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El Comité Editorial de la revista Árido-Ciencia a través de la Facultad de Ciencias Biológicas de la Universidad Juárez del Estado de Durango, agradecen de antemano a quienes hacen posible la cristalización de este proyecto en una estrategia por realimentar el ejercicio de las ciencias naturales entre los especialistas mediante la difusión científica de los resultados de las investigaciones y en forjar un vinculo con la sociedad para beneficio del saber ser y hacer en los ecosistemas áridos y semiáridos del mundo.

Facultad de Ciencias Biológicas
Universidad Juárez del Estado de Durango

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PARASITOIDES DE MOSCAS EN ESTABLOS LECHEROS DE LA COMARCA LAGUNERA DE COAHUILA Y DURANGO, MÉXICO

PARASITOIDS OF DAIRY STABLES OF THE COMARCA LAGUNERA OF COAHUILA AND DURANGO, MÉXICO

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RESUMEN

La mosca común, *Musca domestica* L., la mosca de los establos, *Stomoxis calcitrans* L., y la mosca del cuerno, *Haematobia irritians* L., constituyen un serio problema zoosanitario en la Comarca Lagunera y otras regiones lecheras de México. Esas especies causan: 1) estrés, que afecta negativamente el consumo de alimento y en consecuencia reducción de la producción de leche; 2) contaminación de productos pecuarios con excremento y partes de insectos; 3) transmisión de enfermedades; y 4) incremento en los costos de producción de leche. Por lo anterior, el presente estudio tuvo como objetivos, determinar los parasitoides de pupas de moscas y su parasitismo. El trabajo de campo se realizó en cinco establos productores de leche de la Comarca Lagunera, durante el 2008. Se realizaron colectas de 100 pupas de moscas quincenalmente de mayo a diciembre del 2008. Los parasitoides determinados en orden de mayor a menor abundancia fueron: *Dirhinus* sp., *Spalangia nigroaenea, Spalangia cameroni*, *Spalangia endius* y *Muscidifurax* sp. El parasitismo sobre pupas de moscas varió entre establos y a través del año. El parasitismo fue bajo, por lo que se sugiere implementar un programa de reproducción y liberaciones de las especies de parasitoides más comunes encontradas como *Dirhinus* sp. y *S. nigroaenea*.

ABSTRACT

The housefly, *Musca domestica* L., and the stable fly, *Stomoxis calcitrans* L., as well as the horn fly, *Haematobia irritians* L., represent a serious problem in the Comarca Lagunera and others dairy regions of México. They cause: 1) stress, which affects negatively food animal consumption and consequently cause a reduction in milk production; 2) contamination of milk and derivated products with insect wastes and parts; 3) vectoring several diseases to animals; and 4) increasing milk production costs. The objectives of this study were to determine the species of parasitoids of fly pupae, and their parasitism. Field work was carried out in five dairy stables of the Comarca Lagunera, during 2008. One hundred fly pupae were collected each two weeks from may to december 2008. Based on the results obtained, it was concluded that the parasitoid species determined in order of abundance were *Dirhinus* sp., *Spalangia nigroaenea*, *Spalangia cameroni*, *Spalangia endius* and *Muscidfurax* sp. Parasitism on fly pupae varied among stables and along sampling dates. Parasitism on fly pupae was generally low, therefore it is required the implementation of a mass production program and releasing of the species of parasitoids more common in this region, such as *Dirhinus* sp. y *S. nigroaenea*.

INTRODUCCIÓN

La mosca doméstica, *M. domestica* L, y la mosca del establo, *Stomoxys calcitrans* L. (Diptera: Muscidae), son un serio problema zoosanitario en las áreas pecuarias de México (Jensen y Mackey, 1973). Poblaciones elevadas de moscas causan los siguientes impactos negativos: provocan estrés y afectan negativamente su consumo de alimento y en consecuencia causan reducción de la producción de leche y pérdida de peso; contaminación de los productos pecuarios por los insectos; transmisión de enfermedades a los animales e incrementos en costos de producción de la leche (Nava-Camberos y Ávila-Rodríguez, 2008).

Las moscas también desempeñan un papel importante en la epidemiología de la mastitis en el ganado vacuno. Entre las enfermedades parasitarias transmitidas por las moscas se encuentran los helmíntidos *Parafilaria bovicola*, *Thelazia* spp., *Heterotylenchus autumnales*, *Ascaris, Trichuris* y *Ancylostoma*. Además, la mosca doméstica es vector de la cestodosis y coccidiosis aviar (Borchert, 1981; Lapage, 1984; Harwood y Maulico, 1987, Nava et al., 2002). Entre los patógenos transmitidos se encuentran *Salmonella*, *Shigella*, *Campylobacter*, *Escherichia*, *Enterococcus* y *Chlamydia*. Esta mosca se encuentra relacionada más comúnmente con epidemias de diarrea e infecciones por *Shigella*, aunque también está involucrada en la transmisión de fiebre tifoidea, disentería, tuberculosis, ántrax y oftalmia (Borchert, 1981; Harwood y Maulico, 1987; Quiroz, 1996).

Las pérdidas estimadas en la producción de leche en la Comarca Lagunera de Coahuila y Durango por las moscas son del orden de $0.9/vaca/día, lo que equivale a $78 millones anuales, por cada 1% de reducción en la producción de leche, a nivel regional. Algunos encargados y propietarios de establos de esta región consideran que una estimación conservadora de las pérdidas en la producción de leche se ubica en alrededor del 5%, lo que corresponde a una pérdida económica de $4.5/vaca/día y a $390 millones anuales a nivel regional (Nava et al., 2002).

De acuerdo con trabajos realizados en campo sobre el parasitismo natural e inducido de moscas, se conoce que los himenópteros parasíticos son los de mayor relevancia, ya que actúan sobre pupas y de esta manera causan mortalidad irremplazable, lo que les permite reducir la densidad media de las moscas. El uso de enemigos naturales para el control biológico de moscas más utilizado, es mediante el uso de avispitas (micro himenópteros) parasíticas como *Spalangia* y *Muscidifurax*, sin embargo, existe un gran desconocimiento de la fauna benéfica en las principales regiones productoras de ganado vacuno en México. Algunos estudios reportados en México sobre los niveles de parasitismo promedio, fluctúan significativamente entre regiones ganaderas del país. En la Comarca Lagunera de Coahuila y Durango, durante 1999 se estimó un parasitismo total del 27.1%, variando del 0.8 al 57.1% entre fechas de muestreo a lo largo del año y del 15.2 al 37.0% entre establos productores de leche; mientras que en el 2001 el parasitismo total fue del 20.5%, con una amplia variación entre fechas de muestreo (6.2 a 30.9%) y entre establos (8.6 a 37.0%) (Nava et al., 2002). En Aguascalientes se observó una amplia variación en los niveles de parasitismo entre establos (3.0 a 33.3%) y un parasitismo total del 14.7% (Hernández et al., 2002, Hernández-Hernández et al., 2004). En Tamaulipas los porcentajes de parasitismo sobre pupas de moscas fueron similares durante el 2005 y 2006 (12.5 y 12.6%, respectivamente) (Loera-Gallardo et al., 2008). Los niveles de parasitismo promedio encontrados en California, EE.UU., varían del 17.7 al 25.6% (Meyer et al., 1991), en Illinois van del 10.6 al 13.0% (Jones y Weinzierl, 1997) y en Nebraska del 13.7 a 18.3% (Seymour y Campbell, 1993); mientras que en Hungría se reportan valores de parasitismo del 21.1 al 39.7% (Hogsette et al., 1994, Hogsette et al., 2001) y en Dinamarca éstos fluctúan del 5.1 a 13.1% (Skovgard y Jespersen, 2000).

Por lo anterior el objetivo de este trabajo fue identificar los microhimenópteros parasíticos de pupas de moscas y su parasitismo en establos lecheros de la Comarca Lagunera.

MATERIALES Y MÉTODOS

El trabajo de campo se realizó durante el 2008 en cinco establos productores de leche de la Comarca Lagunera: Desarrollo Lácteo (DESLAC), Facultad de Agricultura y Zootecnia (FAZ-UJED), Puerto Chico, del municipio de Gómez Palacio, Durango.; El Campanario y La Sagra, del municipio de Matamoros, Coahuila. El procesamiento e identificación de muestras de insectos se realizó en el Laboratorio de Entomología de la FAZ-UJED.

Para observar el parasitismo se colectaron 100 pupas de moscas por establo por fecha de muestreo. Las pupas se colocaron en cápsulas de gelatina tamaño 00 y se mantuvieron a temperatura ambiente para observar la emergencia de adultos de moscas o parasitoides. Los parasitoides emergidos se colocaron en alcohol al 80% para su posterior identificación. Los parasitoides se identificaron a nivel de especie con base en las

Tabla I. Número de parasitoides emergidos de pupas de moscas colectadas en el establo lechero FAZ-UJED, durante el 2008.

Fecha de colecta	Pupas colectadas	*S. endius*	*S. nigroaenea*	*S. cameroni*	*Dirhinus*	*Muscidifurax*	Otros
08 Jul.	100	0	0	0	2	0	0
23 Jul.	100	0	0	0	2	0	0
08 Ago.	100	0	0	7	0	0	0
23 Sep.	100	0	0	0	0	0	0
23 Oct.	100	2	2	4	0	0	0
08 Oct.	100	19	3	5	0	0	0
08 Nov.	100	2	3	4	0	0	0
08 Dic.	100	0	0	1	0	0	0
Total	800	23	8	21	4	0	0
Media	100	2.9	1	2.6	0.5	0	0
%		41.0	14.3	37.5	7.1	0	0

características morfológicas de los ejemplares, siguiendo las claves de Rueda y Axtell (1985), Gibson (2000) y Legner et al., (1976).

RESULTADOS

Establo FAZ-UJED, Gómez Palacio, Durango. Las especies más abundantes en este establo fueron del género *Spalangia endius* Walker y *S. cameroni* Perkins seguidas de *S. nigroaenea* Curtis (Hymenoptera: Pteromalidae) y del género *Dirhinus* sp. (Hymenoptera: Chalcididae). En esta localidad no se observaron avispitas del género *Muscidifurax*. En general, los niveles de parasitismo sobre pupas de moscas fueron bajos, con un promedio de 7.0 parasitoides emergidos por 100 pupas. La época de mayor parasitismo de pupas de moscas fue en el mes de octubre (Tabla I).

Establo Puerto Chico, Gómez Palacio, Durango. Las especies con población alta y similar entre sí fueron *S. nigroaenea* y *Dirhinus* sp.; seguidas por *S. cameroni*.

En esta localidad no se encontraron avispitas de la especies *S. endius* ni del género *Muscidifurax sp*. En este establo el parasitismo fue mayor sobre pupas de moscas, con un promedio de 13.7 parasitoides emergidos por 100 pupas. El período de mayor parasitismo de pupas de moscas comprendió de junio a agosto (Tabla II).

Establo DESLAC, Gómez Palacio, Durango. Los parasitoides más abundantes pertenecieron al género *Dirhinus*, seguidos por las especies *S. nigroaenea* y *S. cameroni*. La especie *S. endius* y el género *Muscidifurax* sp. presentaron baja población. En este establo el parasitismo sobre pupas de moscas registró un promedio de 12.1 parasitoides emergidos por 100 pupas, los cuales fueron similares a Puerto Chico y La Sagra. El período de mayor parasitismo de pupas de moscas ocurrió durante agosto y septiembre (Tabla III).

Establo La Sagra, Matamoros, Coahuila. Los parasitoides con mayor prevalencia fueron del género *Dirhinus*, seguidos por *S. nigroaenea*. Las avispitas de las especies *S. cameroni* y *S. endius*; así como las del género *Muscidifurax* presentaron baja población. En este establo el parasitismo fue alto, con un promedio de 21.3 parasitoides emergidos por 100 pupas, los cuales fueron similares a los estimados en los establos Deslac y Puerto Chico. El mayor parasitismo de pupas de moscas tuvo lugar durante junio y julio (Tabla IV).

Establo Campanario, Matamoros, Coahuila. En este establo la especie dominante fue *S. nigroaenea*; mientras que *Dirhinus* sp. y *S. endius* presentaron baja población. Las avispitas de la especie *S. cameroni* y del género *Muscidifurax* no se detectaron. En este establo el parasitismo fue bajo, con un promedio de 4.5

Tabla II. Número de parasitoides emergidos de pupas de moscas colectadas en el establo lechero Puerto Chico, durante el 2008.

Fecha de colecta	Pupas colectadas	*S. endius*	*S. nigroaenea*	*S. cameroni*	*Dirhinus*	*Muscidifurax*	Otros
09 May.	100	0	0	0	3	0	0
24 May.	100	0	0	0	12	0	0
14 Jun.	100	0	19	1	12	0	0
27 Jun.	100	0	17	0	0	0	0
08 Jul.	100	0	29	6	0	0	0
23 Jul.	100	0	1	0	6	0	0
08 Ago.	100	0	2	1	9	0	0
23 Ago.	100	0	1	0	24	0	0
08 Sep.	100	0	0	0	4	0	0
23 Oct.	100	0	1	0	0	0	2
08 Nov.	100	0	0	1	0	0	0
Total	1100	0	70	9	70	0	2
Media	100	0	6.4	0.8	6.4	0	0.2
%		0	46.4	6.0	46.4	0	1.3

Tabla III. Número de parasitoides emergidos de pupas de moscas colectadas en el establo lechero Deslac, durante el 2008.

Fecha de colecta	Pupas colectadas	*S. endius*	*S. nigroaenea*	*S. cameroni*	*Dirhinus*	*Muscidifurax*	Otros
09 May.	100	0	2	0	1	0	0
24 May.	100	0	0	1	0	0	0
14 Jun.	100	0	0	0	10	0	0
27 Jun.	100	0	7	0	1	0	0
08 Ago.	100	2	7	0	8	1	0
08 Sep.	100	3	1	9	8	0	0
23 Sep.	100	0	11	8	39	0	0
08 Oct.	100	0	0	1	0	0	0
23 Oct.	100	0	0	2	4	0	0
08 Nov.	100	1	3	3	0	0	0
Total	1000	6	31	24	71	1	0
Media	100	0.5	2.8	2.2	6.5	0.1	0
%		4.5	23.3	18.0	53.4	0.8	0

Tabla IV. Número de parasitoides emergidos de pupas de moscas colectados en el establo lechero La Sagra, durante el 2008.

Fecha de colecta	Pupas colectadas	*S. endius*	*S. nigroaenea*	*S. cameroni*	*Dirhinus*	*Muscidifurax*	Otros
21 May.	100	2	3	1	0	0	0
31 May.	100	0	9	0	9	3	0
14 Jun.	100	0	1	0	0	0	0
30 Jun.	100	0	1	1	16	0	0
15 Jul.	100	1	9	0	18	1	0
31 Jul.	100	0	1	0	0	0	0
30 Sept.	100	0	1	0	0	0	0
Total	700	3	25	2	43	4	0
Media	100	0.4	3.6	0.3	7.2	0.6	0
%		3.6	29.7	2.4	59.6	4.8	0

Tabla V. Número de parasitoides emergidos de pupas de moscas colectadas en el establo lechero El Campanario, durante el 2008.

Fecha de colecta	Pupas colectadas	*S. endius*	*S. nigroaenea*	*S. cameroni*	*Dirhinus*	*Muscidifurax*	Otros
14 Jun.	100	0	6	0	0	0	0
29 Jun.	100	0	2	0	3	0	0
31 Jul.	100	1	4	0	0	0	0
13 Ago.	100	0	2	0	0	0	0
Total	400	1	14	0	3	0	0
Media	100	0.3	3.5	0	0.8	0	0
%		5.6	77.8	0	16.7	0	0

parasitoides emergidos por 100 pupas (Tabla V).

Por lo anterior, los resultados obtenidos muestran que existió variación tanto en la composición de especies de parasitoides, como en los niveles de parasitismo y épocas de mayor abundancia entre las localidades estudiadas, lo cual puede estar relacionado con las diferencias existentes en el manejo de los establos en general y en el control de moscas, en particular.

DISCUSIÓN

Las especies *Spalangia nigroaenea*, *S. endius* y *S. cameroni* encontradas en los establos lecheros de la Comarca Lagunera han sido reportadas en diferentes regiones productoras de ganado lechero y de engorda, tales como Jalisco (Ávila-Rodríguez et al., 2015), Aguascalientes (Hernández-Hernández et al., 2004), norte de Tamaulipas (Loera-Gallardo et al., 2008) y Estado de México (Hernández-Carrillo et al., 1998; Priego,

2002). Todas las especies de *Spalangia* encontradas en La Comarca Lagunera han sido reportadas para México por Gibson (2009) y Noyes (2014). Adicionalmente Gibson (2009) reporta para México a *S. bethyloides* Boucek, *S. chontalensis* Cameron, *S. imitator* Gibson, *S. impunctata* Howard, *S. leiopleura* Gibson, *S. nigra* Latreille y *S. stictocephala* Gibson. Además, Noyes (2014) reporta a *S. haematobiae* Ashmead. *Spalangia nigroaenea* fue la especie dominante en la Comarca Lagunera, seguida en abundancia por *S. cameroni*; mientras que *S. endius* presentó una muy baja población. Esta misma composición y abundancia de especies de parasitoides de moscas se observó en el norte de Tamaulipas (Loera-Gallardo et al., 2008). En Jalisco y Aguascalientes las especies *S. nigroaenea*, *S. endius* y *S. cameroni* presentaron similar abundancia (Hernández-Hernández et al., 2004; Ávila-Rodríguez et al., 2015). Las avispitas de las especies de *Spalangia* son muy abundantes y ejercen un buen parasitismo sobre las pupas de moscas en los establos lecheros de la Comarca Lagunera y de otras regiones ganaderas del país (Hernández-Hernández et al., 2004; Loera-Gallardo et al., 2008; Ávila-Rodríguez et al., 2015).

Con respecto a los parasitoides del género *Muscidifurax*, las especies *M. zaraptor*, *M. raptor* y *M. raptorellus* están presentes en Jalisco (Ávila-Rodríguez et al., 2015). Las dos primeras especies indicadas, también se reportan en el estado de México (Hernández-Carrillo et al., 1998; Priego 2002; Pérez y Priego 2003). En Aguascalientes (Hernández-Hernández et al., 2004) y norte de Tamaulipas (Loera-Gallardo et al., 2008) sólo se presenta *M. raptor*. Noyes (2014) sólo reporta para México a *M. raptor* y *M. raptoroides* Kogan & Legner. Las avispitas de las especies de *Muscidifurax* son poco abundantes y ejercen un parasitismo sobre las pupas de moscas en los establos lecheros de la Comarca Lagunera y de otras regiones ganaderas de México (Hernández-Hernández et al., 2004; Loera-Gallardo et al., 2008; Ávila-Rodríguez et al., 2015).

Las avispitas del género *Dirhinus* fueron las más abundantes en la Comarca Lagunera; sin embargo, no se reportan en otras regiones productoras de leche en México.

Las diferencias observadas en la composición de especies de parasitoides y su parasitismo de moscas en los establos lecheros de la Comarca Lagunera parecen estar relacionadas con las diferentes condiciones de manejo de los establos, particularmente el manejo del estiércol y el control de moscas. Lo anterior es importante para la cría masiva y utilización de estos parasitoides en el control biológico de moscas en la Comarca Lagunera o cualquier otra región ganadera. En primer lugar, los resultados obtenidos indican dónde y cuándo colectar parasitoides de una especie o género determinados para el establecimiento de un pie de cría. Por otra parte, los resultados obtenidos también indican cuando producir masivamente y cuando realizar las liberaciones de cada especie en los establos de la región, para obtener una mayor adaptación y acción de control de dichos insectos benéficos sobre las moscas. De esta manera, un programa de liberaciones de parasitoides puede ser más efectivo para reducir las poblaciones de moscas en los establos lecheros de la región si se usan conjuntamente las especies de *Spalangia* y *Dirhinus* más abundantes y adaptadas a la región, por ejemplo, *S. nigroaenea*, *S. cameroni* y *Dirhinus* sp., o si se liberan durante periodos específicos en función de las condiciones de clima, de manera que dichas especies se complementen en cuanto a su comportamiento de búsqueda y selección de microhábitats en los establos.

CONCLUSIONES

Las especies de parasitoides determinadas en orden de mayor a menor abundancia fueron: *Dirhinus* sp., *S. nigroaenea*, *S. cameroni, S. endius* y *Muscidifurax* sp.
El parasitismo sobre pupas de moscas varió entre establos y a través del periodo de muestreo.
Los niveles de parasitismo fueron generalmente bajos, por lo que se requiere implementar un programa de control biológico mediante liberaciones de las especies de parasitoides más adaptadas a la región como *Dirhinus* sp. y *S. nigroaenea*.

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VERTEBRATES THAT SHARE ITS HABITAT WITH *Lepus flavigularis*, AN ENDANGERED LEPORID

VERTEBRADOS QUE COHABITAN CON *Lepus flavigularis*, UN LEPÓRIDO EN PELIGRO DE EXTINCIÓN

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RESUMEN

Se registró la diversidad estacional y anual de vertebrados en el pastizal abierto (hábitat de *Lepus flavigularis*) en Santa María del Mar, Juchitán de Zaragoza, Oaxaca. El estudio se realizó entre octubre del 2015 y mayo del 2016 mediante dos muestreos en estación húmeda y dos en seca. Se utilizaron transectos de ancho fijo para monitoreo de herpetofauna; transectos lineales de ancho variable para aves; cámaras trampa para mamíferos medianos y grandes; redes de niebla para quirópteros, y trampas Sherman para mamíferos pequeños. La diversidad alfa estacional y anual se analizó utilizando los índices de Shannon (H') y Simpson (1/D), la diversidad beta con coeficiente de disimilitud de Jaccard (J), y la comparación estacional mediante la prueba U Mann-Whitney (W). Se registraron 77 especies de vertebrados. Para reptiles, la diversidad alfa anual fue de H´=1.2640 y 1/D=2.5905; para aves de H´= 2.7597 y 1/D=9.8032; y para mamíferos medianos y grandes de H´= 1.3100 y 1/D=2.6702. No se encontraron diferencias estacionales para la diversidad de reptiles (W = 94, p= 0.2052) y mamíferos (W = 14, p= 0.5584), pero sí para aves (W = 801, p= 0.0202). Para reptiles (cualitativo J=0.6666: cuantitativo J= 0.4433) y mamíferos (cualitativo J= 0.6666; cuantitativo J=0.6352), se comparten pocas especies estacionalmente, no así para aves (cualitativo J= 0.3829; cuantitativo J= 0.6430). Probablemente la presencia del fenómeno climático El Niño, que acentuó la sequía en el área de estudio, haya contribuido a que la diversidad de anfibios, reptiles y mamíferos fuera menor a la esperada.

ABSTRACT

Seasonal and annual vertebrate diversity that cohabit with the Tehuantepec jackrabbit (*Lepus flavigularis*) in Santa Maria del Mar, Juchitán de Zaragoza, Oaxaca, were recorded. The study was carried out between October of 2015 and May of 2016 (two samplings in the wet season and two in the dry season). Fixed-width transects were used to monitor amphibians and reptiles; variable width transects for birds; camera trapping for medium and large mammals; fog networks for flying mammals and Sherman traps for small mammals. Seasonal and annual alpha diversity were analyzed using Shannon (H') and Simpson (1/D) indices, beta diversity with Jaccard dissimilarity índices (J), and the seasonal comparison with Mann-Whitney U test (W). We recorded 77 vertebrate species. For reptiles, annual alpha diversity was H'= 1.2640 and 1/D = 2.5905; for birds was H'= 2.7597 and 1/D = 9.8032; and for medium and large mammals was H'= 1.3100 and 1/D = 2.6702. No significant seasonal differences were found for reptiles (W = 94, p = 0.2052) and mammals (W = 14, p = 0.5584) diversity, but it was found for birds (W = 801, p = 0.0202). For reptiles (qualitative J = 0.6666: quantitative J = 0.4433) and mammals (qualitative J = 0.6666, quantitative J = 0.6352), few species are seasonally shared, but not for birds (qualitative J = 0.3829, quantitative J = 0.6430). It is likely that the presence of the El Niño climatic phenomenon, which accentuated the drought in the study area, has contributed to the diversity of some groups was less than expected.

INTRODUCTION

Mexico is one of the five megadiverse worldwide countries (CONABIO, 2008; Navarro-Sigüenza et al., 2014) and the Tehuantepec Isthmus is one of the richest regions in this country (Casas-Andrew et al., 2004). Its biological diversity is because it is a biogeographical barrier for incapable species to cross lands with abrupt altitudinal changes, and because the Tehuantepec Isthmus is located in the contact zone of the Neotropical and Nearctic biogeographic regions (Pérez-García et al., 2001). Also, it is a center of endemism for terrestrial vertebrates (Casas-Andrew et al., 2004; González et al., 2004), such as the Tehuantepec jackrabbit (*Lepus flavigularis*), a species catalogued as Endangered (EN) by the IUCN Red List of Threatened Species (Cervantes et al., 2016) and currently considered the most endangered lagomorph species worldwide due to anthropogenic activities such as agriculture, urban development and illegal hunting (Lorenzo et al., 2015). These species populations are currently genetically isolated from each other, making *L. flavigularis* more susceptible to extinction which would mean a significant change in the structure of the grassland community as it plays an important ecological role being part of the trophic networks, and regulating the botanical composition of its habitat (Lorenzo et al. 2015). Different studies have been carried out with the purpose of contributing to the knowledge and conservation of the Tehuantepec jackrabbit (*L. flavigularis*) recording its distribution, population density, reproductive behavior, home range, habitat use, diet, its morphological and genetic characteristics, as well as the effect of anthropogenic activities (extense livestock farming) on its ecology (Rico et al., 2007; Lorenzo et al., 2008; Rioja et al., 2008; Carrillo-Reyes et al., 2010; Rioja et al., 2011; Carrillo-Reyes et al*.,* 2012; Sántiz et al., 2012; Rioja and Carrillo Reyes, 2014; Lorenzo et al., 2015; Luna et al*.,* 2016; Rioja et al., 2016). However, no studies have been focused on the diversity of vertebrates that cohabitate with *L. flavigularis*. Inventories are of great importance because they serve as a repository of data on species residing in a place (Dirzo and Raven 1994). Also, through these studies it is possible to know the distribution of species in different ecosystems, and therefore to develope management and conservation plans in a given region. It is important to consider that the information obtained from the inventories constitutes the basic unit of biosystematic research, so that derived information of these inventories is essential for the advancement of other academic areas such as evolutionary biology, biogeography, comparative anatomy, ecology, among others (Casas-Andrew et al., 2004). The purpose of this study is for the first time to record the diversity of terrestrial vertebrates in the Tehuantepec jackrabbit (*L. flavigularis*) habitat at Santa Maria del Mar, municipality of Juchitán de Zaragoza, Oaxaca. The anterior is key information to develop conservation and management protocols of this lagomorph and its habitat.

MATERIALS AND METHODS

Study site. The study site covers an area of 14 km^2 of the locality of Santa María del Mar (16°14'7" - 16º12'46" N and 94°53'9" - 94º48'15" W) in the municipality of Juchitán de Zaragoza, in Oaxaca state, Mexico. It is located in the south of the semi-arid region of the Tehuantepec Isthmus, between a coastal lake (Mar Tileme) and the Pacific Ocean. The town is inhabited by 862 people of indigenous (Huave) origin (Instituto Nacional de Estadística y Geografía, 2014). The main productive activities in the area are fishing, livestock production and, occasionally seasonal agriculture and subsistence hunting (Carrillo-Reyes et al., 2010). The local climate type is Awo, tropical wet with a pronounced dry season, the driest month has a precipitation less than 60mm and an average annual temperature of 25°C and average annual precipitation of 800mm; the wet season occurs between May and October with a short dry period in August, while the dry season begins in November and ends in April (García and Comisión Nacional para el Conocimiento y Uso de la Biodiversidad [CONABIO], 1998). The habitat of *L. flavigularis* never exceeds 4 or 5 km wide on the shores of salt lagoons and is characterized by extensive zones of grassland, dominated by *Eragrostis prolifera* Steud with an importance value of 64.48, *Jouvea pilos*a J. Presl with an importance value of 49.56, and *Whalteria preslii* Walp with an importance value of 41.15 and isolated elements of species such as *Opuntia tehuantepecana* Bravo and *Opuntia decumbens* Salm-Dyckes; these areas are utilized for cattle husbandry (Pérez-García et al., 2001; Rzedowski, 2006; Carrillo-Reyes et al., 2010).

Monitoring. A total of four visits were made to the site between October 2015 and May 2016 (two in each season of the year). Each visit lasted a minimum of five consecutive days. The monitoring area corresponded only to the Tehuantepec jackrabbit (*L. flavigularis*) habitat (open grasslands; Carrillo-Reyes et al., 2010). Herpetofauna (amphibians and reptiles) monitoring was made through fixed-width line transects (500 m length and fixed width of 10 m) according to Muñoz-Alonso, 2012. A total of four transects were established at random across the jackrabbit habitat, and each transect was covered three consecutive days per visit. The observations were made from 9:00 h to 12:00 h and from 19:00 h to 00:00 h, during the greater activity of amphibians and reptiles (Jones, 1986). Reptiles and amphibians were located on both sides of the transect; once located, the individuals were georeferenced using a manual receiver of the geolocation system (GPS,

Garmin ™ etrex Vista) and recorded the number and the type of plant association where these were captured; photographs of each specimen were taken whenever it was possible. In the case of amphibians the capture was carried out manually; for reptiles, the techniques of capture varied, using rods with sliding ties of hemp thread and manual collection for lacertilians, non-venomous snakes and terrestrial and freshwater turtles, and for the case of venomous snakes were used herpetological tongs 44" length (Karns, 1986; Casas-Andrew et al., 2004). Once the identification of the specimens was carried out, individuals were released at the site where they were found. Taxonomic determination of the individuals was carried out with aid of specialized literature: Campbell and Lamar (1989); Flores-Villela et al. (1995); Conant and Collins (1998); Powell et al. (1998) and Lee (2000). The nomenclatural information was based on the work of Casas-Andrew et al. (2004); Flores-Villela, Canseco-Márquez (2004), Frost et al. (2006) and a review of the works of Köhler (2003) and Köhler (2011) on reptiles and amphibians from Central America, respectively.

Bird monitoring was made through variable-width linear transects (2 km length; Sutherland, 2006; Rioja et al., 2013). A total of three fixed transects were established across the jackrabbit habitat, and each transect was surveyed simultaneously by two observers by walking twice a day: 06:00-10:00 h and 15:00-19:00 h. The starting point of the transect was alternated for every survey to reduce the effect of time of the day on the recordings. Visual observations of the bird species were recorded during a total of 96 observation hours in 12 days of field monitoring. Observations were carried out using binoculars (Konus®, 10x50). Bird species were identified using the field guides of Peterson and Chalif (1989); Howell and Webb (1995) and Sibley (2000). Scientific taxonomic arrangement nomenclature and common names were described according to the American Ornithologists' Union [AOU] (2016). The birds were photographed to obtain an illustrative collection of the species recorded when possible. The following parameters were recorded for each observed individual or group: transect, habitat type, coordinates, perpendicular distance to transect (using a Bushnell® Laser Legend 1200ARC rangefinder), species and number of individuals (Bibby et al., 2000; Gregory et al., 2004). Large and medium mammals monitoring was made using trail cameras, placing 20 simple monitoring stations (CuddebackTM, Ambush IR, model 1187, resolution 5 Megapixels). These were placed along two transects, with five trail cameras within each, located at approximately 150 meters between each one (Chávez et al., 2013). The trail cameras were active for a total of 12 days of field monitoring. Each trail camera was programmed to remain active throughout the night, with a maximum delay of five seconds between each shot, recording still images and video. Small mammals (rodents) monitoring was made through 24 Sherman traps distributed into two linear transects, each placed 50 meters apart across the jackrabbit habitat for four consecutive nights for each field visit (20 days of field monitoring), and barley with oats, vanilla and peanut butter (Becerril-Tesillo, 2006); transects were randomly placed and east-west oriented; finally, for bat monitoring, two mist nets were placed for three consecutive nights in every visit to study area, starting at 19:00 h and remained open until 12:00 h nets were placed in two sites previously selected in which the movement of bats was observed due to the presence of small puddles. The captured individuals were placed in cloth sacks and released after identification (Saldaña-Vázquez, 2010). In order to identify species, the Mammalian Guides of Central America and Southeastern Mexico (Reid, 2009) and the field identification code of Mexican Bats were used (Medellín and Sánchez, 1997). Priority vertebrate species were identified according to the Standard Mexican Official NOM-059-SEMARNAT-2010 (Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT], 2010). In addition, the presence of species on the International Union Conservation of Nature's Red List (IUCN, 2017), as well as listed species in one of the appendices of the Convention on International Trade in Threatened Species of Wild Fauna and Flora (CITES, 2017) was registered.

Analysis of Data. The species accumulation curve was obtained to determine the estimated precision of the sampling effort of each of the monitoring methods. The curve was constructed using the method of random species accumulation (Gotelli and Colwell, 2001). Species richness was plotted using the Bootstrap estimator (Smith and Van Belle, 1984). Seasonal and annual specific richness was estimated for each of group using the number of species recorded during the four field visits, two in the wet season and two in the dry season (Santizo, 2016). The seasonal and annual relative abundance by taxonomic group was also calculated; for herpetofauna it was based on the total abundance of individuals relative to the total number of individuals of all species recorded (Franco-Lopez et al., 1985; Naranjo and Bolaños, 2003); for birds with the Horvitz-Thompson transect variable-width estimator (Miller, 2016); for medium and large mammals by means of the number of independent photographic events between the number of effective days for each monitored season; for small mammals by the capture effort (López et al., 2009) and for bats by the number of individuals/meters net * hours of sampling (Medellín, 1993). The seasonal and annual alpha diversity were calculated using Simpson (1/D) and Shannon (H') indices (Rioja et al., 2013; Rioja and Carrillo-Reyes , 2014). The similarity between seasons (beta diversity) was calculated using quantitative and qualitative

Jaccard indices (J) (Moreno, 2001). The nonparametric Mann-Whitney U test (W) was used to compare the diversity of each group seasonally (Badii et al., 2012; Rioja et al., 2013; Rioja and Carrillo-Reyes, 2014). All statistical analyses were performed using R software (R Development Core Team, 2015), and vegan Packages (Oksanen et al., 2017), fossil (Vavrek, 2011), distance (Miller, 2016) and BiodiversityR (Kindt and Coe, 2005).

RESULTS

Species accumulation curve. According to the Bootstrap estimator (1979), the sampling effort was satisfactory for reptiles (12 species or 87.46%, N = 13.72), birds (49 species or 95.20%, n = 51.47) and medium and large mammals (6 species or 85.71%., n = 7), whereas not sufficient records were obtained for amphibians, bats and rodents to perform the accumulation curve.

Species composition and richness. For amphibians, small mammals (rodents) and bats, statistical analyzes could not be performed, since only one species of amphibian (*Scinax staufferi* Cope, 1865), one species of rodent (*Liomys pictus* Thomas, 1893), and two species of bats (*Artibeus Jamaicensis* Leach, 1821 and *Myotis thysanodes* Miller, 1897) were recorded during the wet season. It should be mentioned that none of these species are within a category of risk according to the Red List (IUCN, 2017), and do not appear within any category according to NOM-059-SEMARNAT-2010 (Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT], 2010) or within none of the CITES Appendices (CITES, 2017). For reptiles, the annual richness was 15 species. During the dry season, a richness of eight species was registered and during the wet season a richness of 15 species was registered. The scorpion turtle (*Kinosternon scorpiodes*) and the brown coral (*M. browni*) are listed under Special Protection according to the NOM-059-SEMARNAT-2010 (Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT], 2010), the green iguana (*Iguana iguana*) as Endangered Species, meanwhile the boa (*Boa constrictor*), the spotted striped snake (*Thamnophis marcianus*), the striped iguana (*Ctenosaura similis*) and the mexican spiny iguana (*C. pectinata*) are Threatened according to the NOM-059-SEMARNAT-2010 (Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT], 2010). It should be mentioned that only the boa (*B. constrictor*) appears within Appendix II of CITES (CITES, 2017) (Table 1). For birds, the annual richness was 49 species, registering 41 species for the wet season and 36 species for the dry season. Ony two species (*Colinus virginianus* and *Thalasseus elegans*) are found to be Almost Threatened according to BLI (BirdLife International, 2016) and IUCN (2017) (Table 2). Finally, for medium and large mammals there was an annual richness of nine species; five species in wet season and four species in dry season. All mammals species are classified as a Minor Concern according to the IUCN Red List of Threatened Species (IUCN, 2017), and only the Tehuantepec jackrabbit (*L. flavigularis*) is in danger of extinction according to this list and with the NOM-SEMARNAT-2010 (Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT], 2010). No mammal species appears in CITES (2016) (Table 3).

Relative abundance. Throughout the study, the most abundant reptile species were the seven-line huico (*A. deppii*) followed by the pink-bellied squamish gecko (*S.variabilis*) and the common home gecko (*Hemidactylus frenatus*), and the less abundant were the striped guinea pig (*Conophis vittatus vittatus*), followed by the brown bass (*Basiliscus vittatus*) and the petalillos (*Drymobius margaritiferus*) (Table 1). The most abundant bird species were the major zanate (*Quiscalus mexicanus*), the common ground-dove (*Columbina passerina*), and the white winged pigeon (*Zenaida asiática*), while the less abundant were the teal (*Spatula discors*), the green egret (*Butorides virescens*) and the collared plover (*Charadrius*) with a single record throughout the monitoring to name some (Table 2). Finally, the most abundant medium and large mammals species were the Tehuantepec jackrabbit (*L. flavigularis*), the gray fox (*Urocyon cinereoargenteus*) and the coyote (*Canis*), while the least abundant species were the white back skunk (*Mephitis macroura*) and the armadillo (*Dasypus novemcinctus*) (Table 3).

Alpha diversity. The Shannon and Simpson indices indicated that the study area showed a reptiles diversity of H '= 1.2640 and 1/D=2.5905 throughout the year, for the wet season the alpha diversity was H'=1.3434 and 1/D=2.8843 and for the dry season was H'=1.0008 and 1/D=2.1258. The alpha diversity of birds throughout the year was H=2.7597 and 1/D=9.8032, for the wet season was H`=2.6962 and 1/D=10.4400 and for the dry season was H'= 2.3426 and 1/D=6.1572. Finally, for medium and large mammals the alpha annual diversity was H'=1.2100 and 1/D=2.6702, for the wet season was H`=1.295 1/D=3.3602 and for the dry season was H'=0.8369 and 1/D=1.7142.

Beta diversity. According to Jaccard qualitative and quantitative dissimilarity indices, few reptile species are shared between the wet and dry seasons, with homogeneous abundances (J=0.6666 and J=0.4433, qualitative and quantitative respectively). In the case of birds, the Jaccard dissimilarity indices presented values of J=0.3829 and J=0.6430 (qualitative and quantitative respectively), indicating that the composition of species in the wet season is very similar to dry season, with abundances that behave differently between the two seasons. Finally, the Jaccard qualitative and quantitative dissimilarity indices showed that medium and large

mammals composition and their abundances are dissimilar between seasons (J=0.6666 and J=0.6352, qualitative and quantitative respectively).

Seasonal comparison of diversity. The U Mann-Whitney test revealed that reptile diversity (W = 94, p = 0.2052) and medium and large mammals diversity (W = 14, p = 0.5584) show no statistically significant difference between the dry and wet seasons. For birds, there was a statistically significant difference (W = 801, p = 0.0202), with a higher diversity during the wet season.

Table I. List of reptiles species found in Santa María del Mar, Oaxaca, México

Species	Common name	NOM[1]	IUCN[2]	CITES[3]	AR-WET[4]	AR-DRY[5]	A R ANUAL[6] -
SQUAMATA							
Corytophanidae							
Basiliscus vittatus	Brown Basilisk				0.0208	0.0	0.0104
Gekkonidae							
Hemidactylus frenatus	Common House Gecko		LC		0.4166	0.125	0.2708
Iguanidae							
Iguana iguana	Common Green Iguana	P	LC		s/d	s/d	s/d
Ctenosaura pectinata	Western Spiny-tailed Iguana	A			s/d	s/d	s/d
Ctenosaura similis	Common Spiny-tailed Iguana, Black Iguana, Black Spiny-tailed Iguana	A	LC		0.0	0.1041	0.0520
Prynosomatidae							
Sceloporus siniferus	Longtail Spiny Lizard		LC		0.0416	0.0	0.0208
Sceloporus variabilis	Rosebelly Lizard				1.3333	0.6666	1
Teiidae							
Aspidoscelis deppii	Blackbelly Racerunner		LC		1.9791	1.5416	1.7604
Colubridae							
Drymobius margaritiferus	Speckled Racer		LC		0.0416	0.0	0.0208
Masticophis mentovarius	Neotropical Whip Snake				0.125	0.0	0.0625
Natricidae							
Thamnophis marcianus	Checkered Garter Snake	A			0.0833	0.0208	0.0520
Boidae							
Boa constrictor	Boa	A		II	s/d	s/d	s/d
Dipsadidae							
Conophis vittatus vittatus	Striped Road Guarder		LC		0.0208	0.0	0.0104
Elapidae							
Micrurus browni	Brown's Coral Snake	Pr	LC		s/d	s/d	s/d
TESTUDINES							
Kinosternidae							
Kinosternon scorpiodes	Scorpion Mud Turtle	Pr			0.0625	0.0	0.0312

[1]Mexican legislation category according to SEMARNAT (2010), Pr=Special protection, A=Threatened, P=Extinction risk. [2]Red list category (IUCN, 2017; LC=Least concern). [3]Appendices of CITES (2017). [4]Relative abundance for wet season. [5]Relative abundance for dry season. [6]Anual relative abundance.

Table II. List of bird species found in Santa María del Mar, Oaxaca, México. Species arrangement according to AOU (2016).

Species	Common name	MS[1]	NOM[2]	IUCN[3]	BLI[4]	CITES[5]	AR-WET[6]	AR-DRY[7]	ARANUAL[8]
ANSERIFORMES									
Anatidae									
Dendrocygna autumnalis	Black-bellied Whistling-duck	R		LC	LC		6.1800	0.0	3.0009
Spatula discors	Blue-winged teal	Nb		LC	LC		0.25	0.0	0.1250
GALLIFORMES									
Odontophoridae									
Colinus virginianus	Northern Bobwhite	R		NT	NT		0.7500	0.5	0.6250
SULIFORMES									
Fragatidae									
Fregata magnificens	Magnificent Frigatebird	Nb		LC	LC		0.5	0.0	0.25
Phalacrocoracidae									
Phalacrocorax brasilianus	Neotropic Cormorant	R		LC	LC		0.75	2.2850	1.5175
PELECANIFORMES									
Pelecanidae									
Pelecanus occidentalis	Brown Pelican	Nb		LC	LC		5.4575	0.0	2.7287
Ardeidae									
Ardea herodias	Great Blue Heron	Wv		LC	LC		0.25	2.5025	1.3762
Ardea alba	Great Egret	R		LC	LC		2.3325	3.1275	2.73
Egretta thula	Snowy Egret	R		LC	LC		0.25	0.0	0.125
Bubulcus ibis	Cattle Egret	R		LC	LC		3.305	2.7525	3.0287
Butorides virescens	Green Heron	R		LC	LC		0.25	0.0	0.125
CATHARIFORMES									
Cathartidae									
Coragyps atratus	Black Vulture	R		LC	LC		2.1275	6.1125	4.12
Cathartes aura	Turkey Vulture	R		LC	LC		2.3475	15.83	9.0887
ACCIPITRIFORMES									
Accipitridae									
Rupornis magnirostris	Roadside Hawk	R		LC	LC		0.0	0.5	0.25
GRUIFORMES									
Rallidae									
Fulica americana	American Coot	Wv		LC	LC		0.5	0	0.25
CHARADRIIFORMES									
Burhinidae									
Burhinus bistriatus	Double-striped Thick-knee	R		LC	LC		0.75	0	0.375
Charadriidae									
Pluvialis squatarola	Black-bellied Plover	Wv		LC	LC		0.75	7.0775	3.9137

Table II. Continuation

Charadrius collaris	Collared Plover	R	LC	LC	0.25	0	0.1250
Charadrius semipalmatus	Semipalmated Plover	Wv	LC	LC	0.5	0.25	0.3750
Charadrius vociferus	Killdeer	Wv	LC	LC	0.25	0	0.1250
Scolopacidae							
Tringa semipalmata	Willet	Nb	LC	LC	0.25	0.0	0.125
Bartramia longicauda	Upland Sandpiper	Nb	LC	LC	0.25	0.0	0.125
Numenius phaeopus	Whimbrel	Wv	LC	LC	9.22	4.385	6.8025
Arenaria interpres	Ruddy Turnstone	Nb	LC	LC	1.665	0.0	0.8325
Laridae							
Larus atricilla	Laughing Gull	Nb	LC	LC	1.00	0.5	0.75
Larus pipixcan	Franklin's Gull	T	LC	LC	0.5	4.005	2.2525
Thalasseus elegans	Elegant tern	T	NT	NT	1.00	1.00	1.00
COLUMBIFORMES							
Columbidae							
Columbina inca	Inca dove	R	LC	LC	0.5	0.0	0.375
Columbina passerina	Common Ground-dove	R	LC	LC	47.0575	13.8125	30.435
Zenaida asiatica	White-winged Dove	Wv	LC	LC	34.3875	0.75	17.568
Zenaida macroura	Mourning Dove	R	LC	LC	14.2375	0.25	7.2437
CUCULIFORMES							
Cuculidae							
Crotophaga sulcirostris	Groove-billed Ani	R	LC	LC	0.5	0.75	0.625
CAPRIMULGIFORMES							
Trochilidae							
Archilochus colubris	Ruby-throated Hummingbird	Nb	LC	LC	0.945	0	0.4725
Caprimulgidae							
Chordeiles minor	Common Nighthawk	R	LC	LC	31.8825	0	15.941
PICIFORMES							
Picidae							
Melanerpes aurifrons	Golden-fronted Woodpecker	R	LC	LC	0.0	0.25	0.125
FALCONIFORMES							
Falconidae							
Caracara cheriway	Crested Caracara	R	LC	LC	0.0	0.5	0.25
Falco sparverius	American Kestrel	Nb	LC	LC	13.925	12.8075	13.3662
PASSERIFORMES							
Tyrannidae							
Pitangus sulphuratus	Great-tailed Grackle	R	LC	LC	3.63	0.5	2.065
Tyrannus verticalis	Western Kingbird	Wv	LC	LC	0.25	0.0	0.125
Tyrannus forficatus	Scissor-tailed Flycatcher	Wv	LC	LC	30.7525	0.25	15.5012
Corvidae							
Calocitta formosa	White-throated Magpie-jay	R	LC	LC	0.25	0.25	0.25
Alaudidae							
Eremophila alpestris	Horned lark	R	LC	LC	1.0	0.5	0.75
Mimidae							
Mimus gilvus	Tropical Mockingbird	R	LC	LC	22.4	11.205	16.8025
Parulidae							
Geothlypis trichas	Common Yellowthroat	Nb	LC	LC	0.25	0.0	0.125
Peucaea ruficauda	Stripe-headed Sparrow	R	LC	LC	3.38	0.25	1.815

Pooecetes gramineus	Vesper Sparrow	R	LC	LC	15.9	0.5	8.2
Chondestes grammacus	Lark sparrow	R	LC	LC	0.0	0.25	0.125
Quiscalus mexicanus	Great Kiskadee	R	LC	LC	66.4125	62.0975	64.255
Icterus gularis	Altamira oriole	R	LC	LC	0.5	0.25	0.375

[1]Migratory status (Sr=Summer resident, R=Resident breeder, T=Transient migrant, Wr=Winter visitor, and Nb=Non- breeding visitor). [2]Mexican legislation category according to SEMARNAT (2010). [3]Red list category (IUCN, 2017; LC=Least concern, NT=Near threatened). [4]BirdLife international category (LC=Least concern, Nt=Near threatened). [5]Appendices of CITES (2017). [6]Relative abundance for wet season. [7]Relative abundance for dry season. [8]Anual relative abundance.

Table III.- List of mammal species found in Santa María del Mar, Oaxaca, México.

Species	Common name	NOM[1]	CITES[2]	IUCN[3]	AR-WET[4]	AR-DRY[5]	ARANUAL[6]
CARNIVORA							
Canidae							
Canis latrans	Coyote			LC	10.52631	5.26315	7.8947
Urocyon cinereoargenteus	Gray Fox			LC	15.7894	0.0	7.8947
Procyonidae							
Procyon lotor	Northern Raccoon			LC	10.5263	0.0	5.2631
Mephitidae							
Mephitis macroura	Hooded Skunk			LC	0.0	5.2631	2.6315
Spylogale gracilis	Western Spotted Skunk			LC	s/d	s/d	s/d
CINGULATA							
Dasypodidae							
Dasypus novemcinctus	Nine-Banded Armadillo			LC	s/d	s/d	s/d
DIDELPHIMORPHIA							
Didelphidae							
Didelphis marsupialis	Common oposum			LC	0.0	5.2631	2.6315
LAGOMORPHA							
Leporidae							
Lepus flavigularis	Tehuantepec jackrabbit	P		EN	31.5789	47.3684	39.4736
Sylvilagus floridanus	Eastern Cottontail			LC	s/d	s/d	s/d

[1]Mexican legislation category according to SEMARNAT (2010; P=Endangered risk). [2]Appendices of CITES (2017). [3]Red list category (IUCN, 2017; LC=Least concern, EN=Endangered). [4]Relative abundance for wet season. [5]Relative abundance for dry season. [6]Anual relative abundance.

DISCUSSION

A complete inventory of the vertebrates that live in the Santa Maria del Mar grasslands was obtained. Regarding the accumulation of species, the monitoring was adequate for the different groups, registering 87.46% of reptiles, 95.20% of birds and 85.71% of mammals expected. According to the literature, when the percentage of species found is greater than 70% of the total estimated richness, monitoring is satisfactory (Soberón and Llorente ,1993; Jiménez-Valverde and Hortal, 2003; Pineda-López and Verdú-Faraco, 2013). During the monitoring period, only amphibian species *S. staufferi* was recorded, which was observed only during the wet season; this species was located near to a water source, which is in agreement with its natural history, indicating it can be found in temporary ponds in pastures (Cedeño-Vázquez et al., 2001). We registered only one species of rodent, the spiny mouse (*L. pictus*), that can inhabit a wide variety of habitats, however, it prefers places with seed availability (López et al., 2009). Finally, only two species of bats (*M. thysanodes* and *A. jamaicensis*) were found, which were captured during the wet season; the first is an insectivorous bat that may have foraging sites in open areas with artificial lighting and artificial dikes according to the literature (Fenton et al., 1992; Gehrt and Chelsvig, 2003, Avila-Flores and Fenton, 2005), which probably allowed it to be in the area despite the fact that it did not have an arboreal stratum. It is important to mention that this bat was captured in the net placed near a small puddle with the presence of insects, which surely is related to the capture of this species. *A. jamaicensis* is a frugivorous bat that can live in a large number of plant communities such as low deciduous forests, savannas, among others (Orozco-Segovia and Vázquez-Yanes, 1982; Fenton et al., 1992; Bredt and Uieda, 1996).

The richness of reptile species recorded in the study site (14 km^2) corresponds to 2.82% of the herpetofauna for the entire state of Oaxaca (Casas-Andrew et al., 2004); this result differs from Rioja et al. (2013) who recorded it an area of 20 km^2 (Montecillo Santa Cruz, municipality of San Francisco del Mar), 49 species of reptiles corresponding to 11.47% of the oaxacan herpetofauna, and from Martín-Regalado et al. (2011), who recorded 36 reptiles at Cerro Guiengola, near Tehuantepec in an area of 4,530 ha (the monitoring took place in a 50% lower area). It should be mentioned that both studies carried out a greater sampling effort, since they comprised 48 and 60 days, respectively, and included different and complex vegetal associations, which could influence the differences of richness recorded between the present study and those. These factors also influenced the different results obtained for birds and mammals; in a previous study in same locality, on a similar surface, but with a monitoring in four different vegetal associations that were sampled during 98 days, Rioja and Carrillo-Reyes (2014) found 75 bird species (10.1% of the total avifauna reported for Oaxaca), while in the present study we recorded 49 species, corresponding to 6.59% of oaxacan birds. Finally, the mammalian richness recorded in the study area corresponded to 4.05% of the state's mastofauna Santos-Moreno (2014); López et al. (2009) recorded 33 species of mammals (14.86% of the oaxacan mastofauna) in a study carried out at the lagoon area of Tehuantepec Isthmus with different plant associations.

The greatest seasonal and annual diversity was presented in the group of birds (annual: H`=2.7597 and 1/D= 9.8032; wet season: H`=2.6962 and 1/D=10.4400), while the mammal group presented the lowest seasonal and annual diversity (annual: H'= 1.2100 and 1/D = 2.6702; dry season: H'=0.8369 and 1/D=1.7142). No significant seasonal differences were found for reptiles (W = 94, p=0.2052) and mammals (W = 14, p = 0.5584) diversity, but it was found for birds (W=801, p = 0.0202). Finally, for reptiles (qualitative J=0.6666: quantitative J=0.4433) and mammals (qualitative J=0.6666, quantitative J = 0.6352), few species are seasonally shared, but not for birds (qualitative J = 0.3829, quantitative J = 0.6430). For reptiles, only the seven lines lizard (*A. deppii*), the pink panza squat lizard (*S. variabilis*) and the common home gecko (*H. frenatus*) were seasonal shared, possibly due to the fact that these species are generalists and have successful thermal characteristics in sites with high solar radiation, such as wooded savannahs or cleared sites, in addition to being tolerant to the disturbance (Vitt et al., 1997; Vitt and Pianka, 2004; Medina-Rangel, 2011), while most of the registered reptiles are specialists, like *D. margaritiferus* and *C. vittatus vittatus* which largely feed on amphibians (García and Ceballos, 1994; Lee, 2000) or with life cycles closely linked to humidity and water bodies (*T. marcianus, K. scorpiodes* and *B. vittatus*) (Berry e Iverson, 2001; Cadeño-Vázquez et al., 2001), so they were only recorded at one season or another. Also for mammals, few species were seasonally shared, the coyote (*C. latrans*) a generalist and tolerant mammal to habitat disturbance (Leopold, 1977; Pacheco et al., 2006) and the Tehuantepec jackrabbit (*L. flavigularis*); because the study was carried out in *L. flavigularis* habitat, so it is natural to have recorded it throughout the sampling (Rioja et al., 2011; Carrillo-Reyes et al., 2012). In contrast, most of the registered mammals are specialists like the raccoon (*P. lotor*) which presents a diet that varies between seasons; during the dry season approximately 50% of the components of its diet are of vegetal type, whereas in the wet season 70% are of animal type (Guerrero et al., 2000). This may help to explain why the raccoon did not appear in the grassland in the dry season because this plant association does not offer great variety of food resources for this species, in contrast, in the wet season it is possible that this species feeds mainly on animals and it finds them in the grasslands, where mammals, reptiles, and birds are part of its diet (Guerrero et al., 2000). In the case of birds, the species present all year were the most abundant like the zanate (*Q. mexicanus*), white pigeon (*Z. asiatica*), buzzard (*C. aura*), among many others; these species have general habits and are tolerant to the disturbance, developing well in grasslands and open zones (CONABIO 2010; Medina-Rangel, 2011), causing

these species were present all year; in contrast, few species not shared were Anseriformes, Pelecaniformes, Charadriiformes and Passeriformes; many of them are migratory species, which during a determined season migrate to other places (Navarro-Sigüenza et al., 2014) and therefore they were registered in one season, or related with water bodies, finally, it is possible that many of the species of Passeriformes may not have been found during both seasons, because some nesting species are looking for higher strata (canopy) to make their nests in spring (CONABIO, 2010).

Results of composition, richness, alpha and beta diversity are due to different factors, such as monitored area and the simple structure of the type of association sampled (open grassland). The open grassland presents only herbaceous stratum, which implies fewer microhabitats available with macro and microclimatic conditions that only allow the permanence of species with a broad spectrum of tolerance (Medina-Rangel, 2011). In addition, this type of vegetal association confers greater vulnerability to predators so that diversity and its components tend to be smaller (Martín-Regalado,2011; Medina-Rangel, 2011; Rioja-Paradela et al., 2013).

Another key factor in the composition, richness and diversity results that the study was carried out during an atypical year in terms of weather, related to the presence of El Niño phenomenon, which caused a precipitation deficit in the wet season, resulting in similar temperature and humidity conditions for both seasons, which, according to the literature, causes the weather to tend to warmer conditions all year round (Manson et al., 2009), thus affecting the environmental temperature, rainfall and the formation of temporary bodies of water that occur during the wet season in the grassland association of the study area (Rioja-Paradela et al., 2014), and that this year were not presented, thereby adversely affecting the diversity of amphibians, reptiles, birds and mammals. Weather is a very important factor, which can positively or negatively influence biodiversity. It has been observed that events such as global temperature increase during the last century have affected ecosystems and a wide range of taxa (Hughes, 2000; McCarty 2001; Walther et al., 2002), generating changes in the scheduling of seasonal events (Gilman et al., 2006). These events could be affecting the results of the present study, because between 2015-2016, the phenomenon El Niño was one of the strongest ever recorded, comparable to the episodes of 1982/1983 and 1997/1998 according to data obtained from the National Water Commission (CONAGUA, 2015; CONAGUA, 2016), the annual rainfall of the Tehuantepec Isthmus region was lower than the average (400 mm), being 2015 the driest year for the region, with an intense drought that occurred throughout the South Pacific, in addition to being the warmest year, according to records since 1971, registering temperature increases of up to 3 °C by the end of 2015 for the Pacific region, with El Niño that varied from moderate to strong intensity over the same year (CONAGUA, 2015), precisely where the study area is located.

CONCLUSIONS

The group that presented a greater diversity was birds, followed by mammals and finally reptiles, probably because the first one presents a greater mobility since much of the wealth of birds was composed by shorebirds that found all food and shelter resources in the habitat of Tehuantepec jackrabbit (*L. flavigulari*s).

El Niño is a phenomenon that significantly affects biological diversity, modifying through fluctuations in temperature and precipitation the spatial distribution of many species. It is probable that the fact that the study was carried out during an atypical year (the presence of the El Niño phenomenon that caused drought in the study area) was the reason for the diversity of amphibians, reptiles and mammals that cohabit with the Tehuantepec jackrabbit (*L. flavigularis*) was low compared to other studies carried out in previous years in neighboring localities; nevertheless, birds presented a high diversity of species compared to previous studies in the region where the study was located, which is probably due to the great capacity of mobility in this group.

It is considered necessary to continue monitoring these groups so that the structure of the community of vertebrates that cohabit with the Tehuantepec jackrabbit (*L. flavigularis*) can be known during typical and atypical climatic conditions.

All these vertebrate species form an integral part of the trophic networks present in the habitat of the Tehuantepec jackrabbit (*L. flavigularis*), an endemic and endangered species; these vertebrate species are part of the ecosystem of the open grassland, so measures that allow them to remain must be taken, emphasizing those under some category of risk, because in the area activities such as extensive cattle ranching and poaching of species such as the green iguana (*I. iguana*), the striped iguana (*C. similis*) and the boa (*B. constrictor*), and the Tehuantepec jackrabbit (*L. flavigularis*) were carried out. In addition, it should be taken into account that the Isthmus of Tehuantepec is a vertebrate endemism center, and has been classified as IBA (Important Area for the Conservation of Birds) of international BirdLife. The area comprises a range of possible microhabitats for different species of amphibians, reptiles, birds and mammals, making it an important area in which management measures for the conservation of biodiversity should be promoted.

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MULTI-OBJECTIVE METHOD TO ASSESS THE QUALITY OF GRASSLANDS IN THE NORTHERN CHIHUAHUAN DESERT

MÉTODO MULTI-OBJETIVO PARA EVALUAR LA CALIDAD DE LOS PASTIZALES DEL DESIERTO CHIHUAHUENSE

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ABSTRACT

It has been demonstrated that conducting a landscape analysis using a single landscape metric yields data of limited predictive value. Therefore, a combination of selected metrics is more desirable. However, universal set of landscape variables that can effectively evaluate the quality of a particular landscape fragment does not exist. This study considered 14 patch-level landscape metrics and evaluated the best suited to estimate the quality of grasslands in an area of the Northern Chihuahuan Desert ecoregion. A principal component analysis was used to select the combination of metrics, while the multi-objective optimization on the basis of ratio analysis (MOORA) method was used to integrate these variables in addition to rank their quality as predictors. This study proposes that Area, Euclidean distance, Proximity index and Similarity index as the best landscape metrics when characterizing the quality of Chihuahuan Desert grasslands.

RESUMEN

Los análisis que utilizan una sola métrica de paisaje poseen un valor predictivo limitado para la toma de decisiones en el manejo de los ecosistemas, por lo que es deseable seleccionar múltiples indicadores simultáneamente. Sin embargo, actualmente no existe un conjunto universal de variables que puedan evaluar efectivamente la calidad de un fragmento dentro de un paisaje determinado. El presente estudio considera 14 métricas con el fin de evaluar cuáles son las mejores para describir la calidad de fragmentos de pastizal natural dentro de la ecoregión del Desierto Chihuahuense. La selección de la combinación de variables se realizó a través de un análisis de componentes principales, mientras que el método de optimización multi-objetivo basado en el análisis de radios (MOORA) fue utilizado para la integración de las variables seleccionadas al mismo tiempo de ponderar la influencia de cada variable. En este estudio se concluye que el área, la distancia euclidiana, el índice de proximidad y el índice de similitud son las métricas de paisaje que mejor caracterizan la calidad de los pastizales en el Desierto Chihuahuense.

INTRODUCTION

Human-dominated landscapes are actually increasing their presence throughout the planet (Foley et al., 2005; Haila, 2002; Lepczyk et al., 2008). Human induced changes in landscape structure are transforming extensive natural areas into habitat patches that are often surrounded by developed land. This type of disturbance is potentially hostile to biodiversity and their processes (Mossman et al., 2015). Although the overall landscape quality has an important influence on wildlife populations, patch attributes determine the distribution of quality among habitat patches giving rise to source-sink dynamics (Heinrichs et al., 2015). If the premise of habitat degradation is listed as the main cause of wildlife population declining, patch-level assessment plans for wildlife management and conservation are needed. Mortelliti et al. (2012) showed that the omission of patch quality in a fragmentation analysis could carry substantial risk in conservation of landscapes where significant variation across the patches exists.

Landscape structure refers to the patterns found within its elements, which are defined as discrete entities or patches (Kupfer, 2012; Tscharntke et al., 2012; Uuemaa et al., 2013). Quantifying landscape structure can be assessed under two approaches: the species-oriented and the pattern-oriented (Fischer and Lindenmayer, 2007). Pattern-oriented approach originated from the island biogeography theory (MacArthur and Wilson, 1967) is the strongest hold on landscape ecology research (Fischer and Lindenmayer, 2007; Haila, 2002).

The patch matrix model (PMM) describes landscape structure as a mosaic of homogeneous areas discretely delineated, with three principal elements, i.e., patches, corridor and matrix (Forman and Gordon, 1986; Forman, 1995). This model can be addressed through landscape composition, which represents the proportion of fragment types and landscape configuration that describes the spatial aspects of the patch mosaic (e.g. size, shape and arrangement). Although the PMM has been heavily criticized due to the oversimplification of the landscape features, Lausch et al. (2015) suggested that this approach should be used in landscapes under severe pressure (e.g. urban and agricultural areas) because they tend to fix vegetation patterns, creating landscapes dominated by homogeneous areas with very distinct boundaries. PMM has been the prevailing model used due to its simplicity, compatibility with data models in geographic information systems, and the availability of remotely sensed data (Fischer and Lindenmayer, 2007).

Landscape metrics characterize quantitatively the landscape structure based on maps or remotely sensed images (Kupfer, 2012; Símová and Gdulová, 2012; Uuemaa et al., 2009). Several dozens of landscape metrics have been proposed to describe landscape structure creating an enormous confusion to which metrics are appropriate in effectively characterizing relevant landscape components (Fan and Myint, 2014; McGarigal, 2015; Schindler et al., 2014; Símová and Gdulová, 2012). To avoid including a large list of redundant variables a pre-selection of metrics is often required. This selection can be based on theoretical consideration, expert knowledge, previously published studies and statistical approaches (Riitters et al., 1995; Schindler et al., 2014). However, there are no universally appropriate indicator variables, because their performance depends mainly on each landscape context (Schindler et al., 2014; Walz, 2011). In the absence of prior knowledge for a specific study system, a pre-selection of landscape metrics is a challenging task for conservationists and policy-makers interested in identifying appropriate indicators (Walz, 2011).

Environmental decision-making process is often complex because it relies on experimental results or computational models that assess human health and ecological risk associated with environmental stressors. The interpretation of these results is extremely difficult because there are many emerging risks for which information is not available and decisions should be made under significant uncertainty. Multi-criteria decision analyses (MCDA) constitutes a set of useful tools for decision-making problems in environmental sciences because it allows the combination of a set of weighted variables to rank the different alternatives under consideration. The use of MCDA as a tool to support decision-making in environmental research has increased mainly due to the recognition of the complexity of environmental problems and the need for transparency from stakeholders throughout the process. When selecting a particular MCDA approach, it is important to consider the complexity of the decision in terms of scientific, social and technical factors as well as understanding the processes needs and the level of available knowledge about the problem (Huang et al., 2011).

The multi-objective optimization, also known as multi-criteria or multi-attribute optimization (MOORA), is a process of simultaneously optimizing two or more conflicting attributes (objectives) subject to certain constraints (Chakraborty, 2011; Gadakh, 2011; Karande and Chakraborty, 2012). This method was first introduced like a multi-objective optimization technique that can be successfully applied to solve various types of complex decision making problems (Brauers et al., 2008; Brauers and Zavadskas, 2006; Karande and Chakraborty, 2012). Thus the aim of this study is identify the set of landscape metrics that best characterize the quality of grassland patches in the Northern Chihuahuan Desert ecoregion trough MOORA approach.

MATERIALS AND METHODS

Study area.- The Chihuahuan Desert encompasses one of the most biologically diverse arid regions on earth. It covers nearly 630 000 km^2, covering from eastern Arizona, southern New Mexico, and western Texas, USA to the edge on Mexico's Meseta Central (Figure 1). Most of the ecoregion lies between 900 and 1500 m.a.s.l., although foothill areas and some isolated mountains in Meseta Central may rise more than 3000 m.a.s.l. (Dinerstein et al., 2000). The climate is relatively uniform with hot summers and cool to cold, dry winters; precipitation is monsoonal during the summer months ranging from 150 to 500 mm annually (Schmidt, 1986).

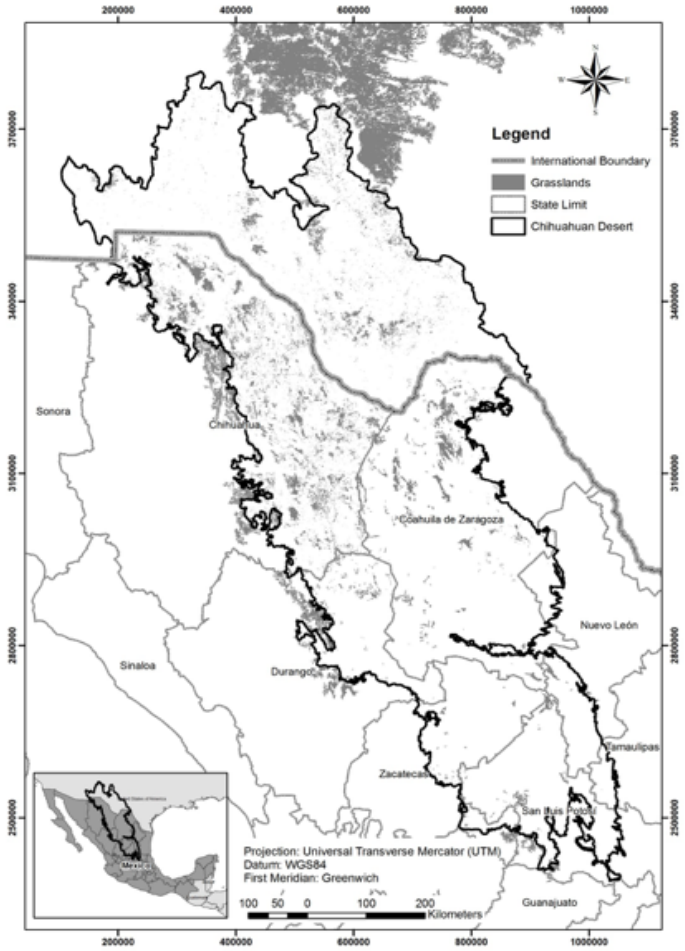

Figure 1. Location of the Chihuahuan desert grasslands

The Chihuahuan Desert is composed mainly of two types of vegetation. One dominated by shrubs, which currently covers more than 85% of its surface and the other dominated by grasses, which covers less than 15% (PMARP, 2012). Chihuahuan desert grasslands were formerly characterized by extensive areas of tobosagrass (*Pleuraphis mutica*) and black gramma (*Bouteloua eriopoda*). However, grassland areas across this ecoregion are undergoing a large-scale transformation mainly due to expanding agriculture, urbanization, energy development, desertification (Pool et al., 2014) and shrub invasion attributed to climate change, over grazing, fire suppression, distribution of shrub seeds by domestic livestock and the removal of native herbivores (Desmond and Montoya, 2006; Manzano-Fischer et al., 2006).

Data sources and processing.- The data used in this study consists of two categorical maps and one raster. The first categorical map was the 1:50,000 Land Use and Vegetation of the state of Chihuahua, Mexico (CONAFOR, 2013). The second categorical map was the 1:250,000 Land Use and Vegetation covered by the rest of the Mexican states within the Chihuahuan Desert (INEGI, 2015). The raster was the land cover of North America at a scale of 1:10,000,000 with a resolution of 250 meters (CEC, 2013). Of the resulting map, patches classified as natural grassland were identified and together with their neighbors polygons were selected to create a raster file with a resolution of 200 meters in ArcGIS 10.0.

Landscape structure analysis.- This study computed 14 metrics at patch level, available in FRAGSTATS software package (McGarigal et al., 2002) as follows: area (AREA), perimeter (PERIM), radius of gyration (GYRATE), perimeter-area ratio (PARA), shape index (SHAPE), fractal dimension index (FRAC), related circumscribing circle (CIRCLE), contiguity index (CONTIG), core area (CORE), number of core areas (NCA), core area index (CAI) Euclidean nearest neighbor distance (ENN), proximity index (PROX) and similarity index (SIMI) (Table 1).

Multi-objective optimization on the basis of ratio analysis (MOORA) method.- The MOORA method (Brauers and Zavadskas, 2006) starts with a decision matrix showing the response of different alternatives with respect to various objectives (attributes):

$$(x_{ij}) \qquad (1)$$

Where *xij* is the response of alternative *j* to objective *i*, *i* 0 1,2,…, *n* are the objectives, *j*= 1,2,… *m* are the alternatives.

The MOORA method is based on a ratio system in which the response of each alternative is compared to a denominator which is representative for all the alternatives concerning that objective. For this denominator the square root of the sum of squares of each alternative per objective is chosen. This ratio can be expressed as:

$$Nx_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \qquad ,(2)$$

Where x_{ij} = response of alternative *j* to objective *i*, *j* = 1, 2,…, *m*; *m* the number of alternatives, *i* = 1, 2,…, *n*; *n* being the number of objectives,
Nx_{ij} = a dimensionless number representing the normalized response of alternative *j* to objective *i*; these normalized responses of the alternatives to the objectives belong to the interval [0;1].

For the multi-objective optimization, these normalized responses of each alternative are added in case of maximization (beneficial attributes) and subtracted in case of minimization (non beneficial attributes) as outlined below:

$$Ny_j = \sum_{i=1}^{i=g} Nx_{ij} - \sum_{1=g+1}^{i=n} Nx_{ij} \qquad (3)$$

with:
i = 1, 2,…, g for the objectives to be maximized, *i* = *g* + 1, *g* + 2,…, *n* for the objectives to be minimized,
Ny_i = the normalized assessment of alternative *j* with respect to all objectives.

In this formula linearity concerns dimensionless measure in the interval [0;1]. An ordinal ranking of the shows the final preference.
In some cases, it is observed that some objectives are more important than others. In order to give more importance to an attribute, it could be multiplied by its corresponding weight.

$$Ny_j = \sum_{i=1}^{i=g} WjNx_{ij} - \sum_{1=g+1}^{i=n} WjNx_{ij\ (j=1,2,\ldots,n)} \qquad (4)$$

Where *Wj*=the weight of *jth* attribute

The Ny_i value can be positive or negative depending of the totals of its maximized (beneficial attributes) and minimized (non-beneficial attributes) in the decision matrix. An ordinal ranking of Ny_i shows the final preference. Thus, the best alternative has the highest Ny_i value, while the worst alternative has the lowest Ny_i value.

Statistical analysis.- To select the landscape structure variables that were used to build the different MOORA combinations, a principal component analysis (PCA) was used, which was performed in SPSS (IBM SPSS, 2013). Pearson correlation analysis allowed detecting redundancy between landscape metrics that helped establishing the number of MOORA and their variable combinations. Eigenvalues of the PCA were used to weight each landscape metric in every MOORA set. The similarity of the results of each MOORA set was evaluated with a dendrogram built with the Euclidean distances using SPSS (IBM SPSS, 2013). The first dendrogram was created using the 30 best patches selected by each MOORA set. The second one was the result of using the 30 worst patches selected by each MOORA set. To evaluate the precision of the quality established by each MOORA set a Kappa analysis was conducted, which provides a quantitative measure of agreement between categorical variables. Kappa is calculated from the difference between how much agreement is actually present (observed agreement) compared to how much agreement would be expected to be present by chance alone (expected agreement) (Viera and Garrett, 2005). Kappa value is standardized to lie on a -1 to 1 scale, where 1 is perfect agreement, 0 is exactly what would be expected by chance. Negative values indicate agreement less than chance.

RESULTS

A total of 22,045 patches of natural grassland were identified in the Chihuahuan Desert Ecoregion. The 14 landscape metrics calculated to assess the quality of each of these fragments are summarized in Table 2. In order to select the variables that constitute each MOORA set a PCA analysis was conducted. Cross-correlation between variables showed a variety of complex relationships (Table 3). AREA-CORE was completely redundant, while AREA-PERIM, AREA-NCORE, PERIM-CORE, and GYRATE-NCORE were strongly correlated in a positive way. While PARA-CONTIG showed a strong and positive correlation, PROX, SIMI, and ENN did not correlate with other metrics.

Nine MOORA sets were built based on the performance of landscape metrics of Chihuahuan Desert grasslands through a PCA and literature review where theoretical relations were established between variables (Table 4). Using the 30 best and 30 worst quality patches with each MOORA combination, it was determined that sets 5, 7, 8 and 9 were most similar when selecting the best grassland patches (Figure 2).

While the MOORA combinations 2, 6, 7, 8 and 9 were similar in the selection of the worst grassland patches (Figure 3). MOORA sets 7, 8 and 9 are consistent in discriminating between patches that have good landscape features and those who do not have them.

The level of agreement between all possible pairs of MOORA set combinations, using the Kappa statistic value showed that 5.55% of them had an almost perfect agreement, 8.3% had a substantial agreement, 16.66% had a moderate agreement, 47.22% had a fair agreement, while 22.22% had a slight agreement (Table 5).

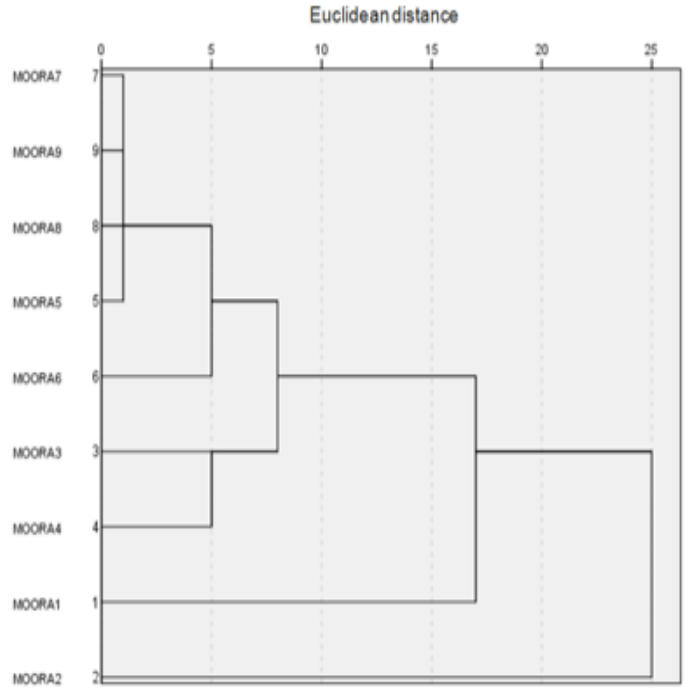

Figure 2. Euclidean distance dendogram of the 30 best grassland fragments selected by each MOORA combination

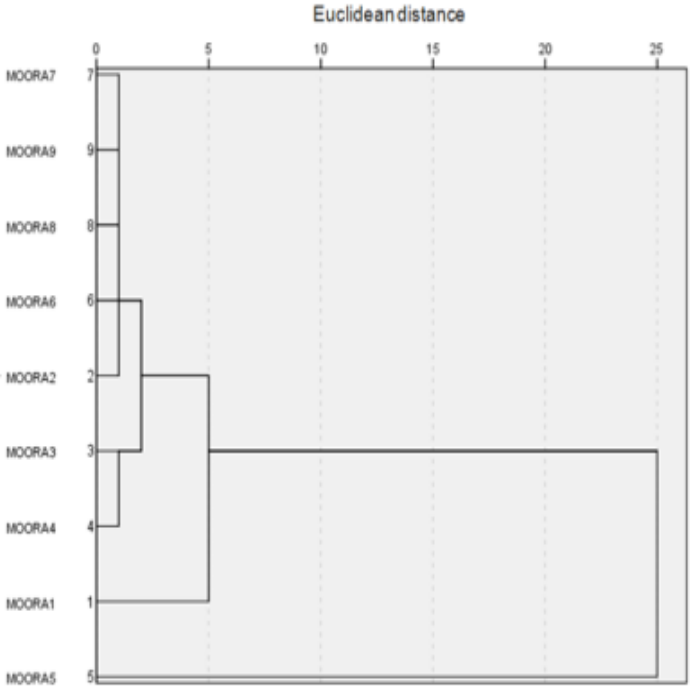

Figure 3. Euclidean distance dendogram of the 30 worst grassland fragments selected by each MOORA combination

DISCUSSION

The values of the landscape metrics estimated for the 22,045 grassland patches confirmed the high fragmentation of the Chihuahuan Desert grasslands described in many studies (Curtin et al., 2002; Manzano-Fischer and Cruzado, 2010; Manzano-Fischer et al., 2006; Pidgeon et al., 2001; Pool et al., 2014). The AREA, PERIM, and GYRATE metrics reveled that the extent of grassland patches is highly variable. The SHAPE, FRAC, and CIRCLE metrics showed that despite the extent of the patch, most grassland patches tend to have simple perimeters with very little convolutions. The CONTIG metric indicates that the spatial connectedness of most grassland patches is limited and the PROX, SIMI, and ENN metrics showed that the aggregation of grassland patches is highly variable throughout the ecoregion. The ambiguity about how far the edge effect influences the patches is a species specific attribute (Helzer and Jelinski, 1999). Therefore, the use of CORE, NCORE and CAI metrics seems not appropriate for general fragmentation models.

The redundancy found between AREA with CORE, PERIM, NCORE, and GYRATE was consistent with previous studies (Szabó et al., 2014). This is mainly because these metrics represent patch extent and therefore polygon area has a very strong influence on their formulation. The strong and positive correlation found between PARA and CONTIG is because both metrics incorporate the extent and shape to address patch complexity (Helzer and Jelinski, 1999). However, Szabó et al. (2014) found a strong negative correlation between these metrics. PROX, SIMI, and ENN did not correlate with other metrics. Consequently, they can be regarded as the ones providing unique information when selecting indices to characterize a particular fragment. Szabó et al. (2014) found that the only non-correlated metrics were PROX and ENN.

It has been established that landscape metrics are very difficult to interpret and associate to ecological patterns and processes (Cushman et al., 2008). Therefore, we thoroughly analyzed each landscape metric both theoretically and empirically to establish the MOORA decision for maximizing (positive influence) or minimizing (negative influence). The MOORA method was chosen to integrate the landscape metrics and build the fragmentation model, because we considered that it is the most robust of all the multi-objective optimization techniques. This method is the only one that fulfills the seven conditions of robustness used to evaluate the performance of MCDA. It includes all stakeholders, evaluation objectives, response alternatives, it is based on cardinal numbers, it uses only non-subjective estimators, it uses the latest information available, and it uses two different methods of multi objective optimization (the ratio system and the reference point approach) (Brauers and Zavadskas, 2009, 2012).

In addition to the mathematical robustness, the operation of this method is very simple. Chakraborty (2011) compared the MOORA to other multi-objective methods (AHP, TOPSIS, ELECTRE, VIKOR, PROMETHEE, and GRA) and demonstrated that the MOORA method besides being mathematically robust, is very simple to comprehend and easy to implement because it involves the least amount of mathematical calculations and

minimal computational skills are required. Therefore, the MOORA method is highly recommended to assist during any complex decision-making process, such as the determination of the quality of grassland patches of the Chihuahua Desert.

Landscape metric combination established in MOORA 7, MOORA 8, and MOORA 9 were consistent in selecting the same patches of good quality and poor quality. The four metrics used in MOORA 7 (AREA, ENN, PROX and SIMI) were the least correlated between themselves. While the MOORA 8 uses the AREA and PERIM which are highly correlated. The effect of the PERIM was absorbed by the AREA because it was minimized. Therefore, AREA, ENN, PROX and SIMI were again the important indicators. Finally, in MOORA 9, PARA was used instead of AREA and/or PERIM. PARA equals to the ratio of the patch perimeter to its area and it has been established that PARA is strongly influenced by patch area (McGarigal et al., 2002).

The KAPPA value showed that MOORA 7 and MOORA 8 had an almost perfect agreement when assigning patch quality. Cushman et al. (2008) noted that it is desirable that a smaller number of independent variables be included when describing landscape structure (Cushman et al., 2008). Therefore, we propose that MOORA 7 (AREA, ENN, PROX and SIMI) includes the patch metrics that best describe the grassland patches of the Chihuahuan Desert Ecoregion.

CONCLUSIONS

The values of the patch metrics confirmed the intense fragmentation that they are undergoing of the Chihuahuan Desert landscape and demonstrate that grasslands ecosystem are in a state of vulnerability. The enormous structural variation of grassland patches (e.g. area, shape and isolation) within the ecoregion and the redundancy of this fragmentation indices make difficult to identify which attributes were the best descriptors to identify grasslands remnants that have a higher quality and thus can be selected as priorities for conservation.
The MCDA MOORA method used in this study proved to be simple, easy to understand, and mathematically robust to discriminate different sets of landscape metrics. This tool allows to simultaneously considering any number of attributes with their relative importance and offering a more objective and logical attribute selection approach.

Finally, it is possible to conclude that the best set of landscape metrics to describe the quality of Chihuahuan Desert Grassland patches includes the area, Euclidean nearest-neighbor distance, and proximity and similarity coefficients.

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Table I. Description of patch-base metrics for the raster image integrated with grassland patch of the Chihuahuan Desert calculated in FRAGSTAT 4.1 Software package (Mcgarigal, 2015).

Indicator	Description	Units	Range
AREA	Equals the area (m^2) of the patch, divided by 10 000. The area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape.	Hectares	AREA > 0, without limit
PERIM	Equals the perimeter (m) of the patch, including any internal holes in the patch. The perimeter of a patch is treated as an edge, and the intensity and distribution of edges constitutes a major aspect of landscape pattern	Meters	PERIM > 0, without limit
GYRATE	Equals the mean distance (m) between each cell in the patch and the patch centroid. Radius of gyration is a measure of patch extent	Meters	Gyrate ≥ 0, without limit
PARA	Equals the ratio of the patch perimeter (m) to area (m^2). Perimeter-area ratio is a simple measure of shape complexity, but without standardization to a simple Euclidean shape.	None	PARA > 0, without limit
SHAPE	Equals patch perimeter (m) divided by the square root of patch area (m2), adjusted by a constant to adjust for a square standard. Shape index corrects for the size problem of the perimeter-area ratio index by adjusting for a square standard and, as a result, is the simplest and perhaps most straightforward measure of shape complexity.	None	SHAPE ≥ 1, without limit SHAPE = 1 when the patch is a square and increase whitout limit as patch shape becomes more irregular.
FRAC	Equals the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2); the perimeter is adjusted to correct for the raster bias in perimeter. Fractal dimension index is appealing because it reflects shape complexity across a range of spatial scales.	None	1 ≤ FRAC ≤ 2
CIRCLE	Equals 1 minus patch area (m^2) divided by the area (m^2) of the smallest circumscribing circle. This index is not influenced by patch size.	None	0 ≤ CIRCLE < 1 CIRCLE = 0 for square patches and approaches 1 for elongated, linear patches one cell wide
CONTIG	Equals the average contiguity value for the cells in a patch minus 1, divided by the sum of the template values minus 1. Contiguity index assesses the spatial connectedness, or contiguity of cells within a grid-cell patch to provide an index on patch boundary configuration and thus patch shape	None	0 ≤ CONTIG ≤ 1 CONTIG equals 0 for a one-pixel patch and increases to a limit of 1 as patch congruity, or connectedness, increases.
CORE	Equals the area (m2) within the patch that is further than the specified depth-of-edge distance from the patch perimeter, divided by 10,000. Core area index is a relative index that quantifies core area as a percentage of patch area	Hectares	CORE ≥ 0, without limit CORE = 0 when every location within the patch is within the specified depth-of edge distance from the patch perimeter. CORE approaches AREA as the specified depth-of-edge distance decreases and as patch shape is simplified
NCORE	Equals the number of disjunctive core areas contained within the patch boundary. A disjunction core is a spatially contiguous (and therefore distinct) core area. Depending on the size and shapes of the patch and the specified depth-of-edge distance(s), a single patch may actually contain several disjunctive core areas.	None	CORE ≥ 0, without limit NCORE = 0 when CORE = 0 (every location within the patch is within the specified depth-of-edge distance from the patch perimeter) NCORE > 1 when, because of shape, the patch contains disjunctive core areas
CAI	Equals the patch core area (m2) divided by total patch area (m2), multiplied by 100 (to convert to a percentage); in other words, CAI equals the percentage of a patch that is core area. Core area index is a relative index that quantifies core area as a percentage of patch area.	Percent	0 ≤ CAI < 100 CAI approaches 100 when the patch, because of size, shape, and edge width, conns mostly core area
ENN	Equals the distance (m) to the nearest neighboring patch of the same type, based on shorts edge-to-edge distance. Note that the edge to edge distances are from cell center to cell center. Euclidean nearest-neighbor distance is perhaps the simplest measure of patch context and has been used extensively to quantify patch isolation.	Meters	ENN > 0, without limit ENN approaches) as the distance to the nearest neighbor decreases
PROX	Equals the sum of patch area (m2) divided by the nearest edge to edge distance squared (m2) between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance (m) of the focal patch.	None	PROX ≥ 0 PROX =) if a patch has no neighbors of the same patch type within the specified radius. PROX increases as the neighborhood is increasingly occupied by patches of the same type and as this patches become closer and more contiguous in distribution
SIMI	Equals the sum, over all neighboring patches with edges within a specified distance the focal patch type and the class of the neighboring patch (0-1), divided by the nearest edge-to edge distance squares (m^2) between the focal patch and the neighboring patch.	None	SMI ≥ 0 SIMI = 0 if all the patches within the specified neighborhood have a 0 similarity coefficient. SIMI increases as the neighborhood is increasingly occupied by patches with greater similarity coefficients and as this similar patches become closer and more contiguous and less fragmented in distribution

Table II. Descriptive statistics of the metric landscape of the natural grassland found in the Chihuahuan Desert Ecoregion

	Mean	Standard deviation	Minimum	Maximum
AREA	671.45	71258.15	4	10572632
PERIM	11264.32	564066.34	800	83099600
GYRATE	334.59	1319.42	100	163609.98
PARA	133.73	49.89	7.53	200
SHAPE	1.4	0.97	1	63.88
FRAC	1.04	0.04	1	1.33
CIRCLE	0.47	0.27	0	0.96
CONTIG	0.29	0.23	0	0.95
CORE	530.25	63135.48	0	9370160
NCORE	0.69	13.52	0	1877
CAI	5.75	13.12	0	89.21
PROX	6433.59	60423.26	0	660828.25
SIMI	2434274.45	2846722.82	0	13113770.11
ENN	834.58	1832.57	400	117459.95

Table III. The Pearson correlation matrix between the 14 landscape variables estimated for the Chihuahuan Desert grasslands

	AREA	PERIM	GYRATE	PARA	SHAPE	FRAC	CIRCLE	CONTIG	CORE	NCORE	CAI	PROX	SIMI	ENN
AREA	*	0.996 p=0.000	0.850 p=0.000	-0.22 p=0.001	0.453 p=0.000	0.050 p=0.000	0.007 p=0.296	0.025 p=0.000	1 p=0.000	0.945 p=0.000	0.055 p=0.000	-0.001 0.923	0.014 p=0.042	-0.001 0.836
PERIM		*	0.881 p=0.000	-0.036 p=0.000	0.508 p=0.000	0.076 p=0.000	0.015 p=0.22	0.040 p=0.000	0.995 p=0.000	0.970 p=0.000	0.075 p=0.000	-0.001 p=0.885	0.015 p=0.026	-0.001 p=0.824
GYRATE			*	-0.247 p=0.000	0.791 p=0.000	0.350 p=0.000	0.153 p=0.000	0.269 p=0.000	0.846 p=0.000	0.926 p=0.000	0.377 p=0.000	0.0002 p=0.821	0.063 p=0.000	0.028 p=0.000
PARA				*	-0.404 p=0.000	-0.503 p=0.000	0.694 p=0.000	0.987 p=0.000	-0.021 p=0.002	-0.087 p=0.000	-0.582 p=0.000	-0.063 p=0.000	0.432 p=0.000	0.126 p=0.000
SHAPE					*	0.731 p=0.000	0.355 p=0.000	0.449 p=0.000	0.447 p=0.000	0.646 p=0.000	0.499 p=0.000	-0.017 p=0.014	0.070 p=0.000	0.004 p=0.577
FRAC						*	0.721 p=0.000	0.668 p=0.000	0.047 p=0.000	0.155 p=0.000	0.517 p=0.000	-0.017 p=0.011	0.152 p=0.000	0.025 p=0.000
CIRCLE							*	0.688 p=0.000	0.0006 p=0.361	0.044 p=0.000	0.287 p=0.000	0.031 p=0.000	0.247 p=0.000	0.057 p=0.000
CONTIG								*	0.023 p=0.001	0.096 p=0.000	0.738 p=0.000	0.056 p=0.000	0.427 p=0.000	0.130 p=0.000
CORE									*	0.942 p=0.000	0.050 p=0.000	-0.001 p=0.926	0.014 p=0.044	-0.001 p=0.835
NCORE										*	0.145 p=0.000	-0.001 p=0.848	0.025 p=0.000	-0.001 p=0.905
CAI											*	0.017 p=0.011	0.230 p=0.000	0.145 p=0.000
PROX												*	0.027 p=0.000	-0.024 p=0.000
SIMI													*	0.109 p=0.000
ENN														*

Table IV. Number of principal component of each set of landscape metrics with the weight and MOORA decision of each landscape metric in all MOORA combinations

	Eigenvalues of PCA	Landscape metrics	Weight	MOORA Decision
MOORA 1	43.89	AREA	7.35	Maximize
		PERIM	7.35	Minimize
		GYRATE	7.35	Maximize
		SHAPE	7.35	Minimize
		CORE	7.35	Maximize
		NCORE	7.35	Minimize
	30.91	PARA	6.18	Minimize
		FRACC	6.18	Minimize
		CIRCLE	6.18	Minimize
		CONTIG	6.18	Maximize
		CAI	6.18	Maximize
	8.68	ENN	8.68	Minimize
	8.54	PROX	8.54	Maximize
	7.97	SIMI	7.97	Maximize
MOORA 2	32.30	CONTIG	16.15	Maximize
		SIMI	16.15	Maximize
	23.55	PROX	23.55	Maximize
	22.29	ENN	22.29	Minimize
	21.87	GYRATE	21.87	Maximize
MOORA 3	45.30	PARA	9.06	Minimize
		SHAPE	9.06	Minimize
		FRAC	9.06	Minimize
		CIRCLE	9.06	Minimize
		CONTIG	9.06	Maximize
	31.36	AREA	10.45	Maximize
		PERIM	10.45	Minimize
		GYRATE	10.45	Maximize
	11.65	PROX	5.82	Maximize
		ENN	5.82	Minimize
	11.65	SIMI	11.65	Maximize
MOORA 4	58.97	AREA	29.48	Maximize
		SHAPE	29.48	Minimize
	41.02	SIMI	20.51	Maximize
		ENN	20.51	Minimize
MOORA 5	41.84	AREA	20.92	Maximize
		SHAPE	20.92	Minimize
	29.27	ENN	29.27	Minimize
	28.87	PROX	14.43	Maximize
		SIMI	14.43	Maximize
MOORA 6	45.04	GYRATE	22.52	Maximize
		SHAPE	22.52	Minimize
	27.65	ENN	27.65	Minimize
	27.29	SIMI	13.64	Maximize
		PROX	13.64	Maximize
MOORA 7	24.73	AREA	24.73	Maximize
	25.57	ENN	25.57	Minimize
	25.97	PROX	25.97	Maximize
	23.71	SIMI	23.71	Maximize
MOORA 8	48.73	AREA	24.36	Maximize
		PERIM	24.36	Minimize
	25.79	ENN	25.79	Minimize
	25.47	PROX	12.73	Maximize
		SIMI	12.73	Maximize

MOORA 9	40.19	PARA	20.09	Minimize
		SIMI	20.09	Maximize
	30.80	PROX	30.80	Maximize
	28.99	ENN	28.99	Minimize

Table V. Agreement analysis and correlation analysis between the different MOORA combinations. Above the diagonal is the agreement Kappa value and below the diagonal is the Kappa value interpretation of the level of agreement

	MOORA 1	MOORA 2	MOORA 3	MOORA 4	MOORA 5	MOORA 6	MOORA 7	MOORA 8	MOORA 9
MOORA 1	*	0.2818 p=0.00	0.7973 p=0.00	0.1067 p=0.11	0.1315 p=0.05	0.2815 p=0.00	0.3939 p=0.00	0.3451 p=0.00	0.3790 p=0.00
MOORA 2	Fair	*	0.1711 p=0.00	0.1335 p=0.06	0.1870 p=0.00	0.2188 p=0.00	0.2732 p=0.00	0.2199 p=0.00	0.5951 p=0.00
MOORA 3	Substantial	Slight	*	0.1797 p=0.00	0.2016 p=0.00	0.3250 p=0.00	0.4859 p=0.00	0.3639 p=0.00	0.4533 p=0.000
MOORA 4	Slight	Slight	Slight	*	0.8960 p=0.00	0.6632 p=0.00	0.2765 p=0.00	0.3905 p=0.00	0.1331 p=0.27
MOORA 5	Slight	Slight	Fair	Almost perfect	*	0.7649 p=0.00	0.3473 p=0.00	0.4534 p=0.00	0.1828 p=0.01
MOORA 6	Fair	Fair	Fair	Substantial	Substantial	*	0.4241 p=0.00	0.5209 p=0.00	0.2606 p=0.00
MOORA 7	Fair	Fair	Moderate	Fair	Fair	Moderate	*	0.8113 p=0.00	0.3893 p=0.00
MOORA 8	Fair	Fair	Fair	Fair	Moderate	Moderate	Almost perfect	*	0.2872 p=0.00
MOORA 9	Fair	Moderate	Moderate	Slight	Slight	Fair	Fair	Fair	*

UN ANÁLISIS CUANTITATIVO DEL ESTADO DEL CONOCIMIENTO DE LA ECOFISIOLOGÍA TÉRMICA DE REPTILES EN MÉXICO

A QUANTITATIVE ANALYSIS OF THE STATE OF KNOWLEDGE OF THE THERMAL ECOPHYSIOLOGY OF REPTILES IN MEXICO.

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RESUMEN

El conocimiento acerca de la termorregulación de los reptiles en México ha crecido considerablemente desde principios de la década de 1990 y se ha enfocado en múltiples ecosistemas, taxones y temáticas, pero la información está dispersa. Por lo tanto, en este ensayo se realizó una revisión de la literatura sobre la ecofisiología térmica de los reptiles en México. Los objetivos fueron concentrar la información publicada y hacer una evaluación cuantitativa del conocimiento de la termorregulación de los reptiles, así como identificar los vacíos en este campo de estudio y proponer nuevas líneas de investigación. El análisis sobre la información que se ha generado sugiere que hay grupos taxonómicos, ecosistemas y enfoques científicos escasamente estudiados. La perspectiva de los trabajos se agrupó en cinco grandes categorías: ecológicos, fisiológicos, evolutivos, conductuales y desde un enfoque de cambio climático.

KEYWORDS:
ectotherms
literature review
thermal ecology
thermo-physiology
thermoregulation

ABSTRACT

Knowledge about thermoregulation of reptiles in Mexico has grown considerably since the early 1990's, and has focused on multiple ecosystems, taxa, and topics, but the information is dispersed. Therefore, a review of the literature on the thermal ecophysiology of reptiles in Mexico was carried out here. The objectives were to focus on the published information and to make a quantitative evaluation of the knowledge of reptile thermoregulation, as well as to identify gaps in this field of study and to propose new lines of research. Analysis of the available information suggests that there are poorly studied taxonomic groups, ecosystems, and scientific approaches. The perspective on the work has been divided into five categories: ecological, physiological, evolutionary, behavioral and climate change approaches.

INTRODUCCIÓN

La idea de que la temperatura es un factor clave en la ecología y fisiología de los reptiles fue abordada en la literatura desde la década de 1930 (e.g., Bogert, 1939; Cowles, 1939). Enseguida, utilizando a los reptiles de ambientes desérticos como modelo de estudio, se demostró la importancia de la conducta y los mecanismos fisiológicos en el control de la temperatura corporal (Cowles, 1940, 1941, 1942; Cowles y Bogert, 1944), así como los factores evolutivos (Bogert, 1949a) y la variación de la temperatura corporal entre especies o en diferentes ecosistemas (Bogert, 1949b; Brattstrom, 1965; Cunningham, 1966). A partir de estos trabajos pioneros se mantuvo un considerable interés por describir la compleja interacción entre las variables biofísicas, bióticas y filogenéticas con respecto a la termorregulación (Heath, 1962; Heath, 1964; Templeton, 1970; Huey y Slatkin, 1976).

Desde entonces, los herpetólogos y ecofisiólogos han generado una gran cantidad de datos sobre la termorregulación de reptiles en el campo y laboratorio. Particularmente, los trabajos se han realizado desde diferentes perspectivas e incluso niveles biológicos, los que han sido: fisiológicos, ecológicos, evolutivos y conductuales (Bennett, 1980; Bartholomew, 1982; Gans y Pough, 1982a; Angilletta et al., 2002). Estas contribuciones han sido compiladas en revisiones exhaustivas como la de Avery (1979) y el destacado

volumen 12 del libro *Biology of the Reptilia* (*Physiological Ecology*) publicado en 1982 que contiene revisiones detalladas sobre la ecofisiología térmica (Gans y Pough, 1982b). Particularmente, algunas de las revisiones más recientes se han realizado desde una perspectiva adaptativa (Angilletta, 2009), resumiendo los mecanismos fisiológicos de la termorregulación (Seebacher y Franklin, 2005) o integrando los rasgos de la variación de la temperatura desde múltiples escalas (Clusella-Trullas y Chown, 2014). Incluso se han publicado glosarios con los términos sobre este tema (Pough y Gans, 1982; IUPS Thermal Commission, 2003).

Particularmente, se han respondido múltiples preguntas de cómo la temperatura puede afectar la biología de los reptiles desde diferentes enfoques, por ejemplo en la reproducción (Angilletta et al., 2006), tasas de crecimiento (Sinervo y Adolph, 1989), coloración (Sherbrooke, 1997), conducta, patrones y estrategias de termorregulación (Heath, 1962; Licht, 1965; Huey y Pianka, 1977; Huey, 1982), entre otros. Además, el avance tecnológico ha permitido describir ampliamente las temperaturas corporales y su relación con las temperaturas micro-ambientales (e.g., aire y/o sustrato; Huey y Slatkin, 1976), también para determinar los niveles térmicos óptimos o para establecer los límites críticos (mínimos y máximos) en campo o bajo condiciones controladas de laboratorio con pruebas de rendimiento en función de la temperatura corporal (Bennett y Huey, 1990; Angilletta, 2006). Incluso se han diseñado metodologías para evaluar, por un lado, la precisión y eficiencia en la termorregulación de los organismos, y por otro lado, la calidad térmica del hábitat utilizando modelos operativos, considerando la perspectiva de los organismos (Hertz et al., 1993; ver también Blouin-Demers y Nadeau, 2005). A su vez, este tipo de estudios han sido englobados bajo los enfoques ecofisiológicos y evolutivos que han sido revisados en numerosas ocasiones (Gans y Pough, 1982a; Angilletta et al., 2002; Seebacher y Franklin, 2005; Angilletta, 2009).

Actualmente, el estudio de la ecología térmica en reptiles ha crecido de forma exponencial sobre múltiples ecosistemas y taxones (Clusella-Trullas y Chown, 2014). Una de las principales razones, como se mencionó anteriormente, es debido a la importancia de la temperatura en su biología y en consecuencia, la alteración de su nicho térmico debido al cambio en las condiciones climáticas que puede afectar la fenología reproductiva, su distribución o incluso causar la extinción local de sus poblaciones (López-Alcaide y Macip-Ríos, 2011). Por ejemplo, se ha documentado que durante las últimas décadas en México se ha extinto el 12% de 200 poblaciones de lagartijas del género *Sceloporus* (todas con hábitats intactos). Con base en estos resultados se han realizado proyecciones a escala global, las cuales predicen que cerca del 39% de las poblaciones de lagartijas a nivel mundial estarán extintas para el 2080 (Sinervo et al., 2010; Sinervo et al., 2011). En este caso, México es uno de los países con mayor diversidad herpetofaunística y ecosistémica, por lo cual ha representado un excelente modelo base para proyectar escenarios de riesgo de extinción a nivel global (e.g., Huey et al., 2010; Sinervo et al., 2010; Kearney, 2013; Sinervo et al., en revisión). Es por esto que los estudios ecofisiológicos acerca de los niveles de tolerancia térmica, adaptación, aclimatación y desempeño son fundamentales para realizar proyecciones precisas de cómo las especies responderán a los cambios en las condiciones ambientales bajo un enfoque mecanicista, es decir incorporando los mecanismos y procesos clave que son relevantes para las especies en los ecosistemas (Buckley et al., 2010).

Por lo anterior, la finalidad de esta revisión es analizar la información que se ha producido en México sobre la ecofisiología térmica de reptiles, la cual será útil en estudios analíticos y comparados. Así, los objetivos del presente trabajo son: 1) proveer una evaluación cuantitativa sobre el conocimiento de la ecofisiología térmica de los reptiles mexicanos; 2) concentrar la literatura y trabajos publicados; 3) identificar los vacíos en este campo de estudio; y 4) proponer nuevas líneas de investigación sobre este tópico.

MATERIALES Y MÉTODOS

Se realizó una búsqueda bibliográfica en *Web of Science* para los artículos que investigaron la termorregulación en reptiles. El principal criterio para la búsqueda de artículos fue utilizando las palabras clave: "*thermal ecology*", "*thermal biology*", "*thermoregulation*", "*body temperature*", "*Mexico*", "*reptiles*" y sus variantes en español. Esta búsqueda inicial dio una lista de 115 artículos. Además de las palabras clave, también se realizó una búsqueda en *Google Scholar* (http://sholar.google.com) con los nombres de los principales investigadores en el campo (e.g., Ballinger Royce, Robin Andrews). También se incluyeron estudios que se encontraron en el proceso de contacto con autores y lectura de otros artículos. Únicamente se incluyeron los estudios que cumplieran los siguientes criterios de selección: a) trabajos realizados en el campo y/o en condiciones controladas de laboratorio; b) trabajos realizados únicamente en México o especies mexicanas, c) que los datos hayan sido colectados por lo menos una estación; d) artículos donde se detalla la metodología empleada; e) los estudios originales hayan reportado los estadísticos necesarios para tener un escenario para esta revisión; f) no hubo un filtro con respecto al año de publicación ya que el enfoque del artículo no justifica la publicación por año. Finalmente, sólo los artículos que cumplieron los criterios de selección fueron incluidos en el análisis (n=92). Posteriormente, los artículos se ordenaron y catalogaron en grupos por características comunes. Para la propuesta de este análisis, se midió el conocimiento sobre la termorregulación en reptiles

como el número de publicaciones por géneros o especies, por periodos específicos de tiempo y bajo temáticas específicas.

RESULTADOS

Síntesis cronológica de la investigación de termorregulación en México. Los primeros artículos publicados en el tema de termorregulación sobre especies mexicanas fueron publicados entre 1949 y 1966, donde sobresalen los trabajos de Bogert (1949b), Soulé (1963) y Brattstrom (1965), en los cuales se reportan algunos aspectos de termorregulación, pero sobre todo las temperaturas corporales de ~164 especies de reptiles. De las anteriores se distinguen 95 especies de lagartijas, de las que en su mayoría fueron de las familias Phrynosomatidae (e.g., *Callisaurus*, *Sceloporus*, *Urosaurus* y *Uta*) y Teiidae (e.g., *Aspidoscelis*); 56 especies de serpientes principalmente de las familias Colubridae (e.g., *Thamnophis*) y Viperidae (e.g., *Crotalus*) y 13 especies de tortugas, sobresaliendo la familia Emydidae (e.g., *Terrapene*) y Testudinidae (e.g., *Gopherus*). Los tres artículos incluyen un gran esfuerzo sobre el conocimiento de las temperaturas corporales en campo, "preferidas" o seleccionadas en laboratorio, incluso los intervalos de temperaturas voluntarias, críticas y letales. Estos trabajos fueron seguidos por investigaciones más puntuales para describir el comportamiento termorregulador en determinadas especies (e.g., *Iguana iguana*; McGinnis y Brown, 1966), pero de forma dispersa y con grandes vacíos en la investigación. Fue hasta principios de los noventas que continuaron los trabajos sobre ecología de lagartijas, donde se abordaron los periodos de actividad y la biología térmica (e.g., Beck y Lowe, 1991; Ballinger et al., 1995; Lemos-Espinal y Ballinger, 1995). A partir de entonces, los trabajos han incrementado considerablemente a lo largo del tiempo (Figura 1A). Sobresale que después del 2010, se ha publicado el 56.9% de los trabajos en el tema (Sinervo et al., 2010; Clusella-Trullas et al., 2011; Clusella-Trullas y Chown, 2014).

Síntesis por grupos taxonómicos. Un tema relevante, que representa el 10% de los trabajos recopilados, ha sido la determinación sexual en tortugas por la temperatura de incubación (e.g., Vogt y Flores-Villela, 1986; Vogt y Flores-Villela, 1992). También sobresalen los trabajos sobre la influencia de la temperatura en cocodrilos (5.6%), la cual ha sido investigada recientemente (Charruau, 2012; López-Luna et al., 2015; Escobedo-Galván et al., 2016; González-Desales et al., 2016). En el caso de las serpientes, es el grupo con menos atención ya que es únicamente el 3.3% de los estudios (e.g., Lemos-Espinal et al., 1997c; Castañeda-Gonzalez et al., 2011; Díaz de la Vega-Pérez et al., 2016). Así mismo, es importante mencionar que en estos trabajos, únicamente describen sus temperaturas corporales en campo y con bajos números de colecta. Finalmente, la mayor parte de los trabajos aquí recabados (80%), han sido realizados con lagartijas como modelo de estudio. De los cuales la gran mayoría han sido realizados con lagartijas diurnas (95.9%; Lara-Resendiz, 2013) y muy pocos han investigado a las lagartijas nocturnas (4.1%; e.g., Lara-Resendiz et al., 2013a; Jiménez-Arcos et al., 2016). La tabla 1 muestra los géneros y especies de reptiles estudiadas bajo este tópico y los porcentajes con respecto al total de especies y géneros de México.

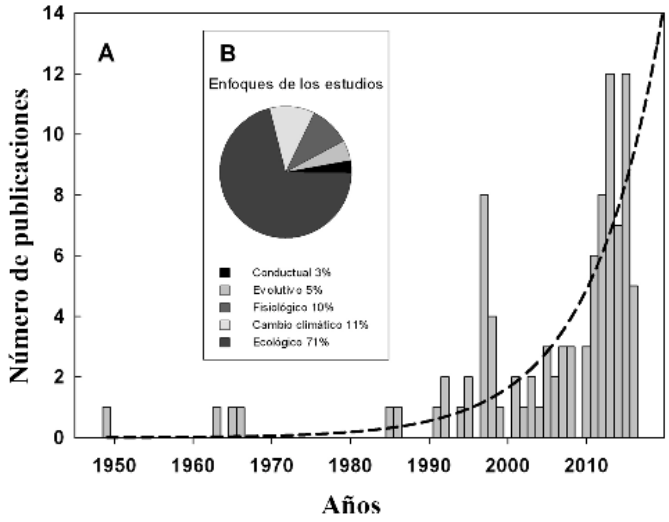

Figura 1. A) Número anual de estudios de termorregulación realizados en México y publicados entre 1949 y 2016. La curva representa la función exponencial ajustada para el periodo 1949-2015 (r2= 0.73; línea punteada). Los estudios de 2016 no se incluyeron en el análisis de regresión debido a que probablemente el número de referencias encontradas del último año en las bases de datos de internet subestimen el número real de publicaciones. B) Enfoque y porcentajes de los estudios de termorregulación en México.

Dentro del grupo de las lagartijas, el taxa más estudiado dentro de la ecología térmica ha sido *Sceloporus* con el 42% (e.g., Andrews et al., 1997a; Gadsden y Estrada-Rodríguez, 2007; Güizado-Rodríguez et al., 2011; Woolrich-Piña et al., 2012b), después *Aspidoscelis* 9.4% (e.g., Woolrich-Piña et al., 2011; Díaz de la Vega-Pérez et al., 2013; Güizado-Rodríguez et al., 2014), seguido por *Phrynosoma* y *Xenosaurus* ambos con 8.4% (e.g., Ballinger et al., 1995; Lemos-Espinal et al., 1998b; Woolrich-Piña et al., 2012c; Lara-Resendiz et al., 2015b), después sobresalen los géneros *Anolis* y *Urosaurus*, ambos con 5.2% (e.g., Lemos-Espinal et al., 1997e; García, 2008; Medina et al., 2016), otros géneros como *Callisaurus*, *Crotaphytus*, *Uma*, *Uta* (e.g., Soulé, 1963; García-De la Peña et al., 2007; Gadsden et al., 2012), *Ctenosaura* (e.g., Blázquez y Rodríguez-Estrella, 1997; Valenzuela-Ceballos et al., 2015), *Barisia*, *Elgaria* (e.g., Lemos-Espinal et al., 1998a; Valdez-Villavicencio y Galina-Tessaro, 2014) y *Heloderma* (Beck y Lowe, 1991) presentan menos de cuatro trabajos (>4%), al igual que los géneros nocturnos *Phyllodactylus* (Lara-Resendiz et al., 2013a) y *Xantusia* (Cruz-Sáenz y Lazcano, 2012; Gadsden et al., 2015b), pero que en total suman el 34% de los trabajos realizados en México. La tabla 2 muestra una lista de las especies de reptiles, donde se estudió su ecofisiología térmica.

Tabla I. Estudios de ecofisiología térmica en reptiles mexicanos. Géneros presentes en México (GM); Géneros estudiados (GE); Especies presentes en México (EM); Especies Estudiadas (EE); Número de trabajos realizados (NT). GM y EM se tomaron de Flores-Villela y García-Vázquez (2014). Nota: únicamente se muestran las familias con las especies estudiadas en esta revisión, para las familias no mostradas en la tabla no hay información sobre este tópico. * = Total de géneros (159) y especies (864) en México.
** = el tamaño de muestra fue de 92, sin embargo varias especies fueron estudiadas en diferentes trabajos y enfoques.

	Familia	GM	GE	EM	EE	NT	Géneros estudiados por familia (%)	% de especies estudiados por familia
Tortugas	Cheloniidae	4	4	6	5	8	100	83.4
	Dermatemydidae	1	1	1	1	2	100	100
	Dermochelyidae	1	1	1	1	1	100	100
	Kinosternidae	2	2	15	2	4	100	13.4
	Staurotypidae	2	1	3	1	1	50	33.4
Lagartijas	Anguidae	7	2	49	2	3	28.6	4.1
	Corytophanidae	3	1	6	1	1	33.4	16.7
	Crotaphytidae	2	1	10	1	1	50	10
	Dactyloidae	1	1	48	3	6	100	6.3
	Helodermatidae	1	1	4	1	1	100	25
	Iguanidae	4	2	19	4	7	50	21.1
	Phrynosomatidae	10	7	138	47	86	70	34.1
	Phyllodactylidae	2	1	16	2	2	50	12.5
	Scincidae	4	1	30	1	2	25	3.4
	Teiidae	2	1	43	14	15	50	32.6
	Xantusiidae	2	1	26	2	2	50	7.7
	Xenosauridae	1	1	8	6	6	100	75
Serpientes	Colubridae	35	1	133	2	2	2.9	1.6
	Viperidae	10	1	60	1	1	10	1.7
Cocodrilos	Crocodylidae	1	1	2	2	4	100	100
Total		**159***	**32**	**864***	**99**	**155****	**20.2**	**11.5**

Por otro lado, considerando el tipo de ambiente en el que se estudió la termorregulación, se simplificaron únicamente en tres tipos: tropical, árido y templado. La mayor cantidad de estudios se realizaron en zonas tropicales con un 44.5% (e.g., García, 2008; Navarro-García et al., 2008; Siliceo-Cantero y García, 2015), por otro lado, en zonas áridas y desérticas se llevó acabo el 34.6% (e.g., Garcia-De La Peña et al., 2005; Gadsden y Estrada-Rodríguez, 2007; Woolrich-Piña et al., 2012b; Gadsden et al., 2015a; Gadsden et al., 2015c; Lara-Resendiz et al., 2015b) y por último, los estudios en zonas templadas o de alta montaña con únicamente el 20.8% (e.g., Lemos-Espinal y Ballinger, 1995; Güizado-Rodríguez et al., 2011; Ávila-Bocanegra et al., 2012; Lara-Resendiz et al., 2014c). Un bajo porcentaje (<2%) incluyeron los trabajos que no cumplieron con los criterios de agrupación. Por otro lado, el 68.5% de los trabajos estudiaron detalladamente a una sola especie (e.g., Woolrich-Piña et al., 2006; Navarro-García et al., 2008; Ruiz et al., 2010; Sandoval et al., 2011), 22.8% estudiaron entre 2 y 9 especies en estudios comparativos o a escala de comunidad (e.g., Soulé, 1963; Lemos-Espinal et al., 1997c; Díaz de la Vega-Pérez et al., 2013; Pike, 2013; Lara-Resendiz et al., 2015a) y 8.7% hicieron estudios a nivel de género (e.g., Andrews, 1998; Hodges, 2004) o analizando una temática en particular en múltiples grupos (e.g., Escobedo-Galvan, 2013).

Síntesis por temas de interés. Con respecto a las temáticas, enfoques y objetivos de los trabajos, se delimitaron cinco categorías: 1) ecológicos, 2) evolutivos, 3) fisiológicos, 4) conductuales y 5) cambio climático (Figura 1B). Cada categoría fue establecida por la naturaleza del estudio, es decir, si el título, palabras claves u objetivos hacen referencia a una determinada categoría, como por ejemplo, *thermal ecology, ecological aspects, nesting ecology*, *ecological niche*, en estos casos el trabajo fue catalogado bajo la temática ecológica; lo mismo para las otras categorías.

Tabla II. Especies de reptiles estudiadas bajo el enfoque de ecofisiología térmica por familia y sus referencias.

	Familia	Especies estudiadas (n)	Referencias
Tortugas	Cheloniidae	*Caretta caretta, Chelonia mydas, Eretmochelys imbricata, Lepidochelys kempii* y *L. olivacea* (5)	McMichael et al., 2008; Sandoval et al., 2011; Pike, 2013; Lamont y Fujisaki, 2014
	Dermatemydidae	*Dermatemys mawii* (1)	Vogt y Flores-Villela, 1992; Ruiz et al., 2010
	Dermochelyidae	*Dermochelys coriacea* (1)	Pike, 2013
	Kinosternidae	*Claudius angustatus* y *Kinosternon leucostomum* (2)	Vogt y Flores-Villela, 1992
	Staurotypidae	*Staurotypus triporcatus* (1)	Vogt y Flores-Villela, 1992
Lagartijas	Anguidae	*Barisia imbricata* y *Elgaria paucicarinata* (2)	Lemos-Espinal et al., 1998a; Lara-Resendiz et al., 2014c; Valdez-Villavicencio y Galina-Tessaro, 2014
	Corytophanidae	*Basiliscus vittatus* (1)	Brattstrom, 1965
	Crotaphytidae	*Crotaphytus antiquus* (1)	Gadsden et al., 2012
	Dactyloidae	*Anolis allisoni, A. nebulosus* y *A. uniformis* (3)	Ramírez-Bautista y Benabib, 2001; García, 2008; Lara-Resendiz et al., 2013c; Siliceo-Cantero y García, 2015; Woolrich-Piña et al., 2015; Medina et al., 2016
	Helodermatidae	*Heloderma horridum* (1)	Beck y Lowe, 1991
	Iguanidae	*Ctenosaura hemilopha, C. oaxacana, C. pectinata* y *Iguana iguana* (4)	Bogert, 1959; Soulé, 1963; Brattstrom, 1965; McGinnis y Brown, 1966; Dupré et al., 1989; Blázquez y Rodríguez-Estrella, 1997; Valenzuela-Ceballos et al., 2015; Piantoni et al., 2016
	Phrynosomatidae	*Callisaurus draconoides, Petrosaurus thalassinus, Phrynosoma asio, P. blainvillii, P. braconnieri, P. cornutum, P. goodei, P. hernandesi, P. modestum, P. orbiculare, P. sherbrookei, P. solare, Phrynosoma taurus, Sceloporus adleri, S. aeneus, S. anahuacus, S. bicanthalis, S. clarkii, S. cyanostictus, S. gadoviae, S. grammicus, S. grandaevus, S. horridus, S. jarrovii, S. magister, S. melanorhinus, S. merriami, S. mucronatus, S. ochoterenae, S. orcutti, S. palaciosi, S. poinsettii, S. serrifer, S. siniferus, S. spinosus, S. squamosus, S. torquatus, S. undulatus, S. utiformis, S. variabilis, S. woodi, Uma exsul, Urosaurus bicarinatus, U. nigricaudus, Uta stejnegeri* y *U. stansburiana* (47)	Bogert, 1949b; Soulé, 1963; Benabib y Congdon, 1992; Lemos-Espinal y Ballinger, 1995; Andrews et al., 1997a; Andrews et al., 1997b; Lemos-Espinal et al., 1997a; Lemos-Espinal et al., 1997c; Lemos-Espinal et al., 1997d, b, e; Andrews, 1998; Andrews et al., 1999; Lemos-Espinal et al., 2001, 2002; Lemos-Espinal et al., 2003b; Garcia-De La Peña et al., 2005; Smith y Lemos-Espinal, 2005; Woolrich-Piña et al., 2006; Gadsden y Estrada-Rodríguez, 2007; García-De la Peña et al., 2007; García, 2008; Güizado-Rodríguez et al., 2011; Sinervo et al., 2011; Ávila-Bocanegra et al., 2012; Gadsden et al., 2012; Valdez-Villavicencio y Peralta-García, 2012; Woolrich-Piña et al., 2012b; Woolrich-Piña et al., 2012c; Bustos-Zagal et al., 2013; Kearney, 2013; Lara-Resendiz y Díaz de la Vega-Pérez, 2013; Lara-Resendiz y García-Vázquez, 2013; Lara-Resendiz et al., 2014a; Lara-Resendiz et al., 2014b; Lara-Resendiz et al., 2014c; López-Alcaide et al., 2014; Gadsden et al., 2015a; Gadsden et al., 2015c; Lara-Resendiz et al., 2015a; Lara-Resendiz et al., 2015b; Martínez-Méndez et al., 2015
	Phyllodactylidae	*Phyllodactylus bordai* y *P. tuberculosus* (2)	Lara-Resendiz et al., 2013a; Lara-Resendiz et al., 2013b
	Scincidae	*Plestiodon copei* (1)	Lemos-Espinal et al., 1997c; Lara-Resendiz et al., 2014c
	Teiidae	*Aspidoscelis angusticeps, A. calidipes, A. ceralbensis, A. costata, A. cozumela, A. deppii, A. hyperythra, A. lineattissima, A. marmorata, A. maslini, A. parvisocia, A. rodecki, A. sackii* y *A. tigris* (14)	Soulé, 1963; Lemos-Espinal et al., 1997c; García-De la Peña et al., 2007; Navarro-García et al., 2008; Woolrich-Piña et al., 2011; Díaz de la Vega-Pérez et al., 2013; Lara-Resendiz et al., 2013d; Güizado-Rodríguez et al., 2014; Jacome-Flores et al., 2015
	Xantusiidae	*Xantusia extorris* y *X. sanchezi* (2)	Cruz-Sáenz y Lazcano, 2012; Gadsden et al., 2015b
	Xenosauridae	*Xenosaurus agrenon, X. grandis, X. newmanorum, X. platyceps, X. rectocollaris y X. tzacualtipantecus* (6)	Ballinger et al., 1995; Lemos-Espinal et al., 1998b, 2003a, 2004; Woolrich-Piña et al., 2012a; García-Rico et al., 2015
Serpientes	Colubridae	*Conopsis biserialis, C. lineata* y *Geophis semidoliatus* (3)	Brattstrom, 1965; Castañeda-Gonzalez et al., 2011
	Viperidae	*Crotalus estebanensis* (1)	Díaz de la Vega-Pérez et al., 2016
Cocodrilos	Crocodylidae	*Crocodylus acutus* y *C. moreletii* (2)	Charruau, 2012; López-Luna et al., 2015; Escobedo-Galván et al., 2016; González-Desales et al., 2016

Desde el enfoque ecológico se ha publicado alrededor del 71% de los trabajos. Dentro de esta temática sobresale la investigación sobre ecología general, pero donde se aborda la termorregulación (e.g., Beck y Lowe, 1991; Lemos-Espinal et al., 2003a; Lemos-Espinal et al., 2003b; Gadsden y Estrada-Rodríguez, 2007; Castañeda-Gonzalez et al., 2011; Woolrich-Piña et al., 2012a). También se incluyen los trabajos sobre ecología o biología térmica, donde se tratan cuestiones específicas sobre termorregulación (e.g., Lemos-Espinal et al., 1997a; Lemos-Espinal et al., 1997d, 1998b; Woolrich-Piña et al., 2012b; García-Rico et al., 2015). Asimismo, sobresalen los trabajos donde se reportan las temperaturas corporales en campo (e.g., Brattstrom, 1965; Lemos-Espinal et al., 1997b; Woolrich-Piña et al., 2011; Woolrich-Piña et al., 2012c), bajo condiciones controladas de laboratorio (e.g., Andrews et al., 1999; Lara-Resendiz et al., 2015a) o incluso estudiando su relación con las temperaturas ambientales, por ejemplo con el aire, sustrato (e.g., Lemos-Espinal y Ballinger, 1995; Woolrich-Piña et al., 2006; Woolrich-Piña et al., 2011; García-Rico et al., 2015) o con las temperaturas ambientales utilizando modelos operativos (e.g., Navarro-García et al., 2008; Díaz de la Vega-Pérez et al., 2013; Lara-Resendiz et al., 2014c). También se han integrado diversas variables térmicas bajo el enfoque de modelado de nicho ecológico para evaluar la distribución de diversas especies (Sinervo et al., 2010; Sinervo et al., 2011; Kearney, 2013; Lara-Resendiz, 2013). Finalmente, un bajo porcentaje de trabajos, dentro de esta categoría, se han enfocado exclusivamente en la ecología térmica de anidación, de los cuales la mayoría fueron en tortugas (Sandoval et al., 2011; Zavaleta-Lizarraga y Morales-Mavil, 2013; Lamont y Fujisaki, 2014), cocodrilos (Charruau, 2012; López-Luna et al., 2015; Escobedo-Galván et al., 2016) y mucho menos en lagartijas (Lara-Resendiz et al., 2013d).

Desde la perspectiva de cómo el cambio climático podría afectar a los reptiles se catalogó el 11% de los trabajos. Este tipo de estudios se han producido a partir del 2010 (Sinervo et al., 2010), principalmente con lagartijas, donde combinan variables de ecología térmica con diversos escenarios de cambio climático (Lara-Resendiz et al., 2015b; Medina et al., 2016; Piantoni et al., 2016). Los trabajos que se han desarrollado para determinar cuál será la respuesta de las especies a este fenómeno climático han sido en ambientes áridos (Gadsden et al., 2012; Lara-Resendiz et al., 2015b), tropicales (Martínez-Méndez et al., 2015; Valenzuela-Ceballos et al., 2015) y en altas elevaciones (Sinervo et al., 2011). Además del tipo de hábitat, también algunos trabajos (Sinervo et al., 2010; Sinervo et al., 2011) han considerado variables como el modo reproductor (ovíparo, vivíparo), hábitos (arborícola, saxícola, fosorial, diurno, nocturno) y las estrategias de termorregulación (heliotérmico, tigmotérmico, termoconformista, termorregulador activo, etc); ver una revisión para reptiles en este tema en Winter et al. (2016). En este tema, las lagartijas, principalmente las especies del género *Sceloporus*, han sido un buen modelo de estudio (ver tabla 2) ya que comparten atributos fisiológicos con otros organismos ectotérmicos, son un grupo marcadamente diverso en su geografía, fisiología, conducta y hábitats, además son relativamente abundantes, fáciles de encontrar en campo y de mantener en condiciones de laboratorio (Huey et al., 2010).

Desde la perspectiva fisiológica se clasificó el 10% del total de los trabajos revisados. Por ejemplo, en esta categoría hubo trabajos que han determinado el efecto de la temperatura de incubación en la determinación sexual y desarrollo embrionario (Vogt y Flores-Villela, 1986; Vogt y Flores-Villela, 1992), el estrés térmico durante la reproducción (Andrews et al., 1997a; Andrews et al., 1997b), la influencia en la tasa de crecimiento (McMichael et al., 2008) y en la estimación de la tasa metabólica (Benabib y Congdon, 1992; Sandoval et al., 2011).

Dentro del enfoque evolutivo se catalogó únicamente al 5% de los trabajos. Por ejemplo, se incluyen los trabajos que estudian la variación geográfica en la temperatura corporal de las lagartijas del género *Sceloporus*, donde los requerimientos térmicos pueden ser conservativos en gradientes altitudinales (Andrews et al., 1999) o latitudinales (Andrews, 1998). También se ha abordado el tema del conservadurismo de las preferencias térmicas entre las especies de complejos partenogenéticos del género *Aspidoscelis* (Díaz de la Vega-Pérez et al., 2013). Por otro lado, resaltan los trabajos donde han abordado la evolución de la viviparidad en frinosomátidos asociada al ambiente térmico (Méndez-de la Cruz et al., 1998; Hodges, 2004).

Por último, son pocos los trabajos que han abordado directamente un enfoque conductual, los cuales incluyen solo el 3% de los trabajos, donde se combina la conducta con los aspectos de la termorregulación. Por ejemplo, las variaciones en las respuestas conductuales, posturas y selección de microhábitats de *Iguana iguana* en un gradiente de temperatura en campo y laboratorio (McGinnis y Brown, 1966). Otro ejemplo es el trabajo donde se estudió la relación entre las estrategias de escape en lagartijas con las temperaturas corporales y micro-ambientales (Smith y Lemos-Espinal, 2005). Por último, también se ha explorado en lagartijas el tema de las estrategias conductuales de termorregulación durante la preñez para evitar el sobrecalentamiento (López-Alcaide et al., 2014). Los trabajos que combinan el enfoque ecológico y conductual, sólo se consideraron en la primer categoría.

TENDENCIAS Y DIRECCIONES FUTURAS

En los trabajos previos se ha respaldado la importancia de la temperatura en procesos ecofisiológicos y en la biología de reptiles. Por mencionar algunos ejemplos en un escenario a largo plazo, la temperatura juega un

papel importante en la tasa de crecimiento corporal, la recuperación de enfermedades o lesiones, la tasa y producción de huevos, el éxito en la tasa de eclosión y en la proporción de sexos; mientras que en el mediano plazo, es fundamental en la eficiencia y tasa digestiva, así como aprendizaje; mientras que al corto plazo, podría considerarse el éxito de depredación o evasión, aceleración, velocidad, agilidad, resistencia, capacidad aeróbica, recuperación del agotamiento, desplantes de conductas, sensibilidad auditiva, metabolismo, pérdida de agua por evaporación y balance hídrico (Huey, 1982 y sus referencias). Esta lista es aún mayor si se consideran particularidades dentro de los grupos. Es por esto que resulta fundamental realizar curvas de rendimiento/desempeño térmico en un amplio espectro de temperaturas, con el objetivo de conocer la temperatura óptima fisiológica (Angilletta, 2006). Los cuales han sido pobremente estudiados en especies mexicanas.

Asimismo resulta fundamental conocer los diferentes umbrales de temperatura (mínimos y máximos), por ejemplo: temperatura letal, crítica, voluntaria y preferida. Con el objetivo de conocer los niveles de sensibilidad y vulnerabilidad. En este caso, la tolerancia térmica podría estar relacionada con la distribución de las especies, es decir, especies con requerimientos térmicos con límites muy estrechos (estenotérmicas) podrían estar restringidas geográficamente, mientras que especies generalistas (euritérmicas), podrían estar presente en una gran gama de ambientes (Lara-Resendiz, 2013). Sin embargo, este campo ha sido poco explorado aunque existe una gran cantidad de trabajos donde describen estas variables incluso a nivel de familia (Sinervo et al., 2010; Clusella-Trullas et al., 2011; Clusella-Trullas y Chown, 2014; también ver sus materiales suplementarios). Existen grupos que aún no han sido estudiados como especies nocturnas (gecos, *Xantusia*, *Lepidophyma*), pero sobre todo en serpientes, en las cuales existen muy pocos estudios (e.g., Lemos-Espinal et al., 1997c; Castañeda-Gonzalez et al., 2011; Díaz de la Vega-Pérez et al., 2016). Es probable que estas contribuciones sigan siendo importantes para probar hipótesis evolutivas alrededor de los requerimientos térmicos de los reptiles (Andrews, 1998; Méndez-de la Cruz et al., 1998; Díaz de la Vega-Pérez et al., 2013), también para delimitar los requerimientos y tolerancias de las especies y predecir los riesgos de los organismos ectotérmicos en un ambiente cambiante.

Los estudios sobre el riesgo de extinción en poblaciones o especies deben ser considerados de alta prioridad a escala regional para reducir las amenazas de extinción en la diversidad biológica. Varios modelos han sido desarrollados para pronosticar los efectos biológicos del cambio climático, pero todos ellos tienen grandes limitaciones. Algunos están basados en efectos convergentes del clima, pero no han sido calibrados con extinciones locales observadas. Otros modelos correlativos o multivariados utilizan la asociación del clima contemporáneo para predecir la distribución actual y futura. Sin embargo, estos modelos ignoran los impactos de otros factores bióticos (i.e., adaptación local, enfermedades, competencia, fisiología, entre otros). Análisis previos muestran que los modelos de riesgo pueden ser confiables, sin embargo carecen de la integración de datos ecofisiológicos e interacciones entre especies, ya que ambas influyen en su riesgo de extinción. Estas limitaciones han generado mucho debate acerca de la magnitud de los impactos del cambio climático sobre las especies de reptiles (López-Alcaide y Macip-Ríos, 2011; Winter et al., 2016).

Basado en lo anterior, para proyectar y modelar la respuesta de los organismos a cambios climáticos extremos, se requiere una comprensión de los factores fisiológicos, conductuales, ecológicos y evolutivos que se relacionan con la distribución de las especies. Por ejemplo, la mayoría de los estudios han utilizado el enfoque correlativo (e.g., Garp, Maxent; Ballesteros-Barrera et al., 2007; Güizado-Rodríguez et al., 2012), que se basa en la asociación estadística entre los datos de presencia de las especies con las variables ambientales bajo múltiples escenarios climáticos; mientras que pocos trabajos se han enfocado en los modelos mecanicistas, que se construyen a partir de rasgos funcionales como datos biofísicos, fisiológicos (Lara-Resendiz et al., 2015b) o demográficos (Sinervo et al., en revisión). En este último enfoque, la relación entre las variables ambientales y las métricas como la ganancia de energía o la preferencia térmica podrían ser fácilmente proyectadas a través del paisaje en escenarios actuales, pasados o futuros (Sinervo et al., 2010; Kearney, 2013; Martínez-Méndez et al., 2015). Por lo tanto, los modelos mecanicistas podrían ser más apropiados que los de enfoque correlativo para aislar el efecto del ambiente abiótico sobre el rendimiento y la distribución potencial de los organismos (Buckley et al., 2010). Sin embargo, los modelos mecanicistas requieren una comprensión precisa de las relaciones ecofisiológicas y pueden requerir información difícil de obtener o que consume mucho tiempo, limitando por el momento el uso más amplio de estos modelos.

Sin duda, existen muchos trabajos que han documentado que el comportamiento termorregulador podría disminuir el efecto de las variaciones climáticas extremas sobre las poblaciones de reptiles (Kearney et al., 2009; López-Alcaide y Macip-Ríos, 2011; López-Alcaide et al., 2014; Valenzuela-Ceballos et al., 2015). Sin embargo, aún no se ha explorado con gran detalle cual será la respuesta de organismos con características de historia de vida contrastantes, por ejemplo: estrategias reproductivas (ovíparo-vivíparo), hábitos (diurno-nocturno-crepuscular), hábitats (e.g., árido, desértico, bosque, etc), modos de termorregulación (euritérmico, tigmotérmico, termorregulador activo/pasivo). Sinervo et al. (2010) siguieron este enfoque, sin embargo fue realizado bajo una escala global. Por lo tanto, estudios comparados entre grupos taxonómicos y

comunidades deben ser considerados bajo este enfoque de estudio y a escala regional. Además, según la revisión de Winter et al. (2016) hace falta realizar estudios sobre los efectos del cambio climático en grupos y especies particulares, ya que únicamente se han estudiado 22 de las 88 familias de reptiles, las cuales representan solo el 1.5% del total de especies descritas.

Finalmente, este tipo de trabajos son necesarios para conocer la vulnerabilidad, predecir extinciones, identificar potenciales contracciones y cambios futuros en la distribución de las especies, así como priorizar áreas naturales protegidas, corredores y microrefugios, donde prevalecerá el tipo de hábitat o las condiciones necesarias de hábitat, incluso para determinar los lugares donde las especies podrían ser traslocadas (Sinervo et al., en revisión) y contar con estrategias de manejo, planes de conservación y acciones de adaptación ante el cambio climático (López-Alcaide y Macip-Ríos, 2011).

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