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falvarez@ib.unam.mx

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Martínez-Salazar, Elizabeth A.; Flores-Rodríguez, Victoria; Rosas-Valdez, Rogelio; Falcón
-Ordaz, Jorge

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Taxonomy and systematics

Helminth parasites of some rodents (Cricetidae, Heteromyidae, and Sciuridae) from Zacatecas, Mexico

Helmintos parásitos de algunos roedores (Cricetidae, Heteromyidae, and Sciuridae) de Zacatecas, México

Elizabeth A. Martínez-Salazar^{a,*}, Victoria Flores-Rodríguez^a, Rogelio Rosas-Valdez^a, Jorge Falcón-Ordaz^b

^a Laboratorio de Colecciones Biológicas y Sistemática Molecular, Unidad Académica de Ciencias Biológicas, Universidad Autónoma de Zacatecas, Av. Preparatoria s/n, Campus Universitario II, Col. Agronómica, 98066 Zacatecas, Zacatecas, Mexico

^b Centro de Investigaciones Biológicas, Universidad Autónoma del Estado de Hidalgo, Apartado postal 1-10, 42001 Pachuca de Soto, Hidalgo, Mexico

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Abstract

Eighty-six specimens representing 7 species of rodents from 9 localities in the state Zacatecas were examined for helminths. Only 5 host species were found to harbor at least 1 species: *Chaetodipus* sp., *Dipodomys merriami atronasus*, *Neotoma mexicana*, *Otospermophilus variegatus*, and *Peromyscus* sp.; in contrast *Mus musculus* and *Reithrodontomys* sp., were not parasitized. Three species of cestodes (*Catenotaeniidae* gen. sp., *Hymenolepis* sp., and *Raillietina* sp.) and 7 nematodes (*Gongylonema* sp., *Heteromyoxyuris longejector*, *Lamotheoxyuris* cf. *ackerti*, *Mastophorus dipodomis*, *Rauschtineria* sp., *Pterygodermatites dipodomis*, and *Trichuris dipodomis*) were recorded. The intestine is the most parasitized (7 taxa) and trematodes were not found. The highest species richness was recorded in *D. merriami atronasus* from Rancho La Barranca (6 taxa), which also had the most sampling effort. *H. longejector* in *Chaetodipus* sp. from El Gordillo, showed the greatest mean abundance, and mean intensity values, followed by *Rauschtineria* sp. in *O. variegatus* from Morelos-Zacatecas Road. All species are new locality records, 14 new host records, and 2 taxa recorded for the first time in Mexico: *Rauschtineria* sp. and *M. dipodomis*. This is the first study of helminth parasites of rodents from Zacatecas.

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Keywords: Nematoda; Cestoda; Mammals; Mexican plateau; Helminthological inventory

Resumen

Fueron examinados 86 especímenes de helmintos representando 7 especies de roedores, de 9 localidades en el estado de Zacatecas. Solo 5 especies de hospederos se encontraron con al menos 1 especie: *Chaetodipus* sp., *Dipodomys merriami atronasus*, *Neotoma mexicana*, *Otospermophilus variegatus* y *Peromyscus* sp.; en contraste, *Mus musculus* and *Reithrodontomys* sp., no resultaron parasitados. Se registraron 3 especies de céstodos (*Catenotaeniidae* gen. sp., *Raillietina* sp., e *Hymenolepis* sp.) y 7 nemátodos (*Gongylonema* sp., *Heteromyoxyuris longejector*, *Lamotheoxyuris* cf. *ackerti*, *Mastophorus dipodomis*, *Rauschtineria* sp., *Pterygodermatites dipodomis* y *Trichuris dipodomis*). El intestino es el más parasitado (7 taxa) y no se encontraron tremátodos. La mayor riqueza de especies y el mayor esfuerzo de muestreo se registró en *D. merriami atronasus* del rancho La Barranca (6 taxa). *H. longejector* en *Chaetodipus* sp. de El Gordillo, mostró la mayor abundancia e intensidad promedio, seguido de *Rauschtineria*

* Corresponding author.

E-mail address: eamsmex@hotmail.com (E.A. Martínez-Salazar).

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sp. en *O. variegatus* de Morelos-Zacatecas. Todos son registros nuevos de localidad, 14 registros nuevos de hospedero y 2 taxones registrados por primera vez en México: *Rauschtneria* sp. y *M. dipodomis*. Este es el primer estudio de helmintos parásitos de roedores de Zacatecas.

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Palabras clave: Nematoda; Cestoda; Mamíferos; Altiplano mexicano; Inventario helmintológico

Introduction

The vegetation cover of Mexico has been transformed, losing up to 50% of its original coverage, 22% of these areas are now composed of secondary coverage and 27% have been transformed into agricultural and livestock areas. As a consequence of this dramatic shift, mammals in Mexico have become much more endangered (López-Ortega, Ballesteros-Barrera, Acosta, & Cervantes-Reza, 2012; Martínez-Meyer, Sosa-Escalante, & Álvarez, 2014), along with the helminth parasites these species harbor. Despite the efforts made to expand our knowledge on the biodiversity and natural history of mammals distributed in Mexico (Sánchez-Cordero et al., 2014), only 24% of the species richness has been examined for helminth parasites, and few studies have been conducted in north-central Mexico (e.g., Caspeta-Mandujano, Jiménez, Peralta-Rodríguez, & Guerrero, 2013; Falcón-Ordaz, Monks, & Pulido-Flores, 2013; García-Prieto, Falcón-Ordaz, & Guzmán-Cornejo, 2012; Guzmán-Cornejo, García-Prieto, Acosta-Gutiérrez, Falcón-Ordaz, & León-Paniagua, 2012; Jiménez-Ruiz, Rosas-Valdez, & Gardner, 2013; Jiménez-Ruiz, Peralta-Rodríguez, Caspeta-Mandujano, & Ramírez-Díaz, 2014; Pulido-Flores, Monks, & Falcón-Ordaz, 2013).

The advances in faunal surveys and inventories of helminth parasites in Mexico are still modest, they have focused only on some host species and are geographically limited (Pérez-Ponce de León, García-Prieto, & Mendoza-Garfias, 2011). As a result, there are undoubtedly many species waiting to be discovered, described and identified for this group of invertebrates. The inventory of the helminth parasite fauna of Rodentia (Bowdich, 1821), which is the most species-rich order in Mexico, comprises 3 phyla: Acanthocephala, Platyhelminthes, and Nematoda, which has the highest percentage of species diversity (e.g., García-Prieto et al., 2012). The geographical distribution of these parasites include localities in 18 states, with most of them located in Hidalgo, San Luis Potosí, Ciudad de México, and Nuevo León (Falcón-Ordaz et al., 2013; García-Prieto et al., 2012; García-Prieto, Mendoza-Garfias, & Pérez-Ponce de León, 2014; García-Prieto, Osorio-Sarabia, & Lamothe-Argumedo, 2014; Pulido-Flores, Moreno-Flores, & Monks, 2005; Pulido-Flores et al., 2013).

Zacatecas is located in north-central Mexico (=Central Mexican Plateau). Its territorial surface encompasses 3.8% of the total area of the country (=75,275 km²), with climate conditions including dry and semi-dry (79% the coverage territory of the state) and temperate sub-humid areas (Inegi, 2013, 2014). One hundred and fifteen species of mammals have been reported in Zacatecas, of these 66% are rodents (López-Ortega

et al., 2012; Sánchez-Cordero et al., 2014). To the best of our knowledge, there are only 2 published works related to the helminth fauna of 1 species of mammal, the bat *Tadarida brasiliensis mexicana* Saussure, 1860 (Chiroptera) from Zacatecas (Falcón-Ordaz, Guzmán-Cornejo, García-Prieto, & Gardner, 2006; Guzmán-Cornejo, García-Prieto, Pérez-Ponce de León, & Morales-Malacara, 2003), but there is no further information on the helminth parasites of rodent wildlife from this state. Loss and changes of vegetation coverage in the state have affected at least half of the territory, which considerably reduces the area available for the establishment of populations of wild mammals (López-Ortega et al., 2012), and their helminth parasites. For this reason, it is important to carry out biodiversity studies in the state for this biological system. Here, a survey of the helminth parasite fauna of rodents from Zacatecas, Mexico is presented for the first time.

Materials and methods

Eighty-six specimens of rodents were collected using live-traps baited with oats from 9 localities within Zacatecas between May 2012 to July 2015 (Table 1; Fig. 1). Four transects were sampled simultaneously for 2 nights at each locality in Spring, Summer and Autumn (15 traps × 4 transects × 2 nights = 120 trap-nights in each locality) (collection data in Table 1). Most specimens were transported live to the laboratory, and euthanized following the standard procedures and techniques of Gannon and Sikes (2007), and were examined for helminths by standard methods under a stereoscope. Parasites were placed in 0.85% w/v saline solution, then fixed by sudden immersion in hot (steaming) 70% ethanol, and stored in 70% ethanol to preserve morphological traits for further identification. Nematodes were cleared for morphological study with Ammann's Lactophenol and with a mixture of ethanol–glycerin (2:8). Cestodes were stained with Delafield's Hematoxylin and Mayer's hydrochloric carmine, and whole-mounted in Canada balsam. Taxonomic identification was conducted by comparing morphological traits using taxonomic keys and descriptions from the specialized literature (e.g., Anderson, 2000; Falcón-Ordaz, Fernández, & García-Prieto, 2010; García-Prieto, Falcón-Ordaz, Lira-Guerrero, & Mendoza-Garfias, 2008; Khalil, Jones, & Bray, 1994; Kruidenier & Peebles, 1958; Lichtenfels, 1970; Quentin, 1970, 1973; Read & Millemann, 1953; Read, 1956; Schmidt, 1986; Smith, 1954; Tiner, 1948; Yamaguti, 1961). Parasites identified were counted to obtain the infection parameters according with the definitions suggested by Bush, Lafferty, Lotz, and Shostak (1997).

Table 1

Localities in Zacatecas state where rodents from the present study (Cricetidae, Heteromyidae, and Sciuridae) were collected for the helminth parasite survey. The numbers for each locality are used in Fig. 1 and Table 2.

Code (Table 2 and Fig. 1)	Locality	Geographic coordinates (altitude)	Sample size (number of host infected)/host species	Collection data (month/year)
1	San Pedro Dam, Ciudad Cuauhtémoc	22°26'18.41" N; 102°23'14.38" W (2,030 m asl)	<i>n</i> = 6(2)/ <i>Peromyscus</i> sp. Gloger, 1841	05/2012; 10/2012
2	Rancho La Barranca, Pánuco	23°01'17.3" N; 102°32'25.11" W (2,308 m asl)	<i>n</i> = 12(6)/ <i>Chaetodipus</i> sp. Merriam, 1889 <i>n</i> = 14(9)/ <i>D. merriami atronasus</i> Merriam, 1894 <i>n</i> = 2(2)/ <i>Neotoma mexicana</i> Baird, 1855 <i>n</i> = 1(0)/ <i>Otospermophilus variegatus</i> Erxleben, 1777 <i>n</i> = 1(0)/ <i>Peromyscus</i> sp. <i>n</i> = 1(0)/ <i>Reithrodontomys</i> sp. Giglioli, 1873	05/2012; 06/2012; 08/2012; 09/2012; 10/2012 05/2012; 06/2012; 08/2012; 10/2012 04/2012 05/2014
3	Rancho El Godillo, Loreto	22°14'2.41" N; 101°48'58.72" W (2,206 m asl)	<i>n</i> = 1(1)/ <i>Chaetodipus</i> sp. <i>n</i> = 3(3)/ <i>D. merriami atronasus</i> <i>n</i> = 7(0)/ <i>Peromyscus</i> sp.	08/2012 05/2012 04/2015 06/2015 03/2013; 04/2013
4	Tlalticoaloya, Susticacán	22°36'21.67" N; 103°9'55.17" W (2,116 m asl)	<i>n</i> = 1(1)/ <i>Chaetodipus</i> sp. <i>n</i> = 5(0)/ <i>Peromyscus</i> sp.	05/2013 05/2015
5	Morelos-Zacatecas Road, Zacatecas	22°48'6.05" N; 102°37'38.31" W (2,321 m asl)	<i>n</i> = 1(1)/ <i>O. variegatus</i>	03/2014
6	Zacatecas City, Zacatecas	22°46'13.0" N; 102°33'21.1" W (2,404 m asl)	<i>n</i> = 1(1)/ <i>O. variegatus</i>	05/2015
7	Ojocaliente, Ojocaliente	22°35'41.57" N; 102°14'21.61" W (2,077 m asl)	<i>n</i> = 1(0)/ <i>Chaetodipus</i> sp. <i>n</i> = 2(0)/ <i>Mus musculus</i> Linnaeus, 1758 <i>n</i> = 2(2)/ <i>Peromyscus</i> sp.	06/2015 06/2015 06/2015
8	Villa de Cos, Villa de Cos	23°14'47.0" N; 102°22'1.8" W (2,006 m asl)	<i>n</i> = 4(2)/ <i>Chaetodipus</i> sp. <i>n</i> = 3(3)/ <i>D. merriami atronasus</i> <i>n</i> = 5(0)/ <i>Peromyscus</i> sp.	05/2015; 06/2015 05/2015 05/2015
9	Montemariana, Fresnillo	23°20'52.4" N; 103°06'07.4" W (2,160 m asl)	<i>n</i> = 6(2)/ <i>Chaetodipus</i> sp. <i>n</i> = 4(1)/ <i>D. merriami atronasus</i> <i>n</i> = 3(1)/ <i>Peromyscus</i> sp.	07/2015 06/2015 07/2015

Voucher specimens of host and parasites were deposited in the Colecciones Biológicas, Unidad Académica de Ciencias Biológicas (UACB), Universidad Autónoma de Zacatecas (UAZ), Zacatecas, Zacatecas, Mexico: Colección de Vertebrados (CVZ) (mammals section) (CVZM 0016–0021, 0036–0042, 0054–0057, 0067–0090, 0153–0173); and Colección de Invertebrados no Artrópodos (CINZ) (CINZ 130–147, 175, 186–202), respectively. Additional vouchers were deposited in the Colección Nacional de Helminthos (CNHE), Instituto de Biología, Universidad Nacional Autónoma de México, Mexico City, Mexico (CNHE 9826–9827, 8195, 9996–10004).

Results

Eighty-six rodents were collected and examined for parasites from 7 host species and 9 localities in Zacatecas (44% of all hosts examined were parasitized). Only *Chaetodipus* sp., *Dipodomys merriami atronasus*, *Neotoma mexicana*, *Otospermophilus variegatus*, and *Peromyscus* sp. were infected with at least 1 species of helminth. No parasites were found in *Reithrodontomys* sp., *Peromyscus* sp. and *O. variegatus* from La Barranca; *Peromyscus* sp. from near Tlalticoaloya, El Godillo, and Villa de Cos; and none from *Chaetodipus* sp. and *Mus musculus* from Ojocaliente.

The helminth inventory of sampled hosts included 9 families and 10 species, as follows: (1) Platyhelminthes; 3 cestodes [*Catenotaeniidae* gen. sp. Spassky, 1950 (*Catenotaeniidae*), *Hymenolepis* sp. Weinland, 1858 (*Hymenolepididae*) and *Raillietina* sp. Fuhrmann, 1920 (*Davaineidae*)], and (2) Nematoda; 6 species [*Heteromyoxyuris longejector* Hanum, 1934 and *Rauschtineria* Hugot, 1980 (*Oxyuridae*), *Lamotheoxyuris* cf. *ackerti* Falcón-Ordaz et al., 2010 (*Heteroxynematidae*), *Pterygodermatites dipodomis* Tiner, 1948 (*Rictulariidae*), *Gongylonema* sp. Molin, 1857 (*Gongylomatidae*), *Mastophorus dipodomis* Read and Millemann, 1953 (*Spiroceridae*), and *Trichuris dipodomis* Read, 1956 (*Trichuridae*)]. No Trematoda were collected in the study.

Prevalence, mean abundance, mean intensity, intensity range, site of infection, hosts and localities are given in Table 2. Nematoda is the group with the highest species richness. Eight of the 10 helminth species inhabit the intestine (*Catenotaeniidae* gen. sp., *Raillietina* sp., *Hymenolepis* sp., *H. longejector*, *L. cf. ackerti*, *Rauschtineria* sp., *P. dipodomis*, and *T. dipodomis*), with an intensity ranging from 1 to 22 helminths per infected rodent. *D. merriami atronasus* presented the highest parasite species richness with 6 helminth species, including 1 cestode (*Hymenolepis* sp.) and 5 nematodes (*Gongylonema* sp.,

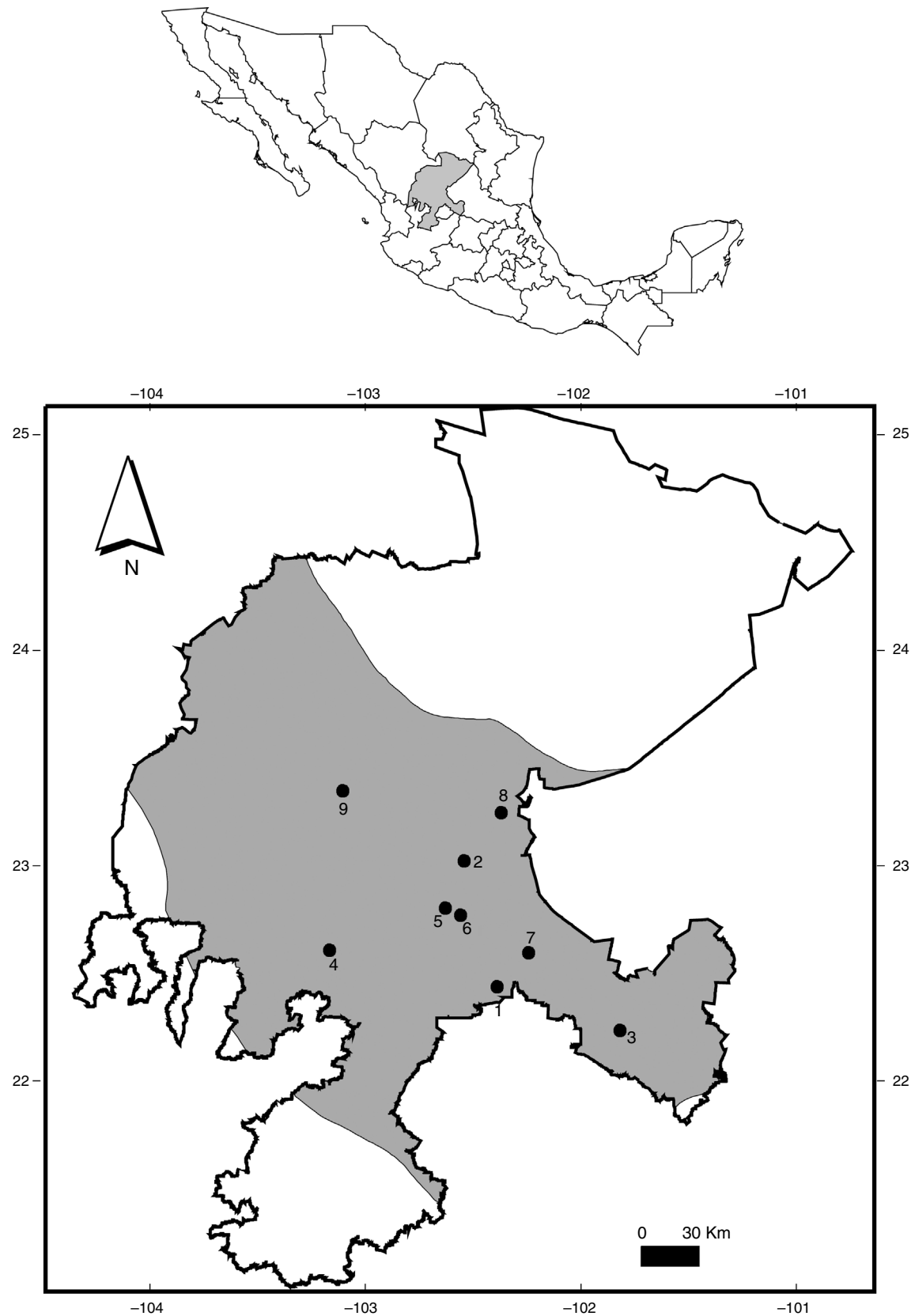


Figure 1. Map of Zacatecas indicating the localities where specimens of some rodents (*Cricetidae*, *Heteromyidae*, and *Sciuridae*) have been examined for helminth parasites (codes in [Table 1](#); gray = Central Mexican Plateau).

Table 2

Characterization of the infection parameters of helminths within rodents from 9 localities from Zacatecas, Mexico. Infection sites: I = intestine, S = stomach. Life cycle: CD = direct; CI = indirect. Host: Cricetidae: Nm. *Neotoma mexicana*; P. *Peromyscus* sp.; Heteromyidae: C. *Chaetodipus* sp.; Dm. *Dipodomys merriami atronasus*; Scuridae: O. *Otospermophilus variegatus*. Host diet[¶]: G = primarily granivore; H = herbivore. HIP = host infected for parasite; N = total collected parasites; Pre (%) = prevalence; MA = mean abundance; MI = mean intensity; IR = intensity range.

Helminth species	Localities (code Table 1)	Host/diet [¶]	HIP	N	Pre (%) (HI)	MA	MI	IR	Accession Number [°]
Platyhelminthes: Cestoda									
Catenotaeniidae gen. sp. ^{I, CI}	1	P ^G	1	1	16.66 (1)	0.166	1	1	CINZ 137–138
<i>Hymenolepis</i> sp. ^{I, CI}	2	Dm ^{G†}	1	1	7.14 (1)	0.071	1	1	CINZ 130–131
<i>Railletina</i> sp. ^{I, CI}	9	C ^{G†}	2	16	33.33 (2)	2.66	8	1–14	CINZ 196 CNHE 8195
Nematoda									
<i>Gongylonema</i> sp. ^{S, CI}	2	Dm ^{G†}	1	1	7.14 (1)	0.071	1	1	CINZ 132
<i>Heteromyoxys longejector</i> ^{I, CD}	2	Dm ^{G†}	2	19	14.28 (2)	1.35	9.50	9–10	CINZ 145 CNHE 9996
	2	C ^G	4	49	33.33 (4)	4.083	12.25	3–22	CINZ 139,146–147 CNHE 9997
	3	C ^G	1	21	100 (1)	21	21	21	CINZ 188 CNHE 9998
	7	P ^{G†}	2	10	100 (2)	5	5	1–9	CINZ 189
	8	Dm ^{G†}	2	7	67 (2)	2.333	3.5	1–4	CINZ 190
	8	C ^G	2	22	50 (2)	5.5	11	1–14	CINZ 192 CNHE 9999
<i>Rauschtineria</i> sp. ^{I, CD†}	5	O ^{H†}	1	14	100 (1)	14	14	14	CINZ 186 CNHE 9827
	6	O ^{H†}	1	8	100 (1)	8	8	8	CINZ 187 CNHE 9826
<i>Pterygodermatites dipodomis</i> ^{I, CI}	1	P ^{G†}	1	1	16.66 (1)	0.166	1	1	Ø
	2	Dm ^G	1	7	7.14 (1)	0.5	7	7	CINZ 144 CNHE 10000
	3	Dm ^G	2	7	67 (2)	2.33	3.5	3–4	CINZ 199
	8	Dm ^G	1	5	33.33 (1)	1.667	5	5	CINZ 194
	8	C ^{G†}	1	5	25 (1)	1.25	5	5	CINZ 191 CNHE 10001
<i>Lamotheoxyuris</i> cf. <i>ackerti</i> ^{I, CD}	2	Nm ^{H†}	2	5	100 (2)	2.5	2.5	1–4	CINZ 136
<i>Mastophorus dipodomis</i> ^{S, CI†}	2	Dm ^{G†}	7	15	50.00 (7)	2.143	1.07	1–6	CINZ 133, 140–142 CNHE 10002
	3	Dm ^{G†}	1	2	33.33 (1)	0.67	2	2	CINZ 198
	2	C ^{G†}	2	3	16.66 (2)	0.25	1.5	1–2	CINZ 143
	8	C ^{G†}	1	4	25 (1)	1	4	4	CINZ 193
<i>Trichuris dipodomis</i> ^{I, CD}	2	Dm ^{G†}	5	9	35.71 (5)	0.642	1.08	1–5	CINZ 134,135 CNHE 10003
	3	Dm ^{G†}	1	6	33.33 (1)	2	6	6	CINZ 200
	4	C ^{G†}	1	7	100 (1)	7	7	7	CINZ 175 CNHE 10004
	8	C ^{G†}	1	4	25 (1)	1	4	6	CINZ 201
	9	Dm ^{G†}	1	3	24 (1)	0.75	3	3	CINZ 197
	9	P ^{G†}	1	1	33.33 (1)	0.33	1	1	CINZ 202

[°] Accession number to the CINZ and CNHE are provided.

Ø The material not deposited; it was lost during the dismount of the semi-permanent preparation.

[¶] According to González-Salazar et al. (2014).

[†] New record for Mexico.

[‡] New host records.

H. longejector, *P. dipodomis*, *M. dipodomis*, and *T. dipodomis*) (Table 2). All of the parasite taxa were recovered in the adult stage, with the exception of *L. cf. ackerti*, which was recovered as a single adult female and 2 larvae (found with the primordium of the vulva). The majority of helminth life cycles sampled here are unknown, however, they could be inferred based on information from the literature based upon closely related species (Anderson, 2000; Falcón-Ordaz et al., 2010; García-Prieto et al., 2008; Joyeux & Baer, 1945; Khalil et al., 1994; Kruidenier &

Peebles, 1958; Lichtenfels, 1970; Quentin, 1970, 1973; Read & Millemann, 1953; Read, 1956; Schmidt, 1986; Smith, 1954; Tiner, 1948; Yamaguti, 1961) (Table 2).

H. longejector from El Gordillo and Ojocaliente, *T. dipodomis* from Tlalticoaloya, *Rauschtineria* sp. from Morelos-Zacatecas Road and Zacatecas City, and *L. cf. ackerti* from Rancho La Barranca, had the highest prevalence (100%), followed by *Hymenolepis* sp. (80%) in *D. merriami atronasus* from Ojocaliente. *H. longejector* had the highest

mean abundance (21), whereas *Chaetodipus* sp. from El Gordillo had the highest mean intensity (21). The nematode *M. dipodomis* infected 2 species of rodents (*D. merriami atronasus* and *Chaetodipus* sp.) from the same locality (Rancho La Barranca), whereas the nematode *T. dipodomis* was present in 2 host species (*D. merriami atronasus* and *Chaetodipus* sp.) at different localities, Rancho La Barranca and Tlalticoaloya, respectively (Table 2). *H. longejector* was present in 3 localities, and infected 2 species of rodents (*D. merriami atronasus*, and *Chaetodipus* sp.), and *P. dipodomis* was present in 3 localities also infecting 3 different host (*D. merriami atronasus*, *Chaetodipus* and *Peromyscus* sp.) (Table 2). Finally, Catenotaeniidae gen. sp. and *P. dipodomis* from San Pedro Dam, were found at the same prevalence, mean abundance, mean intensity, and intensity range, these parameters are equivalent to *Hymenolepis* sp., and *Gongylonema* sp. from Rancho La Barranca (Table 2).

Discussion

The class Mammalia is a widespread and charismatic group of animals in Mexico (Sánchez-Cordero et al., 2014). There are very few studies on the diversity of helminths of wild mammals in Mexico, which contrasts with the number of mammalian species present in this country. Moreover, 67% of terrestrial mammals from Zacatecas are rodents (López-Ortega et al., 2012; Sánchez-Cordero et al., 2014), and have not been examined for helminths (see Falcón-Ordaz et al., 2013; García-Prieto et al., 2012; Pulido-Flores et al., 2013).

In this paper, we present new locality records for 10 taxa of helminths that are recorded in Zacatecas for the first time, and 2 species are reported for the first time in Mexico (*Rauschtineria* sp. and *M. dipodomis*). Nine species of helminths were found that result in 21 new host records, 5 taxa were identified to species, 4 to genus, 1 only to family, and 5 taxa have indirect life cycles (Table 2). Of these helminths, 30% were cestodes (3 taxa) and the rest were nematodes (7). Nematodes showed the highest species richness, a pattern previously observed for mammal hosts in North America (e.g., Decker, Duszynski, & Patrick, 2001; García-Prieto, Mendoza-Garfias et al., 2014; García-Prieto, Osorio-Sarabia et al., 2014; King & Babero, 1974; Munger & Slichter, 1995; Read & Millemann, 1953) (Table 2).

Studies on the life cycles of the helminths of mammals are relatively few (Georgiev, Bray, & Littlewood, 2006; Morand, Bouamer, & Hugot, 2006). We present information of congener species or species of the same family or order and extrapolate them to the present infections only when they are constant at the relevant taxonomic level. This includes an arthropod as the intermediate host for tapeworms and the direct pattern of transmission for most pinworms (i.e., Anderson, 2000; Joyeux & Baer, 1945; Lichtenfels, 1970; Schmidt, 1986; Yamaguti, 1961). This allow us to understand the relationships among a variety of host-related and environmental-related factors in semi-arid and arid environmental (Bienek & Klikoff, 1974; Reichman, 1975).

The cestodes observed here include 3 taxa, Catenotaeniidae gen. sp., *Hymenolepis* sp. and *Railletina* sp. Regarding their life

cycles, it is known that members of Catenotaeniidae (whose host range is restricted to rodents) (Table 2), use mites (Siphonaptera) as intermediate hosts (Joyeux & Baer, 1945), while hymenolepidids use beetles (Coleoptera) (Cunningham & Olson, 2010). Therefore, it is assumed that arthropods are included in the diet of the rodents studied. However, the cestodes have a relative low prevalence (Table 2), suggesting that arthropods represent a low proportion of the diet reported in the literature (Decker et al., 2001).

For identification to species level, more specimens of cestodes will be required, allowing us to confirm if these specimens correspond to other species recorded in the country. For example, Catenotaeniids are represented in Mexico by 1 species from a Central Mexican locality (Carmona-Huerta, 1994). Hymenolepids include 3 species, *Hymenolepis diminuta* Rudolphi, 1819, *Hymenolepis horrida* Linstow, 1910 and *Hymenolepis* sp. from 3 different hosts in the Transmexican Volcanic Belt (Carmona-Huerta, 1994; García-Prieto et al., 2012) and hosts of *Railletina* sp. from Mexico include 7 rodent species from the Mexican Plateau and Mexican Transvolcanic Belt (García-Prieto et al., 2012; Underwood, Owen, & Engstrom, 1986). The distribution previously reported for cestodes and the typical occurrence of these in rodents, is supported by the data found in the current study. It should be noted that hymenolepid cestodes are typically parasites of heteromyids from North America (Gardner, 1985; Gardner & Schmidt, 1987).

The nematode species and localities reported herein represent 12 new hosts and 25 new locality records (Table 2). Specifically, within these host mammals *Gongylonema* sp. and *Rauschtineria* sp., are recorded for the first time in *D. merriami atronasus* and *O. variegatus*, respectively for Mexico. It is noteworthy that *N. mexicana* represents a new host record for *L. cf. ackerti*, a species recorded exclusively from the genus *Neotoma*, *Neotoma nelsoni* Goldman, 1905 in North America (Falcón-Ordaz et al., 2010). *M. dipodomis* is recorded for the first time in Mexico. Identification to species level was possible with the exception of *Gongylonema* sp., whose individual were all females, as male specimens are required for proper identification.

Two life cycle groups of nematodes are recognized. *Gongylonema* sp., *M. dipodomis* and *P. dipodomis* have indirect life cycle (heteroxenic parasites species), where the individuals of the 3 genera require an arthropod as an intermediate host (Coleoptera, Lepidoptera, Orthoptera or Siphonaptera) to complete their life cycles (Dyer & Olsen, 1967; King & Babero, 1974; Ransom & Hall, 1915). The other 4 taxa have direct life cycles (monoxenic parasite species) with no intermediate hosts (Anderson, 2000).

The nematode *Rauschtineria* sp. is known to parasitize terrestrial Sciuridae by habiting the intestinal caecum (Hugot, 1980; Hugot, Feliu, Douangboupha, & Ribas, 2013), and may develop through a direct life cycle as other oxyurids (Anderson, 2000; Gibbons, 2010; Hugot et al., 2013), and this species has not been previously reported in Mexico. There are other known Oxyuridae parasites of squirrels in México, namely *Syphatineria* sp., a parasite of aerial Sicuridae, *Sciurus aureogaster* Cuvier, 1829 from México City, and *Citellina abdita* (Caballero-Caballero, 1937), parasitizing the terrestrial Sciuridae,

O. variegatus (=reported originally as *Spermophilus variegatus*) from Guanajuato and Hidalgo (García-Prieto et al., 2012). This is the first record of the species and a new host record for the genus in Mexico.

No trematodes were found in this study; however, 6 species of trematode parasites in rodents from Mexico have previously been reported (García-Prieto et al., 2012). One species, *Caballerolecythus ibunami* Lamothe-Argumedo, Falcón-Ordaz, García-Prieto, and Fernández-Fernández (2005), has been previously reported in other heteromyid host (*Liomys irroratus*) from the Transmexican Volcanic Belt (Falcón-Ordaz, Acosta-Gutiérrez, Fernández, & Lira-Guerrero, 2012; Lamothe-Argumedo et al., 2005). For localities where trematode species were reported from semiarid zones with similar conditions as the localities from Zacatecas, however, the prevalence of trematodes was low. A possible explanation for this phenomenon is that arid ecosystems generate a lower exposure rate of arthropods (second intermediate host) and to snails (first intermediate host). Conversely, species of *Brachylaima* spp. are parasites of heteromyids (i.e. *Liomys pictus*) and Crisetids (i.e. *Peromyscus guatemalensis* and *P. difficilis*), from tropical zones in Mexico (Caballero-Deloya, 1970; Ubelaker & Dailey, 1966), where habitats are optimal for the survival of snails and exposure to secondary intermediate hosts should be more frequent (Yamaguti, 1971, 1975).

Rodent diet studies associated with semi-arid and arid regions which has been scarcely documented (e.g., Bienek & Klikoff, 1974; Reichman, 1975). Decker et al. (2001) suggested that rodents in dry environments consume variable quantities of arthropods (15.5% of diet) depending upon availability in the ecosystem, while green vegetation made up only 6.1% of the diet (see Reichman, 1975). In contrast, in higher moisture environments, a granivorous diet is preferred. About half of the diversity we sampled is represented by helminths with indirect life cycles (Table 2), which parasitize host species that are primarily considered as “granivores” (González-Salazar, Martínez-Meyer, & López-Santiago, 2014), which suggests that the diet of these hosts is variable (excluding *N. mexicana*). Even though indirect life cycles are predominant in the species reported here, the nematode *H. longejector* (direct life cycle) is the most abundant species and is present in all of the seasons analyzed (Flores-Rodríguez & Martínez-Salazar, Pers. Obs.).

Parasites can be indicative of food-web structure and environmental conditions (Decker et al., 2001; Marcogliese & Cone, 1997), and based upon the presence of helminth parasites with both types of life cycles, we suggest that the localities analyzed still represent an optimal ecological environment for them. Unfortunately, not much is known about the life cycles of these particular species since most of the information is known at the supra-specific level; such is the case of the cestodes, *Catenotaeniidae* gen sp., *Hymenolepis* sp., and the nematodes *P. dipodomis*, *Gongylonema* sp. and *M. dipodomis*. All of these species are thought to require arthropods as an intermediate host to complete their life cycles (Cunningham & Olson, 2010; King & Babero, 1974; Luong & Hudson, 2012; Lyons, 1978). Systematic studies of the hosts that characterize the diet would help to elucidate the life cycles of their parasites, and may help to

answer the question as to why helminths with indirect life cycles are prevalent in these rodents from arid and semi-arid environments (Bienek & Klikoff, 1974; Decker et al., 2001; Garner, Richardson, & Felts, 1976; Reichman, 1975).

As for the geographical distribution of our results, no apparent pattern is observed in terms of the closeness of the locations and parasites. For example, sites 2, 3 and 8, have 4 species of nematodes in common (*T. dipodomis*, *H. longejector*, *P. dipodomis* and *M. dipodomis*), however even though localities 2 and 8 are geographically close, locality 3 is located away far away from them. Furthermore, the presence of parasite species appears to be more related to the rodent family they occur within; we observed that there is host specificity by parasites for the families Heteromyidae and Cricetidae. This assertion is supported by the fact although species of both families were found in locations 2, 3, 7, 8 and 9, no parasite species are shared by members of both families. Furthermore, only one locality has a shared parasite (*T. dipodomis*) between *Peromyscus* sp. (Cricetidae) and *D. merriami atronasus* (Heteromyidae). Species richness could be underestimated based on the sampling effort in our study (Tables 1 and 2); therefore, a greater sampling effort is required at specific localities (e.g. Morelos-Zacatecas Road, San Pedro Dam, Ciudad Cuauhtémoc or Zacatecas city). Although the number of hosts collected was asymmetric, we found fauna typical of *D. merriami* from North America (i.e., *H. longejector*, *P. dipodomis*, *Gongylonema* sp. and *M. dipodomis*) (Decker et al., 2001; King & Babero, 1974; Voge, 1956). The helminth fauna found in *D. merriami* of Zacatecas is similar to other localities of the Mexican Plateau (Durango, San Luis Potosí and Guanajuato, Falcón-Ordaz, Pers. Obs.). The presence of these species of nematodes in *D. merriami atronasus* provides evidence that the environments where the host is similar throughout their distribution. Records for helminth parasites and their geographical distribution was not enough to demonstrate a geographical pattern in Mexico, but nevertheless, Nearctic affinities within helminth fauna reported here in the Central Mexican Plateau is evident.

The geographic distribution and helminth species richness was heterogeneous in this study. Most of the sampling effort during these years was focused on Rancho La Barranca primarily due to the accessibility of the site (Fig. 1, Table 2). This site is next to anthropogenic activities which includes livestock and pastureland, but the landscape is relatively conserved, as well as the other collecting sites. All sites sampled presented almost 1 species of parasite for each (Tables 1 and 2), which may reflect a relatively healthy ecosystem.

It is necessary to increase our knowledge of the dietary preferences of rodents associated with arid and semi-arid desert environments, as well as information on the life cycles of parasitic helminths as an indicator of the food-web structure and trophic interactions. Likewise, monitoring the populations of these host-parasite systems associated with global climate change data and the correlation with anthropogenic landscape changes, could contribute to conservation in arid and semi-arid environments within Mexico in order to provide information for conservation. This is the first study in this region for these host-parasite systems and the beginning of a systematic

inventory of parasites of wild mammals. This allows us to address future questions related to the evolution and biogeography of the parasite-host systems in Zacatecas.

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