in strictly conserved areas surrounded by other intact forests than in regions exposed to deforestation, fragmentation, hunting, and other anthropogenic pressures. Moreover, certain species thrive in areas with high primary productivity, such as fragments of original vegetation or other open habitats (Amiot et al., 2021). Meanwhile, other species tend to be negatively affected by these modified landscapes (Beca et al., 2017).

In this context, it is essential to note that ecosystem changes can significantly impact biodiversity, particularly mammals. Generalist mammal species can thrive in various environments and utilize a wide range of resources, making them more adaptable to changes in environmental conditions. This adaptability allows them to expand their distribution and population size, as demonstrated by studies conducted by Bowen et al. (2009), Zurita et al. (2012), and Oliveira et al. (2019). For example, generalist mammals like opossums (*Didelphis marsupialis* and *Didelphis virginiana*) and raccoons (*Procyon lotor*) have a more significant food variety and population growth when competing or predatory species go locally extinct (Cruz-Salazar et al., 2016; Dharmarajan et al., 2009). In contrast, species that cannot tolerate significant changes in environmental conditions are more vulnerable to population decline. This was observed in specialist mammal species, such as the jaguar (*Panthera onca*), puma (*Puma concolor*), and ocelot (*Leopardus pardalis*) (Zanin et al., 2014). These species are negatively impacted by human activities such as expanding agricultural and livestock areas, which leads to decreased prey availability or conflicts with humans due to predation on domestic animals (De la Torre et al., 2019).

Different approaches have been proposed to explain species assemblages and diversity. This ecological framework has two perspectives regarding the community's assembly and maintenance of diversity. The first postulates that communities result from differentiating ecological niches mediated by biotic interactions, mainly competitive interaction (Hardin, 1960; MacArthur & Levins, 1967). On the other hand, if colonization and extinction patterns are considered more important than the traits of each population, then species assembly is determined by dispersion processes (Hubbell, 1997). HilleRisLambers et al. (2012) suggested that both processes can determine community assemblages. The dispersal process determines which species can access specific areas, while environmental factors mediate species survival and establishment through biotic interactions. Also, the decline of larger species under anthropogenic changes, including herbivores and predators, can significantly impact community composition and structure (Young et al., 2014).

Ecology and conservation face a central challenge in comprehending the mechanisms that shape biological communities amidst diverse perturbations (Resende et al., 2024). The Selva El Ocote Biosphere Reserve in Chiapas, Mexico, hereafter REBISO, presents unique characteristics that make it an ideal system to test hypotheses about landscape effects on mammal assemblages. Its complex topography, ranging from 180 to 1500 m above sea level, creates natural environmental gradients that could influence species distributions. The reserve harbors a mosaic of environments, including 78% of preserved areas with high evergreen forest, low deciduous forest, and sub-evergreen forest, alongside 16% of disturbed and 6% of secondary vegetation. This heterogeneity, combined with varying levels of human influence from 192 indigenous and mestizo communities, provides an excellent opportunity to examine how landscape modification affects mammal distribution patterns. Understanding how species adapt and respond to these changes in their environments is essential for species conservation, particularly in this reserve where fragmentation and reduction of native vegetation in tropical landscapes are evident (Dávalos et al., 2016; Laurance et al., 2014; Rivera-Rivera et al., 2012). Our hypothesis suggests that both environmental factors and human impacts will influence the distribution, richness, and abundance of mammals, thus specialist mammals are expected to respond negatively to sites with higher human pressure such as areas near roads, human settlements, or agricultural areas (Fahrig & Rytwinski, 2009; Penjor et al., 2021).

The objective of this study was to examine the effect of landscape features associated with human activities on the distribution, richness, and local diversity of medium and large terrestrial mammals in the REBISO hereafter). The results of this study are fundamental for the development of land use plans and the conservation of mammals in the region.

Method

Study area

The study was carried out in REBISO (16°45′–17°09′ N; 93°54′–93°21 W), in the western part of the state of Chiapas, southeast Mexico (Fig. 1). It has an area of 101,288 ha (DOF, 1982). The landscape comprises mountain ranges, with an altitude variation of 180 to 1500 m above sea level and rainfall of 800 to 2,500 mm. It presents three climatic types: warm humid with abundant rains in summer, and semi-warm subhumid with rains in summer. The average annual temperature varies between 18 and 22 °C (Ruíz, 2010).

The territory contains 78% of conserved sites with 62,919 ha of high evergreen forest (SAP hereafter), 15,340 ha of low deciduous forest (SBC), and 170 ha of medium sub-evergreen forest (SMS hereafter); 16% of disturbed vegetation with 15,141 ha of grasslands for cattle ranching and 1313 ha of agricultural plantations for subsistence corn and bean crops, and 6% of secondary vegetation of SAP with 4794 ha, SBC with 567 ha and SMP with 391 ha (AMBIO S.C. and CONANP, 2021). In the REBISO, there are 192 human communities comprising Tzotzil and Zoque indigenous people and mestizo communities. Land use is mainly intended for raising cattle (CEIEG, 2021).

The study area includes areas restricted to settlements and productive human activities, where the land is intended for the conservation of natural environments and others that allow the sustainable use of natural resources, such as population centers and agricultural and livestock lands (SEMARNAT, 2001).

Data collection

To study the assemblage of terrestrial mammals in the REBISO, sampling was carried out with camera traps (CT hereafter) between September 1 and December 12, 2016. Thirty-nine sampling stations were installed simultaneously for 102 consecutive days, placed between 1 and 1.5 km, selecting conserved areas located inside the reserve in places far from towns, roads, and productive activities and in areas with some degree of disturbance close to sites with secondary vegetation, towns, roads, livestock, and agricultural areas (Fig. 1). Of the total number

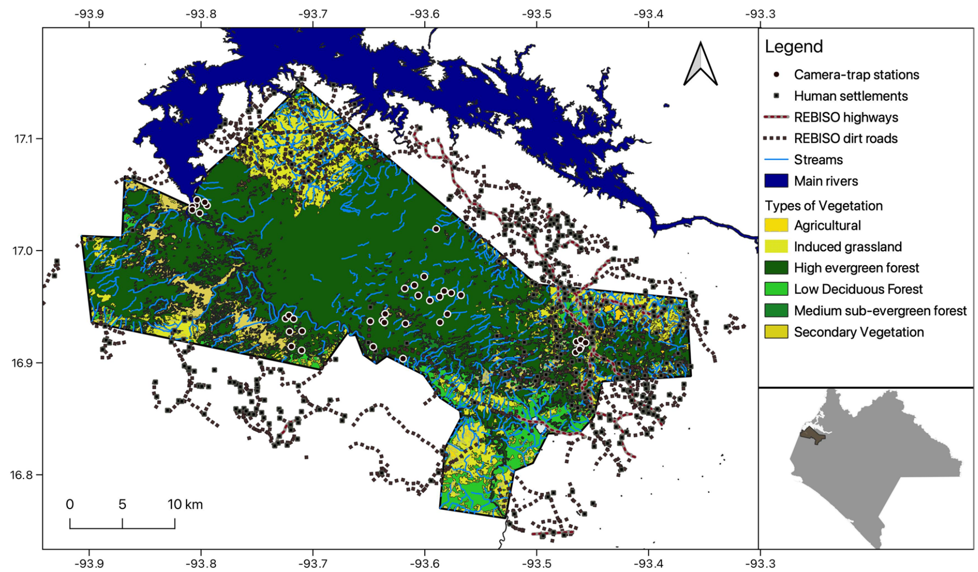

Fig. 1 Map of the study area. Camera traps arranged inside the Selva El Ocote Biospher (REBISO), Chiapas, México

of stations placed, 20 corresponded to the area with the more human impact (disturbed) and 19 to the preserved area.

Each station consisted of a Moultrie ® model A-5 CT, placed at the base of the trees between 40 and 60 cm above the ground, and set to be active for 24 h (Iezzi et al., 2019). All locations were chosen without knowledge of animals' presence, absence, abundance, or diversity; no baits or lures were used. CT locations ranged in altitude from 249 to 1271 m. To increase the detection of moving animals and maximize species identification, CTs were configured to take three successive images per shot without delay between detections (Amiot et al., 2021).

The date and time of each event were recorded in each photograph. To identify the species, we based ourselves on the guides for identifying wild mammals in Mexico by Aranda (2012) and consulted specialist researchers for some groups. Species of terrestrial mammals weighing less than 0.5 kg were not recorded. Records of a species separated by more than 60 min were considered independent photographic events (Cusack et al., 2015). Records of domestic animals such as dogs and cattle were eliminated. Although it was usually possible to distinguish between species, in the case of *Didelphis virginiana* and *D. marsupialis*, it was impossible to determine each species' individuals, so only the genus was considered for the analysis.

Landscape attributes

We collected spatial data on environmental and anthropogenic characteristics of ten independent variables to assess their effect on the richness and composition of mammalian assemblages. Five independent variables were related to environmental factors: (1) altitude ("altitude"), (2) distance to principal rivers ("DMR"), (3) distance to streams ("DS"), (4) forest cover ("for_am"), and (5) Soil Adjusted Vegetation Index ("SAVI"). Five independent human impact variables were also included: (1) distance to towns ("DT"); (2) distance to major highways ("DH"); (3) distance to roads ("DR"); (4) distance to the secondary forest ("DSF"); and (5) distance to induced grassland ("DCP").

The altitude was taken as meters above sea level ("masl") at the coordinates of each station.

Forest cover and SAVI were calculated from the mean value of a 150-m buffer around each camera trap site using a 30-m resolution Sentinel 2 satellite image. To evaluate landscape influence on mammal presence, Euclidean distances were calculated from each sampling station to the nearest feature of each type (streams, rivers, highways, rural roads, human settlements, and induced grasslands) using the NNJoin function in QGIS version 3.20.0 (QGIS Development Team, 2020). These distances quantify the degree of isolation or proximity of stations to elements that may affect mammal distribution. The variables DMR, DS, DT, DT, and DR were obtained from land use cartographic files of the State Committee for Statistical and Geographic Information of Chiapas (CEIEG, 2021), while DSF and DCP were extracted from vegetation cover monitoring in PNA of the Selva Lacandona and Zoque complexes for the formulation of strategies to reduce deforestation (AMBIO and CONANP, 2021).

Abundance, composition, and species similarity

The relative abundance index (RAI) of mammal species in REBISO was determined by the relative frequency of capture records for each species per station, calculated as follows: RAI = the number of independent records of each mammal species divided by the total number of days that the CT was active, multiplied by 100. We then performed a hierarchical cluster analysis using the function hclust() method "ward.D2" and constructed a similarity dendrogram using the Bray–Curtis similarity index (Iezzi et al., 2018). Ward's agglomerative method was used to find the function that best fits the data, combining the groups into a group with minimal variance, using the sum of squares criterion (Vijaya & Batra, 2019). The Nbclust r package was utilized to determine the ideal number of clusters for identifying the composition of medium and large mammal assemblages (Charrad et al., 2014). We constructed range-abundance curves and performed non-metric multidimensional scaling (NMDS) analysis based on a Bray–Curtis dissimilarity matrix using the "decostand" function to standardize the data (Oksanen et al., 2019). Further, we conducted a similarity analysis (ANOSIM) to test general composition differences in the assemblages (Knowlton et al., 2019). By analyzing similarity percentages (SIMPER), we identified the contribution of each species to the general similarity observed between the assemblages (Jambari et al., 2019).

The richness of the identified species assemblages was estimated using Hill numbers, considering the number of species present (species richness) (Chao et al., 2014). Interpolation curves were constructed to estimate richness, and extrapolation was carried out using the iNEXT package (Hsieh et al., 2020). Range-abundance curves were then created for each assemblage, considering the abundance values of each species to provide information about species distribution (Rocchini & Neteler, 2012).

Niche analysis and species-environment relationships

To determine multicollinearity between the covariates, we calculated the variance inflation factor (VIF), which measures multicollinearity between the variables, and those with a VIF $<$ 7 were kept in the model (Piña et al., 2019). Subsequently, to verify if the selected covariates explained the species' composition, we applied the multivariate ordination method restricted redundancy analysis (RDA) using each species' abundance and applying a Hellinger transformation (Borcard et al., 2018). A global test of the RDA model was then run for 1000 permutations to determine its significance ($\alpha = 0.05$), and an ANOVA test by "terms" was run to identify the explanatory variables ($\alpha = 0.05$) for subsequent readjustment of the model. Furthermore, we performed an Outlying Mean Index (OMI) analysis using the standardized environmental variables through the "ade4" package to analyze the species' niche specialization. The OMI analysis measures the distance between a species' average habitat conditions and the sampling area's average habitat conditions (Dolédec et al., 2000; Karasiewicz et al., 2017). The OMI analysis provides three niche parameters: marginality, tolerance, and inertia. Marginality measures the deviation of the average conditions used by a species from the area's average conditions. Tolerance (Tol) measures the breadth of the species' niche. Residual tolerance (RTol) indicates the proportion of variability in the species' niche not explained by the measured axes (Dolédec et al., 2000). For the OMI analysis, species with more than 10 records distributed across more than five sampling sites were considered. The statistical significance of marginality was assessed using

Monte Carlo tests with 10,000 random permutations. All analyses were performed in R 2022.02.3 software (R Core Team, 2022).

Results

Rarefaction

The sampling period was 3978 camera days (39 cameras times 102 days); 20 species of wild mammals were recorded (taking the two species of *Didelphis* as one) and two species of domestic animals, a dog (*Canis lupus familiaris*) and cattle (*Bos taurus*). These last two were recorded only in four sites. The animals belonged to seven orders and 14 families. The best-represented families were Felidae, with five species, followed by Mephitidae, Dasyproctidae, and Didelphidae, with two species each.

Species similarity and composition

The number of species recorded by CT varied from 1 to 7 (mean = 3.56, SD = 1.83). The mean RAI per species varied substantially, with two species recording an RAI > 1.0, two species 0.5–1.0, seven species > 0.1–0.5, and eight species < 0.1. *Cuniculus paca* was recorded in 71.79% (n = 28) of the CTs, followed by *Leopardus pardalis* in 38.46% (n = 15), *Dasyprocta mexicana* in 33.34% (n = 13) and *Nasua narica* in 30.76% (n = 12). The overall richness was 19.12 (±0.43) (Fig. 2a).

The Bray Curtis distance similarity index and Ward's agglomerative method allowed for identifying relationships between species with the most similar abundances, grouping them into two different mammal assemblages with 12 (**A**) and 27 (**B**) CT (Table 1). The identified richness for assemblages was 20.96 (±7.16) for group **A** and 16.12 (±0.43) for group **B** (Fig. 2b). The species of group **A** were detected mainly in the cameras placed northwest of the REBISO in one of the best-conserved areas of the study area called "El Encajonado." In contrast, the species of group **B** were captured more frequently in the center and south of the Reserve in sites with a certain degree of disturbance (Fig. 3 a and b). In group **A**, 15 species were recorded, and in group **B**, 16 species, sharing 12 (63.15%, n = 19), while the rest (n = 7) were divided into three species for group **A** and four for group **B**.

The most abundant species in group **A** were *D. mexicana*, comprising 52.20% of the records, followed by *P. concolor* with 8.17% and *D. tajacu* with 6.29%. In group **B**, *C. paca* presented 54.02% of the records, followed by *L. pardalis* with 8.53% and *Didelphis* spp. with 7.58% each (Fig. 4). In group **A**, *Conepatus leuconotus*, *Conepatus semistriatus*, *Tamandua mexicana*, and *Urocyon cinereoargenteus*

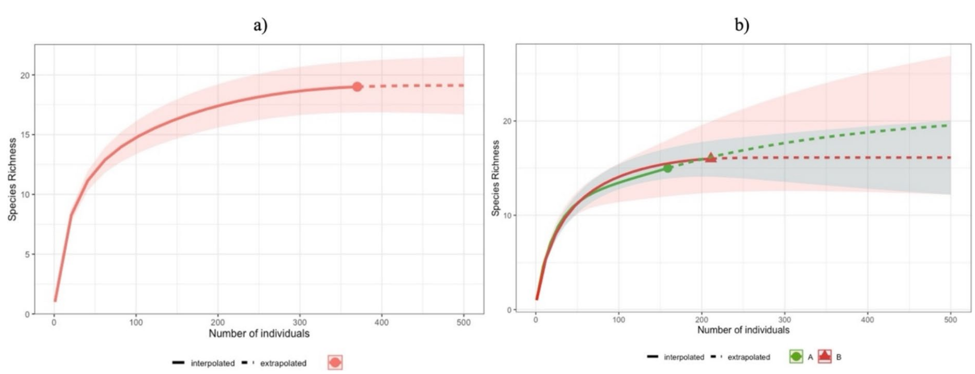

Fig. 2 Species richness of mammal assemblages by number of individuals recorded in the cameras. **a** The red dot is the overall observed species richness. **b** The red and green dots show the richness of the identified assemblages. For both figures, the solid lines are the interpolated values, the dotted lines are the extrapolated values, and the red and green shaded portions are the 95% confidence intervals

Table 1 List of species of medium and large terrestrial mammals recorded in the study area; conservation status according to the IUCN Red List and NOM-059-SEMARNAT-2019 (NOM); number of records obtained per species (Reg.), number of sites and group where they were recorded. *DD*, data deficient; *LC*, least concern; *NT*, near threatened; *CR*, critically endangered; *A*, threatened; and *P*, extinction risk (IUCN, 2022; SEMARNAT, 2019). Sites, sites where the camera traps were installed; Group, groups identified in the cluster analysis

Order/family/scientific name	Common name	UICN	Nom-MX	Reg	Sites	Group
Carnivora						
Canidae						
Urocyon cinereoargenteus	Gray fox	LC		2	1	B
Mephitidae						
Conepatus leuconotus	American hog-nosed skunk	LC		3	2	B
Conepatus semistriatus	Striped hog-nosed skunk	LC		2	2	B
Mustelidae						
Eira barbara	Tayra	LC	P	17	11	Both
Felidae						
Leopardus pardalis	Ocelot	LC	P	26	15	Both
Leopardus wiedii	Margay	NT	P	12	7	Both
Panthera onca	Jaguar	NT	P	3	3	Both
Puma concolor	Puma	LC		13	4	A
Puma yagouaroundi	Jaguarundi	LC	A	3	2	A
Procyonidae						
Nasua narica	White-nosed coati	LC		18	12	Both
Procyon lotor	Northern raccoon	LC		2	2	Both
Cetartiodactyla						
Tayassuidae						
Dicotyles tajacu	Collared peccary	LC		17	10	Both
Cervidae						
Mazama temama	Central American red brocket	DD		6	3	Both
Cingulata						
Dasypodidae						
Dasypus novemcinctus	Nine-banded armadillo	LC		11	9	Both
Didelphimorphia						
Didelphidae						
Didelphis sp.	Opossum	LC		22	12	Both
Lagomorpha						
Leporidae						
Sylvilagus floridanus	Eastern cottontail	LC		1	1	A
Pilosa						
Myrmecophagidae						
Tamandua mexicana	Northern tamandua	LC		2	2	B
Rodentia						
Cuniculidae						
Cuniculus paca	Agouti	LC		122	28	Both
Dasyproctidae						
Dasyprocta mexicana	Mexican agouti	CR		88	13	A

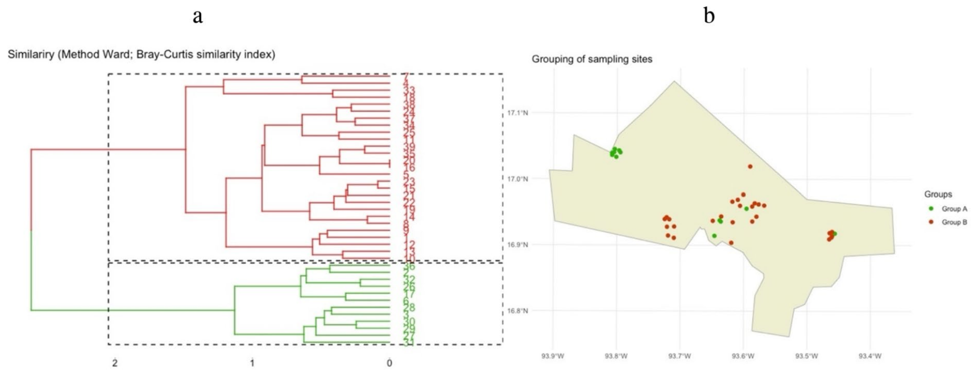

Fig. 3 Clustering and distribution of mammal assemblages in the REBISO. **a** Dendrogram of Ward's hierarchical clustering. Two main groups are observed among the sites where the camera traps were placed. **b** Distribution and grouping of the sampling stations, in green group "**A**" with 12 CT and red group "**B**" with 27 CT. The graph's axes indicate the UTM coordinates, zone 15 of north latitude and west longitude

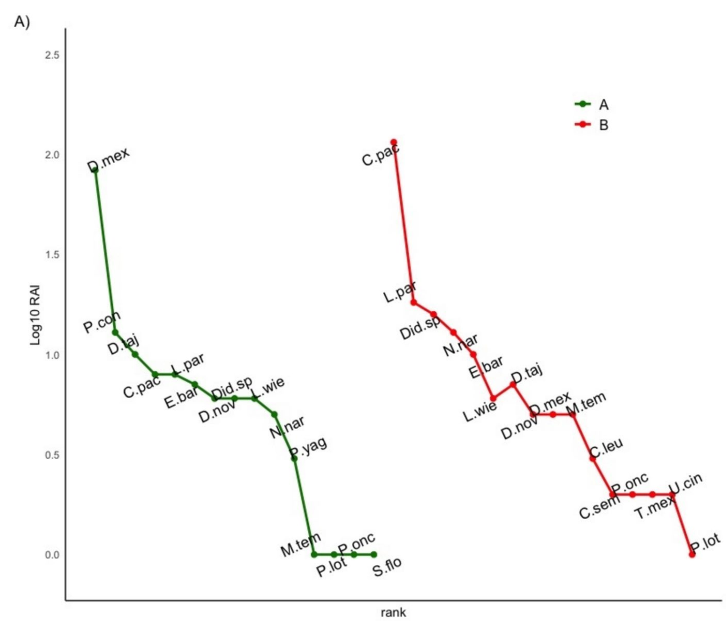

Fig. 4 Rank-abundance curve of the identified mammal assemblages. *D.mex*, *Dasyprocta mexicana*; *C.pac*, *Cuniculus paca*; *P.con*, *Puma concolor*; *D.taj*, *Dicotyles tajacu*; *L.par*, *Leopardus pardalis*; *Did.sp*, *Didelphis* sp.; *E.bar*, *Eira barbara*; *D.nvo*, *Dasypus novemcinctus*; *N.nar*, *Nasua narica*; *L.wie*, *Leopardus wiedii*; *M.tem*, *Mazama temama*; *P.yag*, *Puma yagouaroundi*; *C.leu*, *Conepatus leuconotus*; *P.lot*, *Procyon lotor*; *P. onc*, *Panthera onca*; *S.flo*, *Sylvilagus floridanus*; *T.mex*, *Tamandua mexicana*; *C.sem*, *Conepatus semistriatus*; *U.cin*, *Urocyon cinereoargenteus*

were not recorded, which presented extremely low abundances. In contrast, the unrecorded species for group **B** were *P. concolor*, *P. yagouaroundi*, and *Sylvilagus floridanus*.

The NMDS and ANOSIM ordination analyses showed that the two identified mammal assemblages had a significantly different structure (ANOSIM: $R = 0.66$, $p < 0.01$; stress = 0.19; Fig. 5).

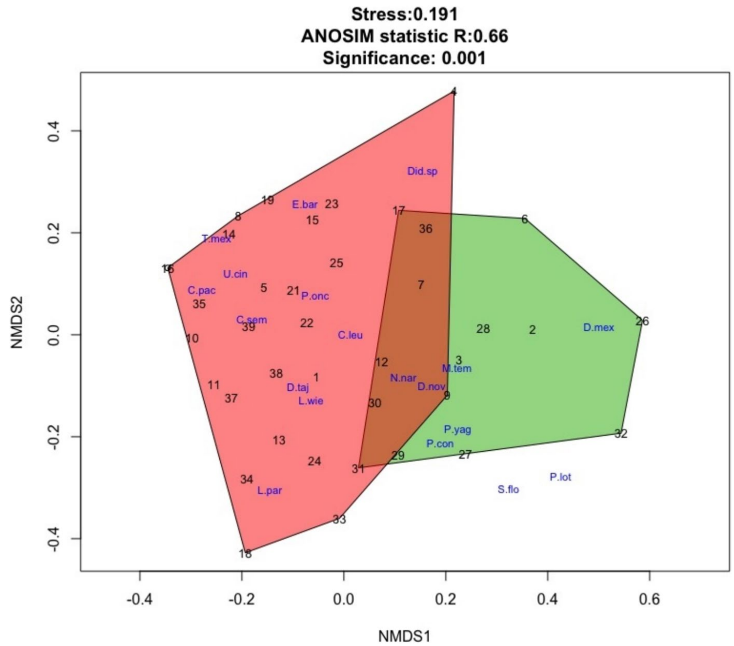

Fig. 5 Composition of the mammal community in the two identified groups. The graph is based on the species abundance using Bray–Curtis non-metric multidimensional analysis (NMDS) (stress = 0.191). The polygons connect the sampling sites that identify each group, in the green group "**A**" and red group "**B**."

The NMDS suggests a close association between groups with species such as *Nasua narica*, *Mazama temama*, and *Dasypus novemcinctus* sharing space. For group **A**, the best-represented species were *D. mexicana*, *P. yagouaroundi*, and *P. concolor*. Group **B**'s most frequently associated species were *C. paca*, *U. cinereoargenteus*, *Tamandua mexicana*, *Didelphis* spp., and *L. pardalis* (Fig. 5). The analysis of percentages of similarity (SIMPER) allowed us to identify six species that contributed to 79% of the variation in the structure of the assemblages between groups: *D. mexicana*, *C. paca*, *L. pardalis*, *Didelphis* spp., *Puma concolor*, and *Eira barbara*, as well as five species with significant differences between groups (Table 2).

Niche analysis and species-environment relationships

Four highly correlated variables were identified: DR, DMR, DH, and DT, then the first two were eliminated. Based on the results of the VIF, eight variables were selected and integrated into the analysis in the RDA (Fig. 6). Permutation results indicated four RDA axes with a significant one (RDA1) determined by ANOVA test ($Pr(>F) = 0.001$). The selection of variables using

Table 2 Contribution of the main species to the difference between the mammal assemblages in the REBISO based on analysis of similarity percentages (SIMPER). Asterisks represent significant statistical differences between groups: 0.001 ≤ (***), and 0.01 ≤ (**)

Species	% contribution	% cumulative contribution
Dasyprocta mexicana	36.2***	36.2
Cuniculus paca	21.3	57.5
Leopardus pardalis	6.1	63.6
Didelphis sp.	5.8	69.4
Puma concolor	4.8***	74.2
Eira barbara	4.8	79.0
Puma yagouaroundi	0.010**	
Sylvilagus floridanus	0.007**	
Procyon lotor	0.094	

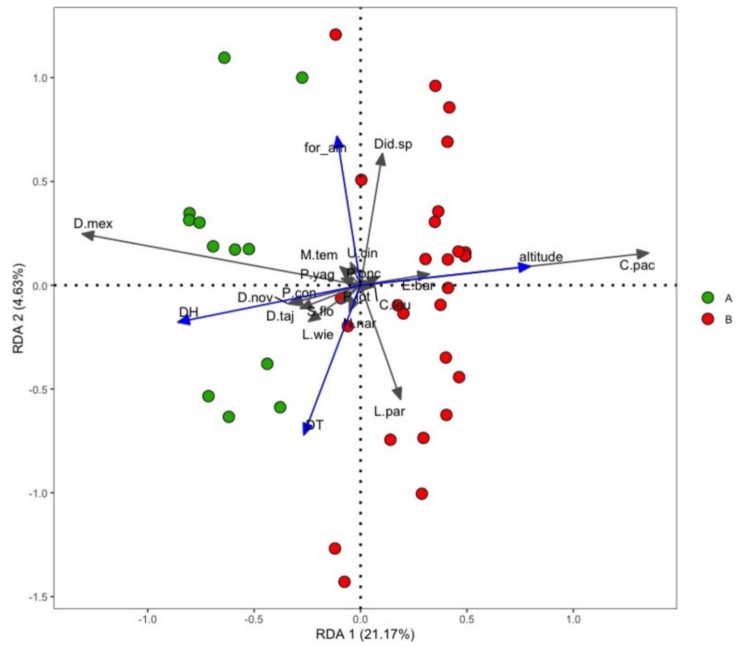

Fig. 6 Redundancy analysis (RDA) ranking of mammal species occurrence concerning variates that had a significant effect ($p<0.05$). The green circles (Group **A**) and red boxes (Group **B**) correspond to the grouping of the CTs

the permutation test (Pr(> F) < 0.05) in the RDA allowed the identification of altitude, distance to main roads (DH), distance to towns (DT), and forest cover (for_am) as the crucial variables. The VIF tests showed all the selected variables with values < 7. The results of the RDA (axis 1 = 21.17%; axis 2 = 4.63%) confirmed a relationship between the explanatory variables, the relative frequency of species records, and the distribution of the groups ($R^2=0.28$; Pr(> F) = 0.001). The RDA results indicate that the variation in species distribution was correlated by distance to main roads (DH), altitude, distance to towns (DT), and forest cover.

The OMI analysis explained 88.75% of the variability in the niche structure of the mammal community through its first two axes (axis 1 69.07%; axis 2 19.67%). *Puma concolor* showed the highest specialization with the highest marginality value (2.96), followed by *Didelphis* spp. (2.22) and *D. novemcinctus* (2.11). In addition, the ellipses are further away from the center in the graph, indicating their preference for specific environmental conditions that differ from the available average, considering them specialists. In contrast, *N. narica* presented the lowest marginality value (0.26) and showed a broad niche close to the origin in the graph, reflecting a generalist behavior and an association with average landscape conditions. *Dacyprocta mexicana* (1.86) and *D. novemcinctus* (1.83) recorded the highest tolerance index (Tol), indicating their ability to occupy diverse environments, while *D. tajacu* (0.57) and *E. barbara* (0.56) showed the lowest values, reflecting more restricted niches. The highest residual tolerance (RTol) corresponded to *N. narica* (7.26), suggesting that its distribution is influenced by factors not considered in the analysis, while *P. concolor* showed a low RTol (2.13), evidencing a close relationship with the modeled gradients (Table 3, Fig. 7a). The spatial distribution of niches revealed that *D. mexicana* occupied the most extensive niche, while *D. tajacu* and *L. wiedii* showed narrow niches with overlap, suggesting that they occupy a limited range of environmental conditions but similar environmental preferences. *Eira barbara* and *C. paca* exhibited restricted and centralized niches, indicating limited

Table 3 OMI niche parameters for mammal species. Inertia; *OMI*, outlier mean index; *Tol*, tolerance index; *RTol*, and residual tolerance index for each species. Values in italics represent the corresponding percentages of variability. Species are identified by their codes, as shown in Fig. 4

Species	Inertia	OMI	Tol	Rtol	*OMI*	*Tol*	*Rtol*	*p* value	Sig
C.pac	7.359	0.559	1.385	5.415	*7.6*	*18.8*	*73.6*	0.067	
D.mex	7.483	1.703	1.866	3.913	*22.8*	*24.9*	*52.3*	0.082	
D.nov	8.553	2.113	1.833	4.608	*24.7*	*21.4*	*53.9*	0.025	*
Did.sp	9.016	2.217	1.408	5.390	*24.6*	*15.6*	*59.8*	0.011	**
E.bar	6.133	0.553	0.565	5.015	*9*	*9.2*	*81.8*	0.628	
L.par	9.084	0.686	1.801	6.596	*7.6*	*19.8*	*72.6*	0.241	
L.wie	10.453	1.908	1.712	6.834	*18.3*	*16.4*	*65.4*	0.134	
N.nar	8.359	0.265	0.834	7.260	*3.2*	*10*	*86.9*	0.943	
D.taj	7.049	1.111	0.577	5.360	*15.8*	*8.2*	*76*	0.348	
P.con	6.432	2.961	1.335	2.136	*46*	*20.8*	*33.2*	0.216	

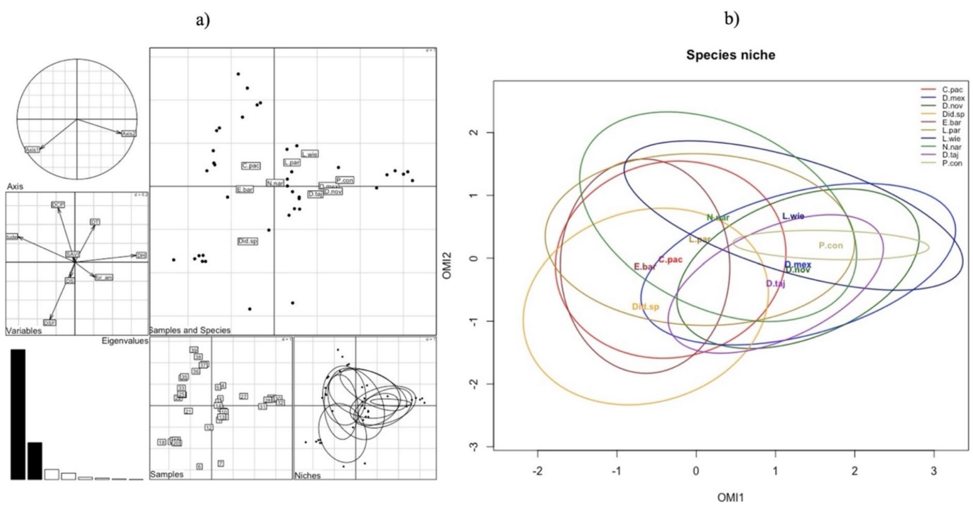

Fig. 7 Niche Margination Analysis by outlier mean index (OMI) and its multifactorial representation for the assembly of medium and large mammals in the Selva El Ocote Biosphere Reserve

tolerances and specific associations with certain environmental conditions (Fig. 7b). Monte Carlo tests revealed statistically significant marginality for *D. novemcinctus* ($p = 0.021$) and *Didelphis* spp. ($p = 0.008$), while *C. paca* ($p = 0.071$), *D. mexicana* ($p = 0.066$), and *L. wiedii* ($p = 0.134$) showed marginal trends, indicating that these species use habitats significantly different from the environmental average (Table 3). Furthermore, the overall mean marginality was significant ($p = 0.013$), suggesting that, as a whole, the species are influenced by the environmental gradients analyzed.

Discussion

Abundance, composition, and species similarities

This research aimed to identify the assemblage of medium to large-sized terrestrial mammals in the REBISO. We found that 20 species of medium and large wild mammals were recorded, one more species than those reported by Pozo-Montuy et al. (2019) for this protected natural area. However, in the present study, *Odocoileus virginianus*, *Galictis vittata*, and *Tapirus bairdii* were not recorded, but

P. yagouaroundi, *P. lotor*, *S. floridanus*, and *C. leuconotus* were reported in low abundances of records ($n = 1$–3). In another study carried out with the same sampling system in the Los Ocotones forestry area, a site considered a biological corridor that connects the REBISO with the La Sepultura Biosphere Reserve, 21 species were recorded. The most abundant were *P. lotor* and *U. cinereoargenteus*, reported at very low abundances in the present study, and *O. virginianus* (Espinoza-Medinilla et al., 2018), which was not detected in this study. These authors did not find *D. mexicana*, the species with the highest records in the study by Pozo-Montuy et al. (2019) and the present work. On the other hand, the richness of species of medium and large mammals observed is like other studies carried out in tropical forests of Chiapas, such as the Lacandon Forest, where 18 species were reported (Porras et al., 2016) and in La Encrucijada Biosphere Reserve, where 19 species were registered (Hernandez-Hernandez & Chavez, 2021). In both cases, *C. paca* and the genus *Dasyprocta* were found among the species with the highest abundances, which coincides with our results.

Medium-sized felids such as *L. pardalis*, *L. wiedii*, and *P. yagouaroundi*, together were recorded in 51.28% ($n = 20$) of the CTs, so they appear to be abundant in the REBISO, which may indicate that an environment of good quality for these species is still present in the study area (Cruz et al., 2018; Horn et al., 2020). The presence and abundance of species of conservation interest, such as *L. pardalis*, *L. wiedii*, *D. mexicana*, *E. barbara*, and *P. onca*, reinforce the importance of protected natural areas such as the REBISO for the conservation of mammals in the tropical forests of southern Mexico. In addition, the presence of *Conepatus semistriatus*, previously reported by Pozo-Montuy et al. (2019), was confirmed.

Ward's grouping analysis showed that in the sites studied in the REBISO, there are two different mammal assemblages. The first group (**A**) is located mainly by a group of seven CTs spatially separated from the rest of the CTs by approximately 25 km on a straight line in the area called "El Encajonado," considered among the best-preserved zones in the REBISO and where human access is more difficult due to the lack of roads and the rugged terrain. The second group (**B**) occurs where there is a more significant presence of human activities (Rivera-Rivera et al., 2012). NMDS and ANOSIM analyses corroborate the formation of these groupings. They showed two significantly distinct groups, divided by species such as *D. mexicana* and *P. concolor*, recorded only in group **A**. *Cuniculus paca* was recorded with greater abundance in group **B**.

Puma concolor and *D. mexicana* were recorded in the same CTs, mainly in the "El Encajonado" area; this suggests that *D. mexicana* could be prey for *P. concolor* since it is part of its diet (Novack et al., 2005). Five group A stations were close to group B This may be due to the presence of *D. mexicana* in those stations. The most abundant recorded species, *C. paca* and *D. mexicana*, are considered resistant to disturbance since they can adapt to transformed habitats with induced flora such as corn (*Zea mays*) and other cultivated plants (Gallina et al., 2012; Martínez-Ceceñas et al., 2018; Reid, 2009). In addition, these two rodents are favored by abrupt topography, such as the one present in the REBISO, which promotes the presence of caves and tunnels that they use as burrows (Lira-Torres & Briones-Salas, 2011). This could explain their high abundance in some areas. Pozo-Montuy et al. (2019) report that illegal hunting for these species could explain their absence or low abundance in other areas. The distribution of *D. mexicana* and *C. paca* in groups **A** and **B** could be explained by food competition, as both species share a frugivorous diet with high overlap. According to Santos-Moreno and Pérez-Irineo (2013), this interaction is modulated by the seasonal availability of fruits and a temporal segregation in their activity, with *C. paca* being nocturnal and *D. mexicana* diurnal. This resource partitioning could minimize direct competition, while the inverse relationship in their presence reinforces the influence of these interactions on their distribution.

Our results indicate that both mammal assemblages conserve 63 of the medium and large species previously recorded, so theoretically, they would be collectively safeguarding more than half of the mammals at each zone. The above shows the importance of preserving the connectivity of areas allowing the flow of individuals to be maintained, particularly of species with greater home ranges and greater sensitivity to anthropogenic disturbance, which in turn are considered critical species in ecosystems such as *P. onca*, *P. concolor*, *L. pardalis*, and *L. wiedii* (Kasper et al., 2016; Hernandez-Hernandez and Chavez, 2021).

Niche analysis and species-environment relationships

RDA and OMI analyses revealed complementary patterns describing mammal community structure in REBISO. RDA results indicate that variation in species distribution was correlated with distance to major roads (DH), altitude, distance to cities (DT), and forest cover (for_am). This ordination demonstrated a clear separation between groups A and B, reflecting how species respond differentially to environmental and anthropogenic landscape conditions. The OMI analysis complemented these findings by explaining 88.75% of the variability by revealing distinct levels of niche specialization among species, suggesting that community structure is strongly influenced by both environmental factors and the species' ability to utilize habitat-specific resources. The RDA1 axis revealed a gradient of species responses to the presence of human infrastructure, where *D. mexicana*, *D. novemcinctus*, and *P. concolor* showed a substantial decrease in their abundance near major roads, while *L. wiedii* and *D. tajacu* exhibited a weaker relationship. The OMI complemented these findings by identifying *P. concolor* as the species with the highest niche specialization. At the same time, *D. mexicana* showed moderate marginality and the highest tolerance among all species, revealing that despite its preference for areas far from infrastructure, it can use a wide range of environmental conditions. In contrast, *C. paca* and *E. barbara* positively correlated with altitude, exhibiting a preference for higher altitude areas. The OMI analysis revealed that both species present low marginality values, indicating that they use conditions close to the environmental average. However, they differ in their tolerance patterns. *Cuniculus paca* showed moderate tolerance, suggesting some flexibility in habitat use, while *E. barbara* presented very low tolerance, indicating a more restricted niche.

The trend of axis 2 of the RDA was positively correlated with forest cover and negatively correlated with distance to cities for *Didelphis* spp., while for L. *pardalis* it only showed a negative correlation with distance to cities. In the case of *Didelphis* spp., they showed a positive trend in areas with higher forest cover and close to cities, exhibiting intermediate niche specialization with flexible habitat use patterns. This observation applies to *D. virginiana* and *D. marsupialis*, as they are considered generalist and non-selective habitat species. This allows them to thrive in areas with different characteristics, including regions with human disturbances and conserved sites (Cruz-Salazar et al., 2016; Cruz-Salazar and Ruiz Montoya, 2020).

According to the RDA analysis, the occurrence and abundance of *C. leuconotus*, *C. semistriatus*, *M. temama*, *N. narica*, *P. onca*, *P. lotor*, *P. yagouaroundi*, *S. floridanus*, *T. mexicana*, and *U. cinereoargenteus* were determined to be independent of the landscape variables analyzed. This independence is supported by the OMI analysis, where *N. narica* exhibited a generalist behavior, using conditions close to the environmental average, with the lowest marginality value and the highest residual tolerance, indicating that its distribution is more influenced by factors not considered. The RDA analysis indicated low values, but other factors, such as habitat matrix attributes and hunting pressure, can influence mammal species composition. For example, Andrade-Núñez and Aide (2010) emphasized the importance of habitat matrix attributes, while Porras et al. (2016) showed the impact of hunting on the richness and abundance of mammal species in the Lacandon Forest of Chiapas, Mexico.

The ANOSIM analysis and Ward's method showed two groups: group **A** (conserved sites) and group **B** (disturbed sites). According to Guerrero et al. (2002) and Monterrubio-Rico et al. (2019), the species *C. leuconotus*, *P. lotor*, and *U. cinereoargenteus* are considered generalists because they are less sensitive to habitat disturbances that are typically associated with human activities, such as proximity to towns and agricultural areas. Although these species were not included in the OMI analysis due to their low abundance records ($n < 10$), their exclusive presence in disturbed areas supports their generalist character. REBISO has a high percentage of forest cover (78%). However, deforestation for agriculture may cause an increase in generalist species in these areas (Pérez-Irineo & Santos-Moreno, 2013).

We found that *D. mexicana* preferred preserved areas with a lower altitude and had a negative tendency towards main roads. Also, this species was mainly found in sites belonging to group **A**. According to Pozo-Montuy et al. (2019), *D. mexicana* occurs in areas with lower degrees of protection near places where activities such as livestock are present in the REBISO. According to the study by Lira-Torres and Briones-Salas (2011), *D. mexicana* is considered a generalist species found both in preserved and degraded areas. In addition, a negative correlation between roads and the presence of *D. mexicana*, *D. novemcinctus*, *P. concolor*, and *L. wiedii* has been observed (Fahrig & Rytwinski, 2009; Piña et al., 2019). These areas could be particularly advantageous for *D. tajacu*, *D. mexicana*, and *D. novemcinctus*, as they are difficult to access for humans. Because hunters highly target these species, they tend to seek refuge in these locations (Flota-Bañuelos, 2018; Naranjo & Cuarón, 2010).

On the other hand, it has been reported that certain species are part of the diet of *P. concolor* and *L. wiedi*. This could be the reason for the presence of these predators in the same sites, as stated by Hernández (2008) and Bianchi et al. (2011). According to Magle et al. (2014) and García-R et al. (2019), the abundance and feeding habits of prey directly influence the abundance and habitat use of carnivorous mammals, highlighting the ecological aspects of their diet. Although *L. pardalis* has traditionally been considered to have specific habitat requirements and is considered a specialist, the OMI analysis suggests otherwise, as it presents low marginality, high tolerance, and distribution that are not significantly associated with specific environmental conditions. However, human activities such as hunting and habitat degradation negatively affect it. As a result, this species tends to occupy areas with less human presence, such as more remote and conserved sites. This behavior indicates that the species actively seeks safer and less disturbed habitats (Di Bitetti et al., 2008).

Puma concolor showed a strong tendency to avoid roads, confirmed by the OMI analysis, which identified it as the species with the highest niche specialization and low residual tolerance. This explains its close association with conserved areas such as El Encajonado, where it encounters less human disturbance. These findings are expected since *P. concolor* can live near areas with human activities but prefer conserved areas where they can find a higher prey abundance (Boron et al., 2018). Wild mammal populations are often adversely affected by human activities, as some species can thrive in human-altered environments, such as agricultural and urban areas, despite not being surrounded by forest cover (Amiot et al., 2021). On the other hand, species that are more sensitive to habitat modifications experience negative impacts (Beca et al., 2017).

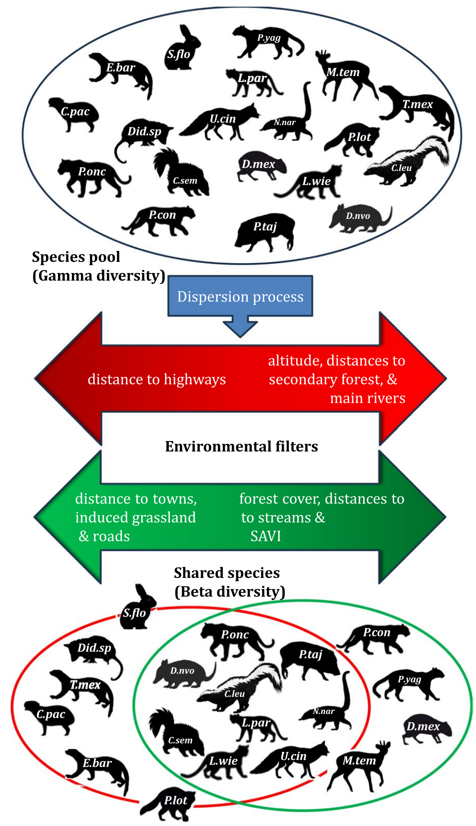

Fig. 8 Species assemblage model. The species pool is affected by landscape attributes, environmental filters, and dispersal limitations. The latter is rendered in sites characterized by species that prefer conserved sites versus species that support human impacts on the landscape. *C.pac*, *Cuniculus paca*; *P.con*, *Puma concolor*; *P.taj*, *Dicotyles tajacu*; *L.par*, *Leopardus pardalis*; *Did.sp*, *Didelphis* sp.; *E.bar*, *Eira barbara*; *D.nvo*, *Dasypus novemcinctus*; *N.nar*, *Nasua narica*; *L.wie*, *Leopardus wiedii*; *M.tem*, *Mazama temama*; *P.yag*, *Puma yagouaroundi*; *C.leu*, *Conepatus leuconotus*; *P.lot*, *Procyon lotor*; *P. onc*, *Panthera onca*; *S.flo*, *Sylvilagus floridanus*; *T.mex*, *Tamandua mexicana*; *C.sem*, *Conepatus semistriatus*; *U.cin*, *Urocyon cinereoargenteus.* Environmental factors: altitude, distances to main rivers, forest cover, distances to streams and "SAVI." Human impact factors: distance to towns, induced grassland and roads

A relevant aspect to consider is that various factors could influence the results obtained. The selection of camera trap locations may introduce biases, particularly if the sites do not adequately represent the heterogeneity of the landscape within the reserve. Additionally, the inability to identify specific individuals limits our capacity to estimate true population abundances and movement patterns. The temporal scope of our sampling period (102 days) may not fully capture seasonal variation in activity patterns and habitat use. To strengthen the conclusions of this study, it is recommended to implement long-term sampling that spans multiple seasons to better understand the temporal dynamics of these mammal communities and their responses to seasonal habitat changes. Furthermore, incorporating complementary methods to identify individuals could enhance the precision of species niche characterization. These actions would contribute to a more robust and general interpretation of the observed patterns.

Conclusions

We did not find a strong relationship between landscape metrics and wild mammal distribution, as reflected by the low percentages of variation explained by the first two RDA axes. However, the OMI analysis revealed significant patterns of niche specialization, with species such as *P. concolor* showing high specialization and *N. narica* exhibiting generalist traits. We observed trends in the distribution of *C. paca*, with a more significant presence at higher altitudes, and *D. mexicana* at better-preserved sites away from main roads. Medium and large mammals were distributed in two main groups: one in more conserved habitats and another in habitats with more significant human impact, sharing 63% of the species. This distribution suggests that certain factors affect their distribution throughout the REBISO area. We found that medium and large-sized mammals were distributed in two main groups. Group **A** was in more conserved habitats, and group **B** was in habitats with more significant human impact. In addition, we observed that two groups of wild mammal assemblages share half of their species. This suggests certain factors affect their distribution throughout the REBISO area (Fig. 8). Therefore, it is essential to maintain habitat connectivity and consistently monitor mammal populations, as many species can serve as indicators of habitat disturbance. Implementing sustainable and productive practices such as conservation agriculture and silvopastoral livestock farming is essential to promote the conservation of wildlife habitat and maintain productivity.

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Data Availability The data supporting this study's findings are available from the authors, but restrictions apply. These data were used under the National Commission of Protected Natural Areas (Mexico) permit for the current study and are not publicly available. However, data are available from the authors upon reasonable request and with permission from the National Commission of Protected Natural Areas.

Declarations

Ethics approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Competing interests The authors declare that they have no competing interests.

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CAPÍTULO VI

Estructura comunitaria y selección de hábitat de mamíferos en un área protegida de la Sierra Madre de Chiapas

UNACH

Paola Ocampo Gonalez <paola.ocampo@unach.mx>

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Para: Paola Ocampo González <paola.ocampo@unach.mx>

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Editor in Chief
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Comments to the authors:

Comments of the Associate editor:

I would like to thank the authors for submitting this manuscript to Mammalian Biology. It is an interesting and well

Mammalian Biology

Community Structure and Habitat Selection of Mammals in a Protected Area of the Sierra Madre de Chiapas

--Manuscript Draft--

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Corresponding Author:	Paola Ocampo González, Ph. D. Universidad Autonoma de Chiapas MEXICO
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universidad Autonoma de Chiapas
Corresponding Author's Secondary Institution:	
First Author:	Jenner Rodas-Trejo, M. Sc.
First Author Secondary Information:	
Order of Authors:	Jenner Rodas-Trejo, M. Sc.
	Paola Ocampo González, Ph. D.
	Sergio López, Ph. D.
	César Tejeda Cruz, Ph. D.
Order of Authors Secondary Information:	
Author Comments:	
Suggested Reviewers:	

Community Structure and Habitat Selection of Mammals in a Protected Area of the Sierra Madre de Chiapas

Jenner Rodas-Trejo[1,2], Paola Ocampo González[2*], Sergio López[3], César Tejeda Cruz[3]

[1] Programa de Doctorado en Ciencias en Biodiversidad y Conservación de Ecosistemas Tropicales, Instituto de Ciencias Biológicas, Universidad de Ciencias y Artes de Chiapas, Libramiento Norte Poniente 1150, C.P. 29039 Tuxtla Gutiérrez, Chiapas, México. https://orcid.org/0000-0001-6158-9734. https://orcid.org/0000-0001-6158-9734, jenner.rodas@unach.mx

[2] Escuela de Estudios Agropecuarios Mezcalapa, Universidad Autónoma de Chiapas, C.P. 29625, Copainalá, Chiapas, México. paola.ocampo@unach.mx

[3] Laboratorio de Ecología Evolutiva, Instituto de Ciencias Biológicas, Libramiento Norte Poniente 1150, C.P. 29039, Tuxtla Gutiérrez, Chiapas, México. https://orcid.org/0000-0001-5173-7238. https://orcid.org/0000-0001-5173-7238, sergio.lopez@unicach.mx; cesar.tejeda@unicach.mx, https://orcid.org/0000-0003-1636-0409

*Corresponding author: paola.ocampo@unach.mx

Abstract

This study evaluated the influence of landscape elements on the community structure and habitat selection of medium- and large-sized mammals in La Frailescana Natural Resource Protection Area, Chiapas, Mexico. Specifically, we analyzed the influence of environmental variables (distance to water bodies, altitude, and vegetation types) and anthropogenic factors (distance to human settlements, roads, and agricultural areas) on the mammal community. We installed 21 camera trap stations, accumulating 1,549 camera-days of sampling effort. Diversity and relative abundance indices were calculated, and generalized linear models were applied to evaluate the relationship between landscape variables and recorded mammals. We recorded 19 species of medium- and large-sized mammals, belonging to 12 families and 7 orders. The most abundant species were

*Pecari tajac*u and *Nasua narica*. Distance to water bodies had a significant negative effect on species abundance and richness, highlighting the importance of these water resources. Responses to human infrastructure revealed that *P. tajacu*, *Urocyon cinereoargenteus*, *Odocoileus virginianus*, and *Puma concolor* were more abundant away from human settlements, while rural roads generated varied responses. The results underscore the importance of considering landscape heterogeneity in conservation strategies. We recommend implementing measures that prioritize the conservation of key habitats, ensure connectivity between forest fragments, and minimize anthropogenic impacts to guarantee the persistence of biodiversity in the region.

Keywords: Camera trapping, Connectivity, Habitat selection, La Frailescana, Protected Natural Area, Terrestrial mammals

Introduction

Human activities have modified natural landscapes worldwide since ancient times, leading to habitat loss, fragmentation, and degradation. These changes disrupt ecosystem balance and affect species distribution and diversity patterns (Mayani-Parás et al. 2020; Torres-Romero et al. 2020; Chi et al. 2020). Such transformations are primarily driven by land-use changes due to agricultural expansion, infrastructure development, and human settlement growth (Hoffmann et al. 2011; Torres et al. 2016; Allan et al. 2019).

Mammals, as key components of terrestrial ecosystems, play crucial ecological roles, including trophic regulation, seed dispersal, and landscape modification (Jones and Safi 2011; Lacher et al. 2019). However, due to their spatial requirements, population densities, and susceptibility to anthropogenic pressures, they are particularly vulnerable to landscape changes and habitat connectivity loss (Ceballos et al. 2017; Lacher et al. 2019). These impacts not only directly affect populations but also trigger cascading effects that alter overall ecosystem dynamics (Jones and Safi 2011).

The Natural Resources Protection Area La Frailescana (La Frailescana) covers 116,743 hectares in the Sierra Madre of Chiapas, one of Mexico's most biodiverse regions. It serves as a strategic biological corridor connecting the La Sepultura and El Triunfo Biosphere Reserves, facilitating species movement and dispersal between these protected areas (Lorenzo et al. 2017; De la Torre et al. 2019). This region features an altitudinal gradient ranging from 800 to 2,280 meters above sea level, with annual precipitation between 800 and 4,000 mm and temperatures from 12 to 34.5°C. These environmental conditions have resulted in a mosaic of seven vegetation types across rugged terrain, including montane cloud forest, pine forest, and oak forest (CONANP, 2019). However, the expansion of productive activities such as agriculture and extensive cattle ranching poses a threat to these ecosystems and their function as a corridor (Pérez et al. 2006; CONANP 2008; CONANP 2019).

Understanding the factors influencing the diversity and abundance of terrestrial mammals is essential for designing effective conservation strategies (Sathyakumar et al. 2011). Environmental variables such as habitat type, vegetation structure, and resource availability determine habitat suitability for different species (Imre and Derbowka 2011; Ferreguetti et al. 2019). Assessing these patterns is crucial to understanding the mechanisms driving species responses to anthropogenic habitat modifications (Pacifici et al. 2020), particularly in protected areas where conservation and human development objectives converge (Olmos-Martínez et al. 2022).

In this context, this study evaluates how landscape elements influence the diversity and distribution patterns of medium- and large-sized mammals in La Frailescana. Specifically, we analyze the influence of natural variables (distance to water bodies, elevation, and vegetation types) and anthropogenic variables (distance to human settlements, roads, and agricultural areas). The study aims to: (1) characterize species richness, diversity, and relative abundance through camera trapping; (2) analyze community structure using diversity indices and occupancy patterns; (3) determine the influence of these variables on community parameters; and (4) identify species-specific responses to landscape variables.

Materials and Methods

Study Area

The study was conducted in the La Frailescana Natural Resource Protection Area (93°37'36"W, 16°16'08"N), located in the Sierra Madre of Chiapas, Mexico (Figure 1). This area covers 116,743 ha, with elevations ranging from 800 to 2,280 m asl, annual precipitation between 800 and 4,000 mm, and temperatures from 12°C to 34.5°C (DOF, 1979; CONANP, 2008). The vegetation comprises seven types: montane cloud forest

(25.15%; 29,360 ha), pine forest (37.18%; 43,409 ha), oak forest (0.81%; 942 ha), pine-oak forest (17.68%; 20,638 ha), tropical evergreen forest (0.31%; 363 ha), and tropical dry forest (1.25%; 1,463 ha). The area also includes agricultural activities (mainly maize and coffee), extensive cattle ranching (17.61%; 20,568 ha), and 162 human settlements (Pérez et al. 2006; CONANP 2019; CEIEG 2021).

Data Collection

Twenty-one camera trapping stations were installed between November 2021 and March 2023, distributed across four sites with montane cloud forest within La Frailescana (Figure 1). Each station consisted of a Moultrie® A-25i camera trap, placed at least 1,000 m apart to ensure spatial independence, and installed 50 cm above the ground in areas with evidence of animal activity. The cameras operated continuously, programmed to take three successive images per trigger with no delay between detections. Camera locations ranged from 922 to 1,856 m asl. Species identification was performed using Camelot software, considering only terrestrial mammals >0.5 kg. Independent records were defined as those separated by ≥60 minutes for the same species at the same station (Cusack et al. 2015; Ferreira et al. 2022; Rodas-Trejo 2024).

Landscape Metrics

Eight covariates were analyzed to assess the influence of environmental and anthropogenic factors on mammal richness and abundance. Environmental factors included altitude, distance to streams, and distance to pine forest. These environmental covariates are useful for identifying key areas for species persistence and survival (Joly and Myers, 2001; Rhim et al. 2014). Specifically, the distance to pine forest was included because pine forests are a critical vegetation type in the Sierra Madre de Chiapas, providing essential resources such as shelter, food, and connectivity corridors for many mammal species. This variable helps to understand habitat preferences and the role of pine forests in maintaining biodiversity and facilitating species movement across the landscape. Anthropogenic factors included distances to infrastructure and human settlements: main roads (paved with high traffic), rural roads (unpaved with low traffic), rural villages (fewer than 250 inhabitants), major towns (more than 250 inhabitants), and agricultural-livestock systems. These variables have been shown to significantly impact species distribution and survival and are key drivers of land cover change both globally and in Mexico (Mendoza-Ponce et al. 2018; Allan et al. 2019).

The minimum distances between each camera trap station and landscape elements were calculated using land-use cartographic data from CEIEG (2021), employing the st_distance() function from the sf package in R (Pebesma, 2018). Correlations among covariates were assessed using the Variance Inflation Factor (VIF) with the car package in R. Covariates were standardized (mean = 0, variance = 1), and those with VIF > 5 were excluded to prevent multicollinearity issues in subsequent analyses (Zuur et al. 2010; Fox and Weisberg 2019; Hernández et al. 2024).

Spatial autocorrelation was evaluated using Moran's I index with the nb2listw() function from the spdep package in R (Bivand et al. 2023). This analysis quantified spatial dependence among sampling stations, considering both geographic distances and species abundances, allowing for the establishment of neighborhood structures between sites (Carroll and Pearson 2000; Vieira et al. 2008).

Data Analysis

Mammal diversity was analyzed using Hill numbers (qD), which provide effective species numbers at different diversity orders: 0D (total species richness), 1D (exponential of Shannon, common species), and 2D (inverse of Simpson, dominant species). The iNEXT package was used to construct interpolation and extrapolation curves for species richness. Sampling robustness was evaluated through non-parametric estimators (Chao, Jackknife1, and Bootstrap) to compare observed and expected richness (Hill 1973; Jost 2007; Chao et al. 2014; Hsieh et al. 2016).

The Relative Abundance Index (RAI) was calculated for each species as: RAI=independent recordscamera-days×100RAI=camera-days independent records ×100 (O'Brien, 2010). Naïve occupancy was obtained to determine the proportion of sites occupied by each species (Soto-Werschitz et al. 2023). The relationship between spatial distribution and abundance was evaluated using the correlation between RAI and naïve occupancy (Mandujano and Pérez-Solano 2019). Rank-abundance curves were generated to visualize the hierarchical structure of the community (Rocchini and Neteler 2012).

The relationship between landscape variables and species abundance and richness patterns was analyzed using generalized linear models (GLMs) with the MASS package, considering species with more than 14 independent records (Smith and Warren 2019; Ripley 2023). Poisson models were initially used, but in cases of overdispersion and poor model fit, negative binomial models were applied (Hoef and Boveng 2007). Model selection was based on the Akaike Information Criterion (AIC) (Burnham and Anderson 2002). In some cases, models were simplified by reducing the number of variables to improve fit.

Results

Abundance and species composition

The total sampling effort was 1,549 camera-days, documenting 19 species of medium- and large-sized wild mammals, belonging to 12 families and 7 orders. Carnivora and Cetartiodactyla dominated taxonomic diversity, with five and two families, respectively (Table 1). Species richness per station ranged from 2 to 10 species (mean = 5.95 ± 2.80 SD). Regarding conservation status, *Tapirus bairdii* is classified as Endangered, *Leopardus wiedii* and *Panthera onca* as Near Threatened, *Mazama temama* as Data Deficient, and the remaining 15 species as Least Concern (IUCN 2022).

The species with the highest RAI were: *Pecari tajacu* (RAI=14.39), *N*asua *narica* (RAI=9.03), *Didelphis marsupialis* (RAI=3.16), *Odocoileus virginianus* (RAI=2.45), *Cuniculus paca* (RAI=2.32). In contrast, those with the lowest RAI were: *Tamandua mexicana* (RAI=0.13), *Bassariscus sumichrasti* (RAI=0.13), *T. bairdii* (RAI=0.19), and *Spilogale angustifrons* (RAI=0.19). Naïve occupancy showed a similar pattern with *P. tajacu*, *O. virginianus*, and *N. narica* occupying the highest proportion of sites (76%, 62%, and 48% respectively), while *B. sumichrasti*, *T. mexicana*, *T. bairdii*, *S. angustifrons*, and *P. onca* occupied less than 15% of the sites (Table 1). The strong correlation (78%) between RAI and naïve occupancy (Figure 3), particularly evident in *P. tajacu* and *N. narica*, along with the rank-abundance curve, confirm a typical community structure with a few dominant species and several rare ones (Figure 4).

Hill numbers revealed a well-sampled and complete community, with an observed richness of 19 species (0D, 95% CI: 19.00–20.67), which aligns with the asymptotic estimation, suggesting that the sampling captured most of the species present. The diversity of common species (1D = 8.47, 95% CI: 8.35–9.23) indicates moderate evenness in the community, while the effective number of dominant species (2D = 5.32, 95% CI:

5.28–5.91) suggests a hierarchical structure with a few predominant species (Figure 2). Non-parametric species richness estimators yielded values close to observed richness. The Chao estimator suggested a richness of 19.16 species (SE = 0.52), first-order Jackknife estimated 19.95 species (SE = 0.95), and Bootstrap estimated 19.83 (SE = 0.80).

Moran's I test produced a statistic of 0.003, with an expected value of -0.05, indicating no statistically significant evidence of spatial autocorrelation in the total mammal abundance data within the study area. This suggests that mammal abundance is uniformly distributed without significant clustering or dispersion patterns. The covariates distance to major populations and distance to main roads showed multicollinearity >5 and were excluded from the GLM analyses.

Habitat Preferences and Landscape Features

Generalized linear models revealed significant patterns in mammal responses to the evaluated variables. Abundance showed a significant negative relationship with distance to water bodies ($z = -3.468$, $P < 0.05$), suggesting that individuals concentrate in greater numbers near water sources and their abundance decreases as the distance increases. Conversely, a positive relationship was observed with distance to pine forests ($z = 2.145$, $P < 0.05$) and human settlements ($z = 3.637$, $P < 0.05$), suggesting that species tend to be more abundant in areas farther from these landscape elements. In contrast, species richness showed only one significant relationship, manifesting as a negative association with distance to water bodies ($z = -2.313$, $P < 0.05$). This underscores the critical importance of water resources for maintaining species diversity in the area (Table 2 and Figure 5).

The species-level analysis revealed different habitat selection patterns. *P. tajacu* showed a strong positive association with distance to settlements ($z = 4.101$, $P < 0.05$), indicating a preference for areas farther from human habitation. It also exhibited significant negative relationships with distance to water bodies ($z = -2.727$, $P < 0.05$) and altitude ($z = -2.327$, $P < 0.05$), suggesting a preference for locations near rivers or streams and at lower elevations. Additionally, a marginal positive trend was observed with distance to pine forests ($z = 1.716$, $P = 0.08$). *O. virginianu*s selected areas far from settlements ($z = 2.01$, $P < 0.05$) but close to rural roads ($z = -2.26$, $P < 0.05$), suggesting that the species may use roads as movement corridors while avoiding areas with higher human presence. *M. temama* showed a strong negative association with distance to rural roads ($z = -2.172$, $P < 0.05$), indicating a preference for areas nearby. A marginal positive trend with altitude ($z = 1.660$, $P = 0.09$) was also observed, suggesting a slight preference for higher elevations (Table 2, Figure 5).

C. paca exhibited a strong negative relationship with altitude ($z = -2.92$, $P < 0.05$), favoring lower areas. *D. marsupialis* only showed a marginal preference for areas near streams ($z = -1.916$, $P = 0.056$). *Dasypus novemcinctus* displayed a marginal positive relationship with distance to pine forests ($z = 1.831$, $P = 0.067$), suggesting a slight preference for areas farther from these forest formations. *N. narica* had a strong negative relationship with distance to water bodies ($z = -3.056$, $P < 0.05$), indicating a clear preference for areas near water sources. Additionally, a marginal positive trend was observed with distance to pine forests ($z = 1.781$, $P = 0.07$). *Urocyon cinereoargenteus* preferred areas far from settlements ($z = 5.087$, $P < 0.05$), while showing significant negative relationships with distance to rural roads ($z = -4.867$, $P < 0.05$), water bodies ($z = -2.946$, $P < 0.05$), and agricultural zones ($z = -2.261$, $P < 0.05$). This pattern suggests that the species favors areas away from settlements but close to rural roads, water sources, and agricultural zones. *Eira barbara* exhibited a significant positive relationship with distance to rural roads ($z = 2.217$, $P < 0.05$), indicating a preference for areas farther from roads. It also showed a significant negative relationship with altitude ($z = -1.979$, $P < 0.05$), demonstrating a clear selection for lower-altitude areas (Table 2, Figure 5).

Felids exhibited species-specific response patterns. *Leopardus pardalis* showed a preference for areas near pine forests ($z = -2.531$, $P < 0.05$). In contrast, *L. wiedi*i presented a more complex pattern, selecting areas away from rural roads ($z = 4.696$, $P < 0.001$) but showing significant negative relationships with distance to pine forests ($z = -2.500$, $P < 0.05$) and water bodies ($z = -2.535$, $P < 0.05$), indicating a preference for areas close to these landscape features. Additionally, marginal negative trends were observed with distance to agricultural zones ($z = -1.85$, $P = 0.063$) and human settlements ($z = -1.83$, $P = 0.067$), suggesting a slight preference for areas near these landscape elements. *Puma concolo*r exhibited only a marginal positive trend with distance to human settlements ($z = 1.826$, $P < 0.067$), suggesting a slight preference for areas farther from direct human influence (Table 2, Figure 5).

Poisson error distribution models fit well for species richness and the abundances of *L. pardalis*, *C. paca*, as well as for *L. wiedii*, *E. barbara*, and *U. cinereoargenteus* in models with a reduced number of variables. Negative binomial distribution provided a better fit for total abundance and for *P. tajacu*, as well as for *O. virginianus*, *M. temama*, *N. narica*, *D. marsupialis*, *D. novemcinctus*, and *P. concolor* in simplified models with fewer variables.

Discussion

The Sierra Madre of Chiapas harbors a remarkable diversity of medium- and large-sized mammals. This species richness is maintained within the complex of protected areas that form the Sierra Madre of Chiapas, including the La Frailescana, La Sepultura, and El Triunfo Biosphere Reserves, which together constitute a strategic biological corridor for mammal conservation in the region (Lorenzo et al. 2017; De la Torre et al. 2019).

Abundance and Species Composition

Of the total medium- and large-sized mammal species documented for La Sepultura, El Triunfo, and La Frailescana, 63.33% of the expected species were recorded, with 11 species remaining undetected (Medinilla et al. 2004; Medinilla et al. 2014; CONANP 2019). The absence of species such as *Procyon lotor*, *Dasyprocta punctata*, and *Canis latrans*, among others, could be explained by inherent limitations of camera trapping and the concentration of sampling in only one vegetation type, which may have biased the detection of species associated with other habitats present in the area (Burton et al. 2015; Andrade-Ponce et al. 2021).

The results from La Frailescana reveal a structured and diverse community of medium- and large-sized mammals, with 19 species displaying complex response patterns to landscape characteristics and human influence. The hierarchical structure of the community, evidenced by Hill numbers (0D = 19, 1D = 8.47, 2D = 5.32), indicates a distribution in which approximately 45% of species are common and 28% are dominant, suggesting a relatively balanced community. The mammal community structure in La Frailescana exhibited clear hierarchical patterns, with species such as *P. tajacu* (RAI = 14.39) and *N. narica* (RAI = 9.03) dominating the assemblage. The strong correlation (78%) between RAI and naïve occupancy indicates that the most abundant species also occupy a larger proportion of the landscape, a pattern that may be related to the ability of these species to adapt to heterogeneous landscapes (Cove et al. 2014; Falconi-Briones et al. 2022).

The presence of protected and disturbance-sensitive species such as *T. bairdii, P. onca, P. concolor, L. wiedii*, and *L. pardalis* at the 21 sampling stations confirms the importance of the area for regional conservation. In the case of *T. bairdii* and *P. onca*, both species were recorded in La Frailescana at low abundances, consistent with the findings of De la Torre et al. (2019) and Rivero et al. (2021). The low number of independent records obtained for both species ($n < 14$) limited statistical evaluation of their relationship with landscape variables. However, distribution patterns indicated that both species select areas of higher elevation and greater topographic complexity, particularly in pine-oak and cloud forests. The convergence of both species in high and topographically complex areas may represent a response to increased anthropogenic pressures in lower and more accessible areas (Gonzalez-Maya et al. 2009). De la Torre et al. (2018, 2019) documented that the primary threat to *P. onca* in La Frailescana was livestock conflict, whereas for *T. bairdii*, it was poaching. This may explain why both species seek refuge in higher elevations where the habitat remains more preserved and less accessible, suggesting that the conservation of these mountainous areas is crucial for their persistence in the region.

Habitat Preferences and Landscape Features

Results revealed that the distance to water bodies emerged as a critical factor in the spatial structuring of the mammal community, a pattern consistent with findings in other Neotropical ecosystems (Reyna-Hurtado et al. 2010; Delgado-Martínez et al. 2023). The significant negative relationship between overall abundance and species richness with distance to water bodies suggests that this resource acts as a structuring element of the landscape (Reyna-Hurtado et al. 2010; Chamaillé-Jammes et al. 2016). This pattern was particularly evident in five species (*N. narica, P. tajacu, L. wiedii, D. marsupialis*, and *U. cinereoargenteus*), which showed a strong association with areas near water. The association of *N. narica*, *P. tajacu*, and *D. marsupialis* with these water bodies may be explained by multiple factors, including the need for thermoregulation, other physiological processes, or the greater availability of food resources in these areas due to the higher plant species richness found along riparian zones (Hafez 1964; Brown et al. 2008; Reyna-Hurtado et al. 2010).

Additionally, riparian habitat strips function as natural corridors that facilitate species movement and dispersal between habitat fragments, which could explain the observed abundance and richness patterns near these areas (Brown et al. 2008). For *L. wiedii* and *U. cinereoargenteus*, the association with areas close to water could be related to hunting strategies, as water bodies may attract potential prey (Harris et al. 2015). The dependence of overall richness and abundance, as well as that of certain species, suggests that water bodies should be considered critical elements in the area's management and conservation strategies.

The response to human infrastructure revealed that *P. tajacu, U. cinereoargenteus* ($P<0.001$), *O. virginianus* ($P<0.05$), and *P. concolor* ($P<0.1$) were more abundant farther from human settlements. For *P. tajacu* and *O. virginianus*, this pattern could be related to the fact that these species are frequently hunted for subsistence in rural Neotropical communities (Nájera et al. 2018), while for *P. concolor* and *U. cinereoargenteus*, avoidance may be linked to reduced prey availability and as a strategy to minimize encounters with humans due to human-wildlife conflicts over livestock predation, which often results in retaliatory hunting (Rodas-Trejo et al. 2016; Nájera et al. 2018; De la Torre et al. 2019).

The response to rural roads showed complex and contrasting patterns among species. While *L. wiedii* exhibited strong avoidance ($P<0.001$), consistent with findings by Goulart et al. (2009) in the Atlantic Forest of southern Brazil, where *L. wiedii* preferentially selected narrow trails and areas with dense forest cover while avoiding wider roads and open areas, other species showed more flexible responses. For instance, *O. virginianus* exhibited a dual response: while it avoided human settlements, it was more abundant near rural roads ($P<0.05$), suggesting that it uses these roads as corridors though maintaining a safe distance from human-populated areas to reduce the risk of poaching or predation (Ramos-Robles et al. 2013; Henderson et al. 2023; Ganz et al. 2024). Similarly, *M. temama* displayed a complex pattern reflecting its habitat specialization. Although it showed a positive association with rural roads ($P<0.05$), it also tended to use higher elevation areas. This apparent contradiction can be explained by the species' strategy of using rural roads as movement corridors to access different patches of suitable habitat, while favoring higher elevation areas where the most conserved zones of the reserve are located. These elevated areas likely provide anti-predator advantages and access to specific food resources, such as dense forest cover, which offers vertical protection and foraging opportunities (Contreras-Moreno et al. 2016; CONANP 2019; Vazquez and Tessaro

2016). This dual behavior highlights the species' ability to balance mobility and safety in a heterogeneous landscape. In the case of *U. cinereoargenteus*, this species avoided human settlements but showed higher abundance near rural roads (*P*<0.05). This ecological flexibility reflects its ability to exploit heterogeneous landscapes and coexist with human activities, which aligns with its generalist and opportunistic habits in terms of both habitat use and diet (Gallina et al. 2016; Wong-Smer et al. 2022).

E. barbara showed a preference for avoiding roads and low-altitude areas (P<0.05), findings consistent with the literature. Bianchi et al. (2021) found that the presence of this species is positively related to forest cover and proximity to water bodies, while its presence decreases in landscapes dominated by grasslands or near human infrastructure such as roads and buildings. Goulart et al. (2009) also reported that *E. barbara* avoids wide roads and prefers moving through animal paths and areas with dense vegetation cover, suggesting a greater dependence on habitat structure. The decrease in its presence with altitude could be related to changes in the availability of shelter and food resources, as well as to forest structure, which favors its scansorial behavior, and to more favorable microclimatic conditions for a species that maintains high metabolic rates (Bianchi et al. 2021).

The results on habitat preferences of mammals in La Frailescana reveal interesting patterns that partially align with those reported by Lorenzo et al. (2017) for temperate and pine forests in Chiapas. Felids such as L. pardalis and *L. wiedii* showed a clear preference for areas near pine forests, consistent with studies highlighting the importance of these ecosystems for carnivorous species that require well-preserved and heterogeneous habitats (Di Bitetti et al. 2008; Espinosa et al. 2017). In contrast, more generalist species such as *N. narica*, *P. tajacu*, and *D. novemcinctus* tended to increase in abundance farther from pine forests, which could be explained by their adaptability to disturbed habitats and ecotones, as also suggested in studies describing their plasticity in response to land-use changes (De Matos Dias et al. 2018; Mendoza et al. 2019). Overall mammal abundance showed a positive pattern away from pine forests, which may seem contradictory to reports by Lorenzo et al. (2017) regarding high diversity in these ecosystems in Chiapas. However, our findings suggest that this pattern could be explained by the numerical dominance of generalist species in the study area, as well as by the conservation status and specific configuration of pine forests in La Frailescana. These factors emerged as key determinants in the distribution patterns of mammalian fauna in our study, highlighting how local conditions and species composition can influence ecological patterns differently than those reported in broader regional studies.

Lastly, the results of this study emphasize the need to understand how landscape heterogeneity and habitat characteristics influence mammal distribution. Given the multiple threats faced by wildlife in the Sierra Madre de Chiapas, including habitat loss, poaching, and human encroachment, it is crucial to strengthen conservation strategies that mitigate these impacts (Lorenzo et al. 2017; De la Torre et al. 2018, 2019; Rivero et al. 2021). In particular, improving knowledge on the distribution and ecological requirements of endemic and endangered species will provide a stronger basis for evidence-based conservation planning.

Conservation Implications

The findings of this study highlight the importance of preserving landscape heterogeneity in La Frailescana to ensure the persistence of medium- and large-sized mammals. The identification of water bodies as structuring elements of the mammal community suggests the need to establish specific protection measures for these areas, including maintaining riparian zones and regulating human activities in their vicinity. Furthermore, the avoidance of human settlements by sensitive species indicates that fragmentation and anthropogenic pressure can negatively affect wildlife distribution, emphasizing the urgency of management strategies that minimize the impact of agricultural expansion and infrastructure development. The presence of threatened species such as *T. bairdii* and *P. onca* in high-elevation areas underscores the need to strengthen the protection of these mountainous regions. Implementing biological corridors and restoring degraded habitats in key areas particularly those with high species diversity and low human presence can enhance landscape connectivity and reduce the effects of population isolation. This study provides valuable information to guide conservation policies in the region, promoting the design of evidence-based strategies that integrate the protection of critical habitats with sustainable development compatible with biodiversity conservation.

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Competing Interests

The authors declare that they have no competing interests.

Author Contributions Statement

Conceptualization: J.R.T., S.L. Data curation: J.R.T. Formal analysis: J.R.T., C.T.C, S.L. Investigation: J.R.T., C.T.C, S.L., P.O.G. Methodology: J.R.T., C.T.C, S.L., Resources: J.R.T., P.O.G. Writing –original draft: J.R.T. Writing –review & editing: J.R.T., C.T.C, S.L., P.O.G.

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Declarations

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

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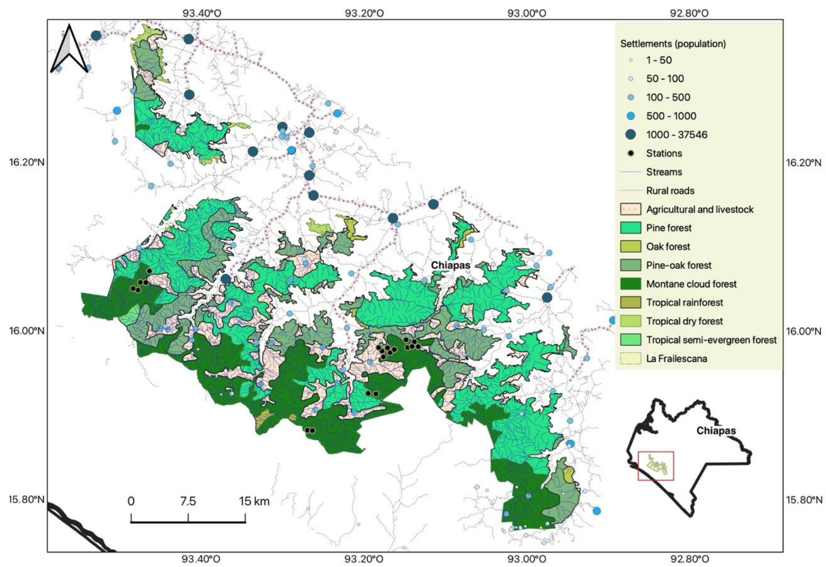

Fig 1. Study area and location of the 21 sampling sites in the La Frailescana Natural Resources Protection Area.

Table 1. Species richness of mammals, conservation status categories, independent observations, Relative Abundance Index, and naïve occupancy in the La Frailescana Natural Resources Protection Area.

Taxa	**Common name**	**Obs**	**RAI**	**Naïve**	**UICN**
CARNIVORA					
Canidae					
Urocyon cinereoargenteus	Gray Fox	30	1.93	0.29	LC
Mephitidae					
Conepatus leuconotus	American Hog-nosed Skunk	4	0.25	0.10	LC
Spilogale angustifrons	Southern Spotted Skunk	3	0.19	0.14	LC

Mustelidae					
Eira barbara	Tayra	16	1.03	0.24	LC
Felidae					
Leopardus pardalis	Ocelot	15	0.96	0.43	LC
Leopardus wiedii	Margay	27	1.74	0.19	NT
Panthera onca	Jaguar	4	0.25	0.14	NT
Puma concolor	Puma	14	0.90	0.29	LC
Puma yagouaroundi	Jaguarundi	4	0.25	0.19	LC
Procyonidae					
Nasua narica	White-nosed Coati	140	9.03	0.48	LC
Bassariscus sumichrasti	Cacomixtle	2	0.12	0.05	LC
CETARTIODACTYLA					
Tayassuidae					
Pecari tajacu	Collared Peccary	224	14.39	0.76	LC
Cervidae					
Mazama temama	Central American Red Brocket	16	1.03	0.33	DD
Odocoileus virginianus	White-tailer Deer	38	2.45	0.62	LC
CINGULATA					
Dasypodidae					
Dasypus novemcinctus	Nine-banded Armadillo	14	0.90	0.33	LC
DIDELPHIMORPHIA					
Didelphidae					
Didelphis marsupialis	Common opossum	49	3.16	0.43	LC
PERISSODACTYLA					

Tapiridae					
Tapirus bairdii	Baird's Tapir	3	0.19	0.10	EN
PILOSA					
Myrmecophagidae					
Tamandua mexicana	Northern Tamandua	2	0.12	0.10	LC
RODENTIA					
Cuniculidae					
Cuniculus paca	Agouti	36	2.32	0.38	LC

Obs= Number of independent observations recorded; RAI= Relative Abundance Index; DD= Data deficient, LC= Least concern, NT= Near Threatened, CR= Critically endangered, A= Threatened, P= Endangered, Sites = sites where the CTs were installed, Group = Groups identified in the cluster analysis (IUCN, 2022).

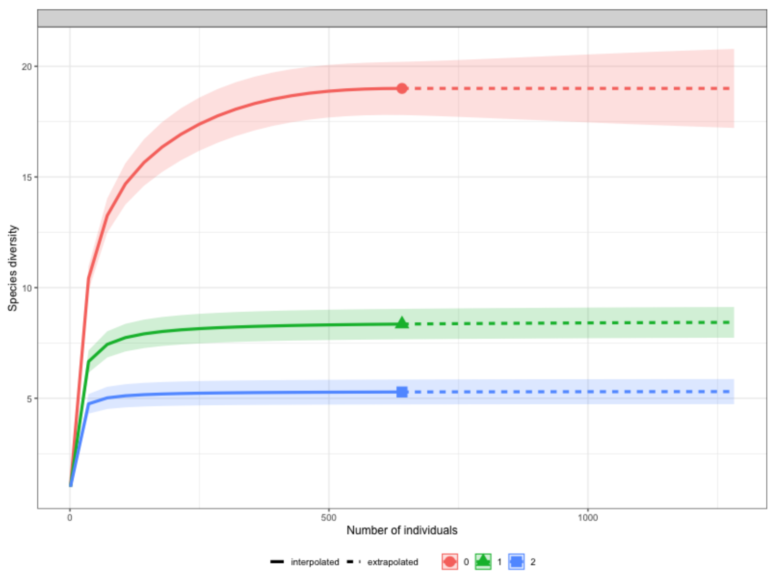

Fig 2. Rarefaction curves of diversity based on the sample and extrapolated curves with 95% confidence intervals. Expected diversity ^{q}D is shown as a function of the number of individuals with q = 0, 1, 2.

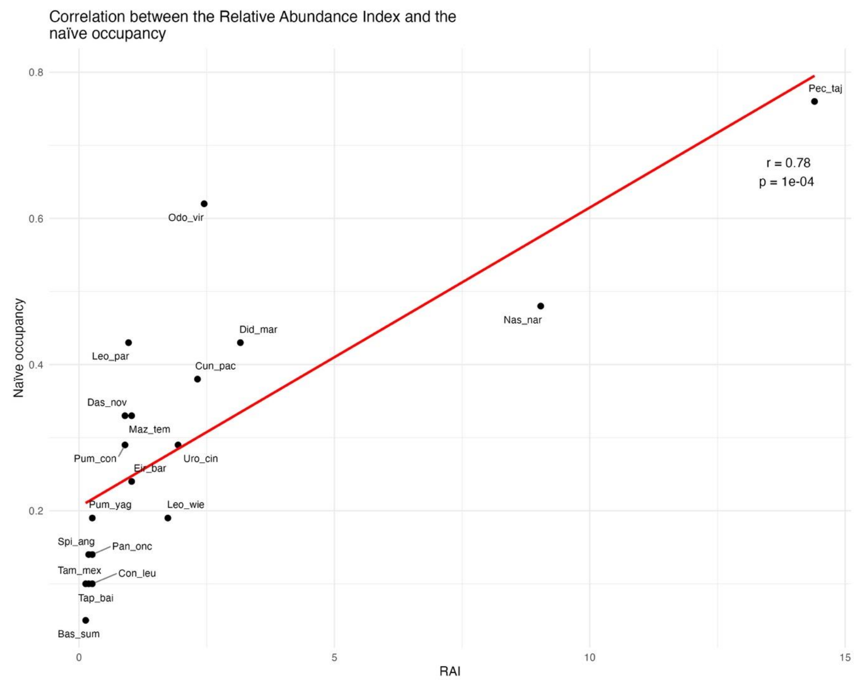

Fig 3. Correlation between the Relative Abundance Index and naïve occupancy. Bas_sum= *Bassariscus sumichrasti*, Con_leu= *Conepatus leucotonus*, Cun_pac = *Cuniculus paca*, Das_nov= *Dasypus novemcinctus*, Did_mar= *Didelphis marsupialis*, Eir_bar= *Eira barbara*, Leo_par= *Leopardus pardalis*, Leo_wie= *Leopardus wiedii*, Maz_tem= *Mazama temama*, Nas_nar= *Nasua narica*, Odo_vir= *Odocoileus virginianus*, Pan_onc= *Panthera onca*, Pec_taj= *Pecari tajacu*, Pum_con= *Puma concolor*, Pum_yag= *Puma yagouaroundi*, Spi_ang= *Spilogale angustifrons*, Tam_mex= *Tamandua mexicana*, Tap_bai= *Tapirus bairdii*, Uro_cin= *Urocyon cinereoargenteus*.

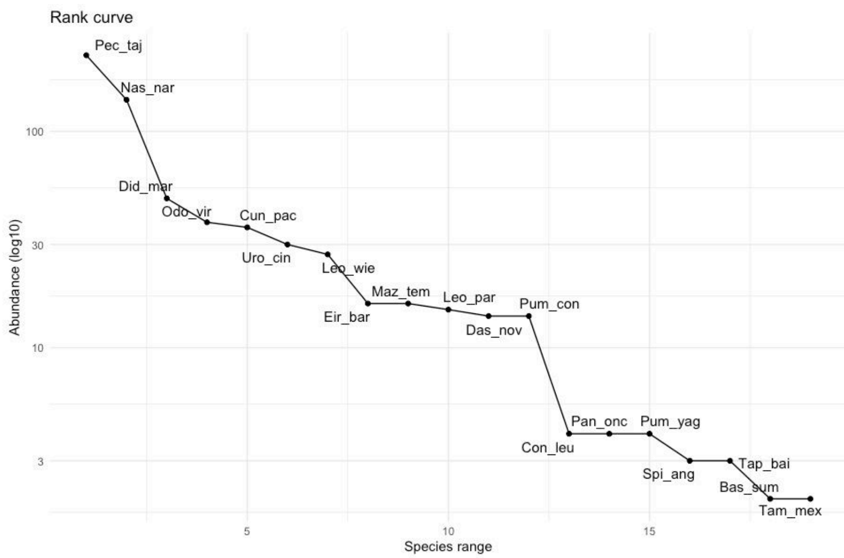

Fig 4. Rank-abundance curve. Species are identified by their codes, as shown in Figure 3.

Table 2. Generalized Linear Models (GLM) of the relationship between environmental variables and the patterns of abundance and richness of medium and large mammals in La Frailescana, Chiapas. Covariates: distances to agricultural areas (dist_agri_farm), pine forests (dist_pine), water bodies (dist_stre), rural roads (dist_rural_road), altitude (dist_altitude), and villages (dist_town). Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1.AIC = Akaike Information Criterion.

Variable	Estimate	Std. Error	z value	P value	Sig	AIC
Abundance	--------:	----------:	-------:	----------------:	:---	1030
(Intercept)	0.2152	0.1385	1.554	0.1202		
dist_agri_farm	-0.1739	0.2099	-0.829	0.4073		
dist_pine	0.3969	0.1851	2.145	0.0320	*	
dist_stre	-0.5554	0.1602	-3.468	0.0005	***	

dista_rural_road	-0.0463	0.2037	-0.227	0.8201		
dist_town	0.6025	0.1657	3.637	0.0003	***	
dist_altitude	-0.2427	0.1687	-1.439	0.1501		
Richness	--------:	----------:	-------:	----------------:	:---	105
(Intercept)	1.7414	0.0934	18.638	<2e-16	***	
dist_agri_farm	-0.1370	0.1422	-0.963	0.3353		
dist_pine	0.0982	0.1254	0.783	0.4338		
dist_stre	-0.2596	0.1122	-2.313	0.0207	*	
dista_rural_road	0.0355	0.1326	0.268	0.7891		
dist_town	0.1311	0.1084	1.209	0.2267		
dist_altitude	0.0113	0.1168	0.096	0.9232		
Pecari tajacu	--------:	----------:	-------:	----------------:	:---	136
(Intercept)	4.7403	1.6145	2.936	0.0033	**	
dist_agri_farm	-0.0008	0.0006	-1.405	0.1599		
dist_pine	0.0005	0.0003	1.716	0.0861	.	
dist_stre	-0.0093	0.0034	-2.727	0.0064	**	
dista_rural_road	-0.0010	0.0007	-1.609	0.1075		
dist_town	0.0008	0.0002	4.101	4.11E-05	***	
dist_altitude	-0.0025	0.0011	-2.327	0.0200	*	
Leopardus pardalis	--------:	----------:	-------:	----------------:	:---	50.2
(Intercept)	-2.7550	1.7520	-1.573	0.1158		
dist_agri_farm	-0.0005	0.0005	-0.951	0.3418		
dist_pine	-0.0009	0.0004	-2.253	0.0243	*	
dist_stre	-0.0078	0.0066	-1.184	0.2365		
dista_rural_road	0.0011	0.0009	1.218	0.2234		

dist_town	0.0001	0.0003	0.217	0.8283		
Mazama temama	--------:	----------:	-------:	----------------:	:---	51.8
(Intercept)	-3.65658	3.636409	-1.006	0.3146		
dist_pine	0.00056	0.000417	1.345	0.1788		
dista_rural_road	-0.0019	0.000877	-2.172	0.0298	*	
dist_altitude	0.00358	0.002156	1.66	0.0969	.	
Odocoileus virginianus	--------:	----------:	-------:	----------------:	:---	78.7
(Intercept)	1.5446	1.1521	1.341	0.1801		
dista_rural_road	-0.0016	0.0007	-2.265	0.0235	*	
dist_town	0.0004	0.0002	2.01	0.0444	*	
Nasua narica	--------:	----------:	-------:	----------------:	:---	101
(Intercept)	-0.9349	2.0040	-0.467	0.6409		
dist_pine	0.0009	0.0005	1.781	0.0749	.	
dista_rural_road	0.0013	0.0009	1.474	0.1404		
dist_stre	-0.0215	0.0070	-3.056	0.0022	**	
Didelphis marsupialis	--------:	----------:	-------:	----------------:	:---	82.4
(Intercept)	-1.2347	1.8487	-0.668	0.5042		
dist_pine	0.0007	0.0004	1.57	0.1164		
dist_town	0.0003	0.0003	1.127	0.2599		
dist_stre	-0.0112	0.0059	-1.916	0.0553	.	
Cuniculus paca	--------:	----------:	-------:	----------------:	:---	45.2
(Intercept)	5.4880	2.1130	2.598	0.0094	**	
dist_agri_farm	0.0011	0.0011	1.013	0.3111		
dist_pine	0.0000	0.0006	-0.058	0.9541		
dist_stre	-0.0055	0.0042	-1.302	0.1930		

dista_rural_road	0.0005	0.0013	0.343	0.7313		
dist_town	0.0000	0.0004	-0.107	0.9149		
dist_altitude	-0.0057	0.0019	-2.92	0.0035	**	
Urocyon cinereoargenteus	--------:	----------:	-------:	----------------:	:---	50.7
(Intercept)	3.1154	0.8848	3.521	0.0004	***	
dist_agri_farm	-0.0021	0.0009	-2.261	0.0237	*	
dist_stre	-0.0263	0.0089	-2.946	0.0032	**	
dista_rural_road	-0.0031	0.0006	-4.867	1.13E-06	***	
dist_town	0.0013	0.0003	5.087	3.64E-07	***	
Leopardus wiedii	--------:	----------:	-------:	----------------:	:---	48.8
(Intercept)	-3.3773	2.5738	-1.312	0.19		
dist_agri_farm	-0.0017	0.0009	-1.855	0.0637	.	
dist_pine	-0.0017	0.0007	-2.5	0.0124	*	
dist_stre	-0.0137	0.0054	-2.535	0.0113	*	
dista_rural_road	0.0065	0.0014	4.696	2.65E-06	***	
dist_town	-0.0011	0.0006	-1.83	0.0672	.	
Dasypus novemcinctus	--------:	----------:	-------:	----------------:	:---	54.1
(Intercept)	-5.1191	2.9708	-1.723	0.0849	.	
dist_pine	0.0014	0.0007	1.831	0.0670	.	
dist_stre	-0.0098	0.0062	-1.572	0.1160		
dist_town	0.0005	0.0003	1.512	0.1306		
Puma concolor	--------:	----------:	-------:	----------------:	:---	53.9
(Intercept)	-1.7575	2.3800	-0.738	0.4603		
dist_pine	0.0006	0.0005	1.154	0.2484		

dista_rural_road	-0.0013	0.0010	-1.277	0.2018		
dist_stre	-0.0049	0.0067	-0.737	0.4610		
dist_town	0.0007	0.0004	1.826	0.0679	.	
Eira barbara	--------:	----------:	-------:	----------------:	:---	39.3
(Intercept)	-1.81654	4.092988	-0.444	0.6572		
dista_rural_road	0.0035	0.00158	2.217	0.0267	*	
dist_altitude	-0.00326	0.001645	-1.979	0.0478	*	
dist_agri_farm	-0.00185	0.001256	-1.473	0.1407		

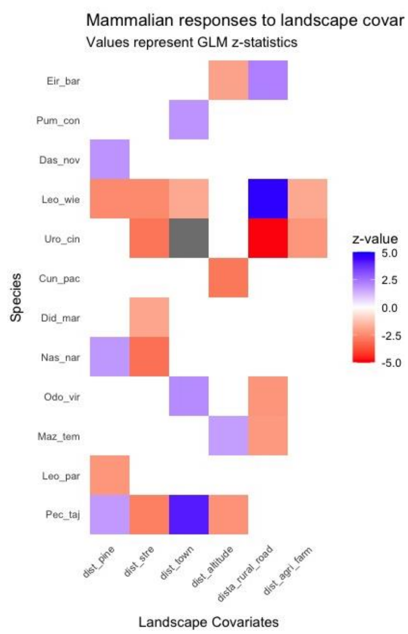

Fig 5. Relationship between the relative abundance of mammals and landscape variables in La Frailescana, Chiapas. The heat map shows the z statistics of the GLMs, where blue (z > 0) indicates positive associations and red negative associations (z < 0), with the color intensity reflecting the magnitude of the effect. Variables:

distances to agricultural areas (dist_agri_farm), pine forests (dist_pine), water bodies (dist_stre), rural roads (dist_rural_road), villages (dist_town), and altitude (dis_altitude). Species are identified by their codes, as shown in Figure 3. Significant ($P<0.05$) and marginally significant ($P<0.1$) relationships are shown. Blank cells indicate the absence of a significant effect.

CAPÍTULO VII

DISCUSIÓN Y CONCLUSIONES GENERALES

7.1 Discusión general

7.1.1 Síntesis y Alcance de la Investigación

El objetivo general de la tesis fue evaluar los efectos de los atributos del paisaje y la influencia de las actividades humanas sobre la estructura, composición y patrones de diversidad de las comunidades de mamíferos medianos y grandes en dos Áreas Naturales Protegidas en Chiapas, México. Para ello, la investigación se estructuró en diferentes capítulos que abordan aspectos clave sobre la diversidad y la influencia de los factores ambientales y antropogénicos en la distribución de estas especies

7.1.2 Estado del Conocimiento: Análisis de la Literatura sobre Efectos del Paisaje en Mamíferos

El primer objetivo de la tesis fue realizar una revisión y análisis del conocimiento sobre los efectos de los atributos del paisaje en mamíferos terrestres medianos y grandes no voladores, a través de estudios realizados con cámaras trampa. Para ello, se realizó una revisión sistemática que presenta un meta análisis de estudios de 2010-2023, que explora los efectos de los atributos del paisaje y la fragmentación del hábitat en las poblaciones de mamíferos terrestres de tamaño mediano y grande, destacando el papel de la ecología del paisaje en la conservación de la biodiversidad. La revisión documentó un incremento notable en el número de publicaciones sobre el tema, particularmente en los últimos seis años, donde se concentró el 66.11% de los artículos analizados. Este crecimiento refleja tanto el mayor interés en comprender los efectos del paisaje sobre la fauna como la consolidación de las cámaras trampa como herramienta metodológica robusta. Como señalan Burton et al., (2015) y Steenweg et al., (2016), este aumento se ha visto facilitado por la reducción en los costos del equipo, avances en software de análisis, mayor acceso a sistemas de información geográfica y disponibilidad de imágenes satelitales de alta resolución.

La distribución geográfica de los estudios mostró que América (Brasil, México y Argentina), Asia y África, fueron los continentes con el mayor número de estudios. Esto contrasta con revisiones anteriores como las de McCallum (2012) y Uuemaa et al., (2013) que encontraban una dominancia de estudios en Norteamérica. Este cambio podría reflejar una mayor accesibilidad a la tecnología en países en desarrollo, la formación de redes de investigación regionales y el reconocimiento de la urgencia de estudiar ecosistemas tropicales amenazados.

La mayoría de los estudios se enfocaron en comunidades completas de mamíferos (68.89%), mientras que solo el 16.11% abordaron especies específicas. Carroll et al., (2003), menciona que el enfoque multiespecie puede ser más eficiente para la conservación de la biodiversidad, aunque podría ser menos efectivo para especies particulares que requieren estrategias específicas. En cuanto a las variables de respuesta más estudiadas, la riqueza de especies (28.45%) y ocupación (25.63%) fueron las más abordadas, seguidas de la abundancia relativa (12.39%). El predominio de estas variables refleja tanto su importancia ecológica como las limitaciones inherentes al fototrampeo. Moeller et al. (2018) y Gilbert et al. (2020), señalan que una limitación importante de las cámaras trampa es la dificultad para identificar individuos específicos, lo que complica estimaciones más precisas de densidad poblacional.

La revisión identificó patrones en la respuesta de los mamíferos a ciertos atributos del paisaje. Los factores más frecuentemente estudiados fueron los disturbios humanos como infraestructura y asentamientos, la cantidad de hábitat disponible y factores abióticos como altitud y precipitación. Esto demuestra el interes de conocer los efectos de los impactos humanos y algunas características del paisaje sobre las especies de mamíferos, con la finalidad de establecer estrategias de conservación. Existe un debate científico sobre la importancia relativa de las características del fragmento *versus* la pérdida total de hábitat (Fahrig 2013; Hanski 2015). Los resultados sugieren que la cantidad de hábitat disponible podría ser más importante que las características específicas de los fragmentos.

Se identificaron que los mayores impactos sobre la riqueza y abundancia de mamíferos de los atributos del paisaje, fueron la cobertura forestal, la conectividad y la proximidad a cuerpos de agua. En general, los estudios revisados muestran que los paisajes altamente fragmentados presentan una reducción en la diversidad de especies, favoreciendo a aquellas con mayor plasticidad ecológica y afectando negativamente a especies especialistas y depredadores tope. La revisión resaltó la necesidad de mantener la conectividad entre fragmentos de hábitat, la importancia de considerar tanto factores naturales como antropogénicos y la urgencia de expandir estudios a regiones subrepresentadas. Se identificaron varios vacíos importantes que requieren atención, como la escasez de estudios a largo plazo, la poca representación de ciertas regiones geográficas y la limitada integración de factores socioeconómicos.

Por todo lo anterior, conocer los efectos de los atributos del païsaje tanto naturales como inducidos por actividades humanas, sobre las poblaciones de mamíferos de mamíferos medianos y grandes en áreas naturales protegidas, para establecer estrategias de conservación adecuada, se hace indispensable. Derivado de ello, se plantearon analizar la estructura y composición de las comunidades de mamíferos medianos y grandes en áreas con diferentes grados de conservación, identificar los factores ambientales y antropogénicos que determinan los patrones de diversidad y distribución de mamíferos y caracterizar las respuestas específicas de las especies a los gradientes ambientales y antropogénicos, en dos áreas naturales protegidas del estado de Chiapas.

7.1.3 Caracterización y Relevancia de las Áreas de Estudio

La Reserva de la Biosfera Selva El Ocote y el Área de Protección de Recursos Naturales La Frailescana representan dos sistemas únicos para estudiar los efectos del paisaje sobre las comunidades de mamíferos en el sureste mexicano. La importancia de estas áreas radica en la importancia como refugio especies y por los ecosistemas presentes, en sus características biogeográficas distintivas, en su papel como corredores biológicos y los problemas que enfrentan ante la presión antropogénica (SEMARNAT, 2001; CONANP, 2019).

La REBISO, ubicada en la porción occidental de Chiapas, se caracteriza por un gradiente altitudinal que va de los 180 a los 1,500 metros sobre el nivel del mar, lo que genera una notable heterogeneidad ambiental. Esta variación topográfica, combinada con diferentes regímenes de precipitación y temperatura, ha dado lugar a una diversidad de ecosistemas que incluyen selva alta perennifolia, selva mediana subperennifolia y bosque tropical caducifolio (SEMARNAT, 2001). Estas características ambientales proporcionan una variedad de nichos ecológicos que mantienen una diversa comunidad de mamíferos (Rivera-Rivera et al., 2012). Sin embargo, el área enfrenta presiones significativas debido a la presencia de comunidades que desarrollan actividades agrícolas y ganaderas (SEMARNAT, 2001). Por su parte, La

Frailescana representa un corredor biológico estratégico que conecta las Reservas de la Biosfera La Sepultura y El Triunfo, por lo que esta área juega un papel crucial en el movimiento y dispersión de especies entre estas reservas (Lorenzo et al., 2017; De la Torre et al., 2019). Su gradiente altitudinal, va de los 800 a los 2,280 msnm y la precipitación oscila entre 800 y 4,000 mm anuales, lo que ha generado un mosaico de siete tipos de vegetación que incluye bosque mesófilo de montaña, bosque de pino y bosque de encino.

La importancia de estudiar estas áreas se sustenta en tres aspectos fundamentales. Primero, ambas reservas albergan poblaciones viables de especies amenazadas, constituyendo refugios críticos para la conservación de mamíferos en riesgo (CONANP, 2019). Segundo, presentan un gradiente de presión antropogénica y estados de conservación diferenciados, proporcionando un escenario natural ideal para evaluar las respuestas de las comunidades de mamíferos a distintos niveles de perturbación humana. Tercero, su posición estratégica en la Sierra Madre de Chiapas y en la región occidental del estado las posiciona como elementos clave para mantener la conectividad regional de las poblaciones de mamíferos. Además, estas áreas enfrentan desafíos similares pero presentan contextos socioecológicos distintos. Mientras La REBISO mantiene extensiones significativas de bosque continuo, La Frailescana presenta un mayor grado de fragmentación debido a la expansión de actividades agrícolas y ganaderas (CONANP, 2019). Esta diferencia permite examinar cómo la configuración del paisaje influye en la persistencia de las especies. La presencia de asentamientos humanos en ambas áreas añade una dimensión social importante al estudio, ya que las interacciones entre las comunidades locales y la fauna silvestre son complejas y pueden influir significativamente en los patrones de distribución y abundancia de las especies.

7.1.4 Estructura y Composición de las Comunidades de Mamíferos

La investigación proporcionó evidencia significativa sobre cómo los atributos del paisaje y las actividades humanas influyen en la estructura y composición de las comunidades de mamíferos medianos y grandes en la REBISO y en La Frailescana, revelando patrones complejos de respuesta de las especies a la modificación del paisaje y la presión antropogénica. La comprensión de cómo las especies utilizan el paisaje es fundamental para la planificación de acciones de conservación efectivas (De la Torre et al. 2018).

En la REBISO, los resultados docuentaron la presencia de 20 especies, con la existencia de dos ensamblajes distintivos de mamíferos, caracterizados por diferentes niveles de especialización y separados geográficamente. El primer grupo, asociado a zonas mejor conservadas como "El Encajonado", mostró una mayor presencia de especies especialistas como *P. concolor*, mientras que el segundo grupo, vinculado a áreas con mayor influencia humana, presentó mayor abundancia de especies generalistas como *Didelphis sp* (Cruz-Salazar et al., 2016; Cruz-Salazar et al., 2020). Por su parte, en La Frailescana, los resultados documentaron una comunidad diversa con 19 especies, incluyendo algunas amenazadas como *T. bairdii* y *P. onca*.

7.1.5 Efectos de la Actividad Humana sobre las Comunidades de Mamíferos

En La Frailescana, las especies mostraron respuestas diferenciales a la infraestructura humana, especies como *P. tajacu*, *U. cinereoargenteus*, *O. virginianus* y *P. concolo*r fueron más abundantes lejos de asentamientos humanos. Para *P. tajacu* y *O. virginianus*, esto podría relacionarse con el hecho de que estas especies son frecuentemente cazadas para subsistencia en comunidades rurales del neotrópico (Nájera et al., 2018). Mientras que para el caso de *P. concolor* y *U. cinereoargenteus*, la evitación podría vincularse con la reducción de presas y como estrategia para minimizar encuentros con humanos debido a conflictos por depredación de animales domésticos, lo que frecuentemente resulta en cacería de represalia (Rodas-Trejo et al., 2016; De la Torre et al., 2019).

La respuesta a los caminos rurales mostró patrones más complejos y contrastantes entre especies. Para *L. wiedii* exhibió una fuerte evitación de estos caminos, lo cual es consistente con lo documentado por Goulart et al. (2009) en el Bosque Atlántico del sur de Brasil, donde esta especie seleccionó preferentemente senderos estrechos y áreas con densa cobertura forestal, evitando caminos más amplios y áreas abiertas. En contraste, otras especies mostraron respuestas más flexibles, como *O. virginianus* que evitó asentamientos humanos pero fue más abundante cerca de caminos rurales, sugiriendo el uso de estos como corredores de movimiento mientras mantiene distancia de zonas con mayor presencia humana, posiblemente como estrategia para reducir el riesgo de cacería furtiva o depredación (Ramos-Robles et al., 2013; Henderson et al., 2023; Ganz et al., 2024). De manera similar, *M. temama*, presentó una asociación positiva con caminos rurales y mostró tendencia a utilizar zonas de mayor elevación. Esto sugiere que la especie utiliza caminos rurales para movilizarse entre parches de hábitat adecuado, manteniendo distancia de asentamientos humanos y prefiriendo áreas elevadas donde se encuentran las zonas más conservadas de la reserva. Este comportamiento podría estar asociado con estrategias antidepredatorias o acceso a recursos alimenticios específicos lo que refleja su carácter como especialista de hábita (Contreras-Moreno et al., 2016; CONANP, 2019). En tanto, *U. cinereoargenteu*s evitó asentamientos humanos pero presentó mayor abundancia cerca de caminos rurales. Esta flexibilidad ecológica refleja su capacidad para aprovechar paisajes heterogéneos y coexistir con actividades humanas, siendo consistente con sus hábitos generalistas y oportunistas tanto en términos de uso de hábitat como de dieta (Gallina et al., 2016; Wong-Smer et al., 2022).

En la REBISO, los análisis sugirieron que la distancia a carreteras principales y asentamientos humanos fueron variables significativas que explicaron la variación en la distribución de especies. Especies como *D. mexicana*, *D. novemcinctus* y *P. concolor* mostraron una fuerte disminución en su abundancia cerca de las carreteras principales, mientras que *L. wiedii* y *P. tajacu* exhibieron una relación más débil con esta variable. Se ha observado una correlación negativa entre los caminos y la presencia de *D. mexicana*, *D. novemcinctus*, *P. concolor* y *L. wiedii* (Fahrig & Rytwinski, 2009; Piña et al., 2019). Estas áreas podrían ser particularmente ventajosas para *D. mexicana* y *D. novemcinctus*, ya que son de difícil acceso para los humanos. Debido a que los cazadores tienen como objetivo principal a estas especies, tienden a buscar refugio en estas ubicaciones (Naranjo y Cuarón, 2010; Flota-Bañuelos, 2018). Para *P. concolor* mostró una marcada tendencia a evitar carreteras, lo que fue confirmado por el análisis OMI que lo identificó como la especie con mayor especialización de nicho y baja tolerancia residual, lo que explica su estrecha asociación con áreas conservadas como El Encajonado, donde encuentra menor perturbación humana. Estos hallazgos son consistentes con lo reportado por Boron et al. (2018), quienes indican que aunque *P. concolor* puede habitar cerca de áreas con actividades humanas, prefiere zonas conservadas donde encuentra mayor abundancia de presas.

En cuanto a la relación con los asentamientos humanos, los análisis mostraron que *L. pardalis* presentó una correlación negativa con la distancia a poblados. Este comportamiento indica que la especie busca activamente hábitats más seguros y menos perturbados, a pesar de que el análisis OMI sugiere que no está significativamente asociada con condiciones ambientales específicas, mostrando baja marginalidad y alta tolerancia. Di Bitetti et al. (2008) señalan que las actividades humanas como la cacería y la degradación del hábitat afectan negativamente a esta especie, lo que resulta en su tendencia a ocupar áreas con menor presencia humana. Por otro lado, *Didelphis sp* mostró una tendencia positiva en áreas con mayor cobertura forestal y cercanas a las ciudades, exhibiendo una especialización de nicho intermedia con patrones flexibles de uso del hábitat. Esta observación aplica tanto para *D. virginiana* como para *D. marsupialis*, ya que son consideradas especies generalistas y no selectivas en cuanto al hábitat, lo que les permite prosperar en áreas con diferentes características, incluyendo regiones con perturbaciones humanas y sitios conservados (Cruz-Salazar et al., 2016; Cruz-Salazar et al., 2020).

Los hallazgos de cómo influyen la relación entre las especies y las actividades humanas en la estructura y composición de las comunidades de mamíferos medianos y grandes en ambas reservas, coinciden con estudios previos que documentan cómo la presión antropogénica puede alterar los patrones de distribución y abundancia de mamíferos en paisajes tropicales (Oliveira & Wellington, 2017).

7.1.6 Influencia de los Atributos Naturales del Paisaje

En cuanto a atributos del paisaje, la distancia a cuerpos de agua emergió como un factor crítico en la estructuración de las comunidades de mamíferos en La Frailescana, un patrón consistente con lo documentado en otros ecosistemas neotropicales (Reyna-Hurtado et al., 2010; Delgado-Martínez et al., 2023). Este efecto fue particularmente evidente a en especies como *N. narica*, *P. tajacu* y *L. wiedii*, que mostraron una fuerte asociación con áreas cercanas al agua. La relación negativa entre la abundancia y riqueza de especies con la distancia a cuerpos de agua sugiere que estos recursos actúan como elementos estructuradores del paisaje, proporcionando no solo agua sino también recursos alimenticios y facilitando el movimiento de especies entre fragmentos de hábitat (Chamaillé-Jammes et al., 2016). Esto fue particularmente evidente en cinco especies: *N. narica*, *P. tajacu*, *L. wiedii*, *D. marsupialis* y *U. cinereoargenteus* que mostraron una fuerte asociación con áreas cercanas al agua. Para *N. narica*, *P. tajacu* y *D. marsupialis*, esta asociación puede explicarse por múltiples factores, incluyendo la necesidad de termorregulación, otros procesos fisiológicos o la mayor disponibilidad de alimento en estas zonas debido a la mayor riqueza de especies de plantas encontrada en las riberas (Hafez, 1964; Brown et al., 2008; Reyna-Hurtado et al., 2010). Para *L. wiedii* y *U. cinereoargenteus*, la asociación con áreas cercanas al agua podría relacionarse con estrategias de cacería, al actuar los cuerpos de agua como atractores de presas potenciales (Harris et al., 2015). En cuanto a la vegetación en La Frailescana, los felinos como *L. pardalis* y *L. wiedii* mostraron una clara preferencia por áreas cercanas a bosques de pino, lo que concuerda con estudios previos sobre la importancia de estos ecosistemas para especies de carnívoros que requieren hábitats conservados y heterogéneos (Di Bitetti et al., 2008; Espinosa et al., 2017). En contraste, especies más generalistas como *N. narica*, *P. tajacu* y *D. novemcinctus* mostraron una tendencia a aumentar su abundancia lejos de los bosques de pino, lo que podría explicarse por su capacidad de adaptación a hábitats perturbados y ecotonos (De Matos Dias et al., 2018; Mendoza et al., 2019).

En La REBISO, la cobertura forestal, se mostró como una variable significativa en la estructuración de la comunidad. En la Reserva se mantiene un alto porcentaje de cobertura forestal (78%), lo que podría explicar la presencia de especies de interés para la conservación como *L. pardalis*, *L. wiedii*, *D. mexicana*, *E. barbara* y *P. onca*. Sin embargo, como señalan Pérez-Irineo y Santos-Moreno (2013), la deforestación para agricultura puede causar un aumento de especies generalistas en estas áreas.

La altitud se presentó como un elemento importante para diferentes especies en ambas reservas. Tanto la Reserva de la Biosfera Selva El Ocote como el Área de Protección de Recursos Naturales La Frailescana, presentan terrenos accidentados con serranías, donde la vegetación se mantiene en mejor estado de consevación (SEMARNAT, 2001). Para *C. paca* y *E. barbara* mostraron una fuerte relación negativa con la altitud en La Frailescana, prefiriendo áreas más bajas. En el caso de *E. barbara*, esta preferencia podría estar relacionada con cambios en la disponibilidad de refugios y recursos alimenticios, así como con la estructura del bosque que favorece su comportamiento escansorial y condiciones microclimáticas más favorables para una especie que mantiene altas tasas metabólicas

(Bianchi et al., 2021). Por otro lado, *M. temama* mostró una tendencia marginal positiva con la altitud, sugiriendo una ligera preferencia por sitios más elevados, lo cual es consistente con estudios previos que indican que su presencia está fuertemente determinada por la disponibilidad de cobertura forestal densa que provea protección vertical contra depredadores y recursos alimenticios específicos (Vazquez & Tessaro, 2016). Es importante notar que las franjas de hábitat ribereño funcionan como corredores naturales que facilitan el movimiento y dispersión de las especies entre fragmentos de hábitat, lo que podría explicar los patrones observados de abundancia y riqueza cerca de estas áreas (Brown et al., 2008). La dependencia de la riqueza y abundancia general y de algunas especies a estos elementos naturales del paisaje sugiere que deberían ser considerados elementos críticos en las estrategias de manejo y conservación del área. Especies amenazadas como *T. bairdii* y *P. onca* se registraron en las zonas más elevadas y de difícil acceso, lo que sugiere una respuesta adaptativa ante la presión humana. De la Torre et al. (2018) y Rivero et al. (2021) documentaron que la principal amenaza para P. onca en La Frailescana fue el conflicto ganadero, mientras que para *T. bairdii* fue la caza furtiva, por lo que, la convergencia de estas especies hacia zonas altas y topográficamente complejas puede representar una estrategia para evitar las presiones antropogénicas más intensas en zonas bajas y accesibles (Gonzalez-Maya et al., 2009).

Por otro lado, a diferencia de lo registrado en La Frailescana, en La REBISO *C. paca* y *E. barbara* mostraron una marcada preferencia por áreas de mayor elevación, posiblemente relacionada como una estrategia de evitación con humanos. La abundancia de *C. paca* en el área de estudio puede explicarse por características topográficas específicas de la REBISO. Según Lira-Torres y Briones-Salas (2011), la topografía abrupta favorece a esta especie ya que promueve la presencia de cuevas y túneles que utilizan como madrigueras. Además, *C. pac*a es considerada una de las especies resistentes a la perturbación, capaces de adaptarse a hábitats transformados con flora inducida como maíz (*Zea mays*) y otras plantas cultivadas (Reid, 2009; Gallina et al., 2012; Martínez-Ceceñas et al., 2018), o bien puede ser una estrategia de evasión a los humanos, ya que esta especie se encuentra ente las mayormente cazadas (Pozo-Montuy et al., 2019).

7.1.7 Recomendaciones para la Conservación y Manejo

Por ultimo, los resultados de esta investigación destacan la importancia de considerar múltiples factores al evaluar la distribución y abundancia de mamíferos medianos y grandes en áreas naturales protegidas, ya que tanto en la REBISO como en La Frailescana, la estructura y composición de las comunidades está determinada por una compleja interacción entre factores naturales (altitud, cobertura forestal y distancia a cuerpos de agua) y antropogénicos (presencia de asentamientos humanos y caminos). La respuesta diferencial de las especies a estos factores sugiere la necesidad de estrategias de conservación que consideren tanto los requerimientos específicos de cada especie como el manejo integral del paisaje, lo que puede influir en decisiones sobre zonificación, establecimiento de corredores biológicos, delimitación de actividades humanas en sitios clave para la conservación y la implementación de estrategias de mitigación de conflictos entre humanos y fauna silvestre. Esto es particularmente relevante dado que ambas áreas mantienen poblaciones importantes de especies amenazadas, funcionan como corredores biológicos críticos en la región y es crucial desarrollar estrategias que consideren tanto las necesidades de la fauna como de las poblaciones humanas.

7.2 Conclusiones generales

La revisión sistemática de estudios con cámaras trampa (2010-2023) reveló un incremento significativo en el uso de esta metodología para estudiar los efectos del paisaje sobre mamíferos medianos y grandes, especialmente en ecosistemas tropicales y subtropicales, demostrando su efectividad para evaluar patrones de diversidad y distribución.

En la Reserva de la Biosfera Selva El Ocote se identificaron dos ensamblajes distintivos de mamíferos:

- Un grupo asociado a zonas mejor conservadas, caracterizado por especies especialistas.
- Un grupo vinculado a áreas con mayor influencia humana, dominado por especies generalistas.

Esta diferenciación evidencia cómo la calidad del hábitat y la presión antropogénica influyen en la estructura de las comunidades.

El Área de Protección de Recursos Naturales La Frailescana mantiene una comunidad diversa de mamíferos (19 especies), incluyendo especies amenazadas como *Tapirus bairdii* y *Panthera onca*. Sin embargo, estas especies mostraron abundancias bajas y patrones de distribución restringidos a zonas de mayor elevación y complejidad topográfica, sugiriendo una respuesta adaptativa ante presiones antropogénicas.

Los cuerpos de agua emergieron como elementos críticos del paisaje en ambas áreas protegidas, mostrando una relación negativa significativa con la distancia tanto para la riqueza como para la abundancia de especies. Esto resalta la importancia de estos recursos como elementos estructuradores de las comunidades de mamíferos.

Las especies mostraron respuestas diferenciales a la infraestructura humana:

- Especies como *Pecari tajacu*, *Urocyon cinereoargenteus* y *Odocoileus virginianus* evitaron activamente los asentamientos humanos.

- Los caminos rurales generaron respuestas variables, siendo utilizados por algunas especies como corredores de movimiento mientras otras los evitan.
- Especies como *Leopardus wiedii* exhibieron patrones complejos de selección de hábitat, equilibrando requerimientos ecológicos con presiones antropogénicas.

La investigación identificó umbrales críticos en la respuesta de las especies a la modificación del paisaje, donde factores como la distancia a asentamientos humanos, cobertura forestal y acceso a recursos hídricos determinan la persistencia de poblaciones viables, especialmente para especies especialistas y amenazadas.

Los hallazgos tienen implicaciones directas para el manejo y conservación:

- Resaltan la necesidad de mantener la conectividad entre fragmentos de hábitat.
- Enfatizan la importancia de proteger elementos críticos del paisaje como cuerpos de agua.
- Sugieren la implementación de zonas de amortiguamiento efectivas alrededor de asentamientos humanos.
- Recomiendan el establecimiento de corredores biológicos que faciliten el movimiento de especies entre áreas conservadas.

Aunque este estudio proporciona información clave sobre la ecología de mamíferos en estos ecosistemas, se requieren investigaciones a largo plazo que incluyan análisis más detallados de la dinámica poblacional y las interacciones ecológicas entre especies. Esto permitirá mejorar las estrategias de conservación y manejo de la biodiversidad en paisajes fragmentados. Los resultados subrayan la importancia de las áreas naturales protegidas estudiadas como refugios para la biodiversidad regional, pero también evidencian los desafíos que enfrentan ante la creciente presión antropogénica, señalando la necesidad de fortalecer las estrategias de conservación y manejo adaptativo. El trabajo de investigación proporciona una base científica para el desarrollo de estrategias de conservación más efectivas en paisajes tropicales fragmentados, considerando tanto los requerimientos específicos de las especies como el mantenimiento de elementos críticos del paisaje que facilitan su persistencia en ambientes modificados por humanos.

7.3 Referencias

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