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Diversity of fleas (Siphonaptera) on small mammals within a subalpine ecosystem in the Nevado de Toluca Protected Area, State of Mexico

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Abstract

In Mexico, few studies on the species of fleas associated with rodents in high mountain areas have been conducted, even though these mammals are mainly associated with these ectoparasites to a large extent, and it is a group of species that have a wide distribution and great diversity. The present study determined the diversity of ectoparasites (fleas) in rodents from a subalpine grassland within the Nevado de Toluca Flora and Fauna Protection Area, State of Mexico. Rodent sampling was carried out during the dry season (March and April) and rainy season (August and November) of 2017, at an elevation of 4,050 m above sea level. A total of 147 Sherman traps were set during three consecutive nights across both seasons. Fleas were collected from rodent hair and placed in 70% ethanol in separate vials for each specimen. A total of 217 rodents of three different species were captured: *Reithrodontomys megalotis, Peromyscus melanotis,* and *Microtus mexicanus*. From the last two species a total of 117 Siphonaptera from three families, five genera *(Hystrichopsylla, Ctenophthalmus, Plusaetis, Strepsylla, Rhadinopsylla*), and seven species were obtained. *Plusaetis sibynus* was the most abundant species and the one that showed the highest prevalence in *P. melanotis*, the most abundant rodent. Of the flea species found, *Ctenophthalmus tecpin* and *Strepylla villai* were new records for the State of Mexico, and three species of the genus *Plusaetis* had not previously been reported for the Nevado de Toluca area.

Key words: Siphonaptera, subalpine grassland, Trans-Mexican Volcanic Belt, Mexico, distribution

Introduction

Fleas (Siphonaptera) represent a relatively small order of obligate blood-sucking parasitic insects, mainly of mammals and birds (Eisen & Gage 2012). More than 2,229 species in 21 families of fleas are known (Bossard *et al.* 2023; Hastriter & Bossard 2024), some of which are widely distributed and present practically throughout the world (Medvedev 2000). These blood-sucking insects in particular play an important role as vectors in the transmission of pathogens, either through their bite or by direct contact with their feces (Eisen & Gage 2012). They have been associated with the circulation and epidemiology of emerging and re-emerging diseases worldwide such as plagues, bartonellosis, rickettsiosis, and viral diseases of importance to human and animal health (Bitam *et al.* 2010).

Evolutionarily speaking, fleas probably appeared with mammals and currently, more than 70% of the known species are associated with rodents as their main host in the adult stages of these ectoparasites (Whiting *et al.* 2008). The Order Rodentia is the most diverse group of terrestrial mammals on the planet, with 2,552 species present in all ecosystems, except polar environments (Burgin *et al.* 2018), with cricetid rodents being the most frequent hosts of these ectoparasites (Acosta-Gutiérrez 2014; Light *et al.* 2020).

It is important to highlight that in Mexico, there are few studies focused on understanding the host-parasite interaction between rodents and the flea fauna associated with them (Acosta-Gutiérrez 2014). There are studies on

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the knowledge of Siphonaptera in high mountain areas, such as the work of Barrera (1968) for Popocatépetl, State of Mexico, where he recognized 38 species of fleas. Tipton & Méndez (1968) in Cerro Potosí, Nuevo León, mentioned the presence of 28 species. Ayala-Barajas *et al.* (1988) in Nevado de Toluca, State of Mexico, reported four species of fleas. Acosta & Fernández (2006) and Aguilar-Montiel *et al*. (2018) for La Malinche, Tlaxcala, reported 16 species. Acosta *et al.* (2020, 2024) found 12 species of fleas in Cerro del Mohinora, Chihuahua. In all these studies, the reported species are considered to have Nearctic biogeographic affinity (Acosta & Fernández 2007).

Along the Trans-Mexican Volcanic Belt in central Mexico, there is a group of elevations up to 4,000 m, all classified as mountain ecosystems. Within these elevations, the Nevado de Toluca Flora and Fauna Protection Area (APFF Nevado de Toluca) in the south-central part of the State of Mexico can be found. Its geological origin, rugged topography, variety of soils and climates make possible the coexistence of a great diversity of ecosystems, biodiversity, species interaction and endemism (Ferrusquía 1998). These conditions have favored the establishment of different types of vegetation such as pine forest (*Pinus hartwegii* Lindl*, P. montezumae* Lamb.), fir forest (*Abies religiosa Kunth* Schltdl. Et Cham.), oak forest (*Quercus*), pine-oak forest (*Pinus-Quercus*), pine-fir forest (*Pinus-Abies*), alpine grasslands (*Calamagrostis tolucensis* (Kunth) Trin. ex Steud., *Festuca tolucensis* Kunth), and high-altitude moorlands (lichens *Umbilicaria aff. hirsute* (Sw. ex Westr.) Hoffm*, Rhizocarpon geographicum* (L.) DC. and *Alectoria ochroleuca* (Hoffm.) A. Massal.). The fauna reported for the APFF Nevado de Toluca is made up of 43 species of mammals, 100 species of birds, 19 reptiles, 13 amphibians, and 35 species of invertebrates (CONANP 2016). Among mammals, eight rodent species have been recorded (Table 1), which corresponds to 18% of the total mammal fauna of the ANP (Natural Protect Area) (Chávez & Ceballos 1998; Ceballos *et al.* 2005; CONANP 2016).

TABLE 1. Systematic list of rodents with current distribution in Nevado de Toluca, State of Mexico, Mexico, including their altitudinal range. The taxonomic order follows the phylogenetic sequence proposed by Ramírez-Pulido *et al.* (2014).

Taxon	Elevation (m)
ORDER RODENTIA	
Family Cricetidae	
Subfamily Arvicolinae	
***Microtus mexicanus* (Saussure, 1861)**	2400 to 4250
Subfamily Neotominae	
***Neotomodon alstoni* (Merriam, 1898)**	2850 to 4250
***Peromyscus difficilis (*J.A. Allen, 1891)**	1200 to 3700
***Peromyscus maniculatus* (Wagner, 1845)**	2400 to 2800
***Peromyscus melanotis* (J.A. Allen & Chapman, 1897)**	2850 to 4250
***Reithrodontomys chrysopsis* Merriam, 1900**	2850 to 3950
***Reithrodontomys megalotis* (Baird, 1857)**	2400 to 3950
Subfamily Sigmodontinae	
***Sigmodon hispidus* Say & Ord, 1825**	0 to 2700

The APFF Nevado de Toluca is considered a transition zone between the Nearctic and Neotropical regions; therefore, it is relevant to know aspects of flea ecology such as its distribution and abundance patterns in rodents and the seasonal variation of these patterns. The life cycles of fleas as well as their ecological and epidemiological roles are closely linked to the environmental conditions of its host communities. Therefore, in the face of climate change it is relevant to know how these parasitic insects behave in extreme environments such as that present in the Nevado de Toluca area (Ferrusquía 1998; Morrone & Gutiérrez-Velázquez 2005; Acosta & Fernández 2007).

Considering the above, the aim of the present study was to identify the composition of Siphonaptera present on rodents (hosts) in an alpine grassland within one of Central Mexico's mountain system. Similarly, the study aims to recognize the important role that rodents play as hosts of these ectoparasites, beyond being reservoirs of a significant number of zoonotic diseases, more than any other order of mammals (Kian *et al.* 2009).

Materials and methods

Study Area. The Nevado de Toluca (19° 07' 07" N; -99° 46' 53" W) is a natural protected area of federal interest, under the category "Flora and Fauna Protection Area". It is located in the central part of the State of Mexico and is part of the Trans-Mexican Volcanic Belt (Fig. 1; CONANP 2016). It has a maximum elevation of 4,660 m and has a cold climate (E(T)H wig type) and a semi-cold humid (C(E) wig type), with rainfall during the summer (García 1973). The average monthly temperature fluctuates between 2° and 5° C, while extreme maximum temperatures rise to 21° C in the summer and extreme minimum temperatures drop to -10° C in winter (CONANP 2016). The Nevado de Toluca has one of the last forest massifs in the region. However, it has been exposed to strong impacts caused by human activities, such as changes in land use mostly for agriculture, livestock, and illegal logging activities.

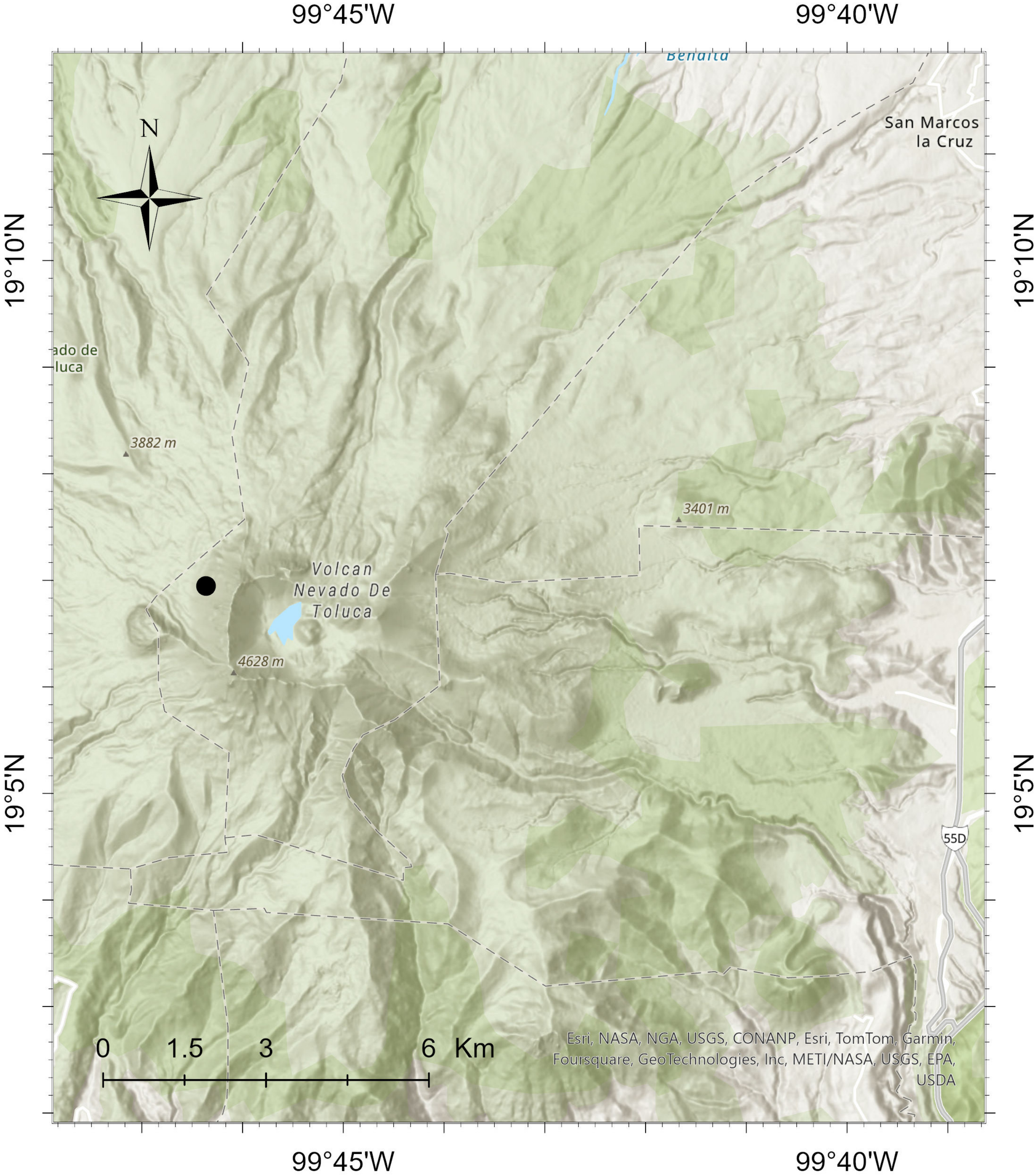

FIGURE 1. Location of sampling site (black circle) in the Nevado de Toluca, State of Mexico.

The sampling site was located on the outer northwest slope of the volcano cone (19° 07′ 08.80" N, -99° 46′ 36.80" W, Fig. 1) in the subalpine grassland ecosystem at an elevation of 4,050 m. Sampling was done in three different quadrants separated from each other by 200 linear meters, to maintain independence between them.

Rodent Trapping. All rodent capture, handling, and sampling were carried out following the Guidelines of the American Society of Mammalogists (Sikes & the Animal Care and Use Committee 2016). Sampling was conducted under permit SGPA/DGVS/01603/17, issued by the Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT) in Mexico. It was carried out in March, April, August, and November 2017, during the new moon phase, since previous studies have shown that rodents exhibit lunar phobia (Clarke 1983). In each quadrant, 49 Sherman traps (7.62 × 8.89 × 22.86 cm) were placed, following a 7×7 grid, with a separation of 10 meters between traps. The traps were baited with a mixture of oats, vanilla, and peanut butter, left open for three consecutive nights and checked the following morning.

Each trapped individual was taxonomically identified following an identification guide (Álvarez *et al.* 2015; Ceballos 2014). External body measurements (total length, tail, leg, ear), total weight, sex and reproductive condition of each rodent was recorded (Romero-Almaraz *et al.* 2000). Prior to release, each rodent was processed for flea collection and a metal earring was placed on the right ear and further released at the same point of capture.

Collection and Identification of Flea Species. For flea collection, each rodent was brushed for one minute in different areas of the body (axillary regions, groin, neck, and back of the ears). The blanket bags where the rodents were kept were also checked. The collected ectoparasites were preserved in Eppendorf® tubes containing 70% ethanol. Each tube was labelled with the rodent number and date of collection (Muñoz *et al.* 2016). The ectoparasites were taken to the Diagnostic and Parasitology Laboratory of the Faculty of Veterinary Medicine of UNAM for processing according to the method proposed by Guzmán-Cornejo *et al.* (2012). Identification were made using taxonomic keys (Traub 1950; Morrone *et al.* 2000; Acosta & Morrone 2003, 2013; Acosta 2011) and a Zeiss optical microscope at the Conservation Biology Laboratory of the Universidad Autonoma Metropolitana, Unidad Lerma. Fleas were deposited at the Colección de Siphonaptera, Museo de Zoología "Alfonso L. Herrera", Facultad de Ciencias (MZFC-S), Universidad Nacional Autónoma de México (UNAM).

Data Analysis. To quantify and analyze the presence of species in the rodent community, the following parameters and indices were calculated (Bush *et al.* 1997):

a) Species richness where S = number of species.

b) Total mean abundance (MA) using the following formula (MA = Ea/Ht),

where EA = total number of individuals of a parasite species on a host and Ht = total number of species including infested and uninfested individuals.

c) Prevalence (P %) for each rodent species using the following formula (P = Re/Rt * 100%) where Re = number of individuals of a host species infested by a parasite species and Rt = total number of individuals examined.

Results

Flea host range. A total of 247 rodents of the Cricetidae family were collected, belonging to three genera and three species: *Reithrodontomys megalotis* (Baird, 1857), *Peromyscus melanotis* (J. A. Allen & Chapman, 1897), and *Microtus mexicanus* (Saussure, 1861). *Peromyscus melanotis* and *M. mexicanus* had a total of 177 fleas belonging to three families (Ceratophyllidae, Ctenophthalmidae, Hystrichopsyllidae), five genera, and seven species (Table 2). The most abundant rodent species was *P. melanotis* with a total of 201 individuals, representing 81.3% of the captures throughout the year, followed by *M. mexicanus* with 43 individuals, while *R. megalotis* was the least abundant with only three individuals captured. Of the total number of rodents captured, only 84 individuals (P=34%) had one or more than one species of flea. *Peromyscus melanotis* was the host species that had the highest number of fleas (113 individuals) with five of the seven species recorded. Meanwhile, *Microtus mexicanus* had the seven species of fleas with a lower abundance (n=64 fleas).

Abundance of Fleas. Of the seven species of fleas identified (Table 2), *Plusaetis sibynus* (Jordan, 1925) (Ceratophyllidae) was the most abundant with a total of 96 individuals, and the least abundant were *Hystrichopsylla orophila* (Barrera, 1952) (Hystrichopsyllidae) and *Rhadinopsylla (Actinophthalmus) mexicana* (Barrera, 1952) (Ctenophthalmidae) with one specimen each. Of the three species of fleas of the genus *Plusaetis* that were recorded, two of them had a high prevalence, *P. sibynus* in *P. melanotis* with 19.4% and *Plusaetis asetus* with 11.7% in *M. mexicanus*; however, compared to the prevalence that other flea species had, these values turned out to be low (Table 2). On the other hand, the prevalence value in the two rodent species with the most fleas was 30%; likewise, the prevalence for the Nevado de Toluca study area was 34.4% and the total average abundance was 0.7165. Additionally, five of the seven flea species (*Ctenophthalmus tecpin* Morrone, Acosta & Gutiérrez, 2000, *Strepsylla villai* Traub Barrera, 1955, *P. aztecus* (Barrera, 1954), *P. sibynus* and *P. asetus* (Traub, 1950), were found in *P. melanotis* and *M. mexicanus*, while *Hystrichopsylla orophila* and *Rhadinopsylla (Actinophthalmus) mexicana* were only found parasitizing *M. mexicanus*.

TABLE 2. Table 2. Species of fleas and rodents found in the Nevado de Toluca, their prevalence, and those reported in the literature. Nt = total number of individuals, Ni = number of infested individuals, P % = Prevalence.

Fleas / Rodents	Nt	*M. mexicanus*	P %	*P. melanotis*	P %	*R. megalotis*	Literature
Nt / Ni		43 /14		201 / 70		3	
Hystrichopsyllidae							
Atyphloceras tancitari							Ayala *et al.*, 1988
Hystrichopsylla orophila	1	1 / 1	2.3				Ayala *et al.*, 1988
***Hystrichopsylla* sp.**	2	1 / 1	2.3	1 / 1	0.4		
Ctenophthalmidae							
Ctenophthalmus tecpin	6	5 / 4	9.3	1 / 1	0.4		
***Ctenophthalmus* sp.**	1	1 / 1	2.3				
Rhadinopsylla (Actinophthalmus) mexicana	1	1 / 1	2.3				
***Rhadinopsylla* sp.**							Ayala *et al.*, 1988
Strepsylla villai	13	1 / 1	2.9	12 / 10	4.9		
***Strepsylla* sp.**	1	1 / 1	2.9				
Ceratophyllidae							
Foxella macgregori							Ayala *et al.*, 1988
Plusaetis aztecus	2	1 / 1	2.9	1 / 1	0.4		
Plusaetis sibynus	96	8 / 4	11.7	88 / 39	19.4		
Plusaetis asetus	9	6 / 5	14.7	3 / 2	0.9		
***Plusaetis* sp.**	45	38 / 31	91.1	7 / 8	3.9		

Discussion

Of the eight rodent species recorded for Nevado de Toluca, three were recorded in the subalpine grassland area: *P. melanotis, M. mexicanus*, and *R. megalotis*. The first of these was the most abundant at an elevation of 4,050 m, which also corresponds to the findings of Barrera (1968) and Tipton & Méndez (1968). *Reithrodontomys megalotis* is normally found between 2,400 and 3,950 m elevation, which could explain why few individuals of this species were captured. On the other hand, Barrera (1968) mentioned that *P. melanotis* and *M. mexicanus* could be present up to 4,250 m, as well as *Neotomodon alstoni* Merriam, 1898 (Muridae), a species that was not captured in this study. A possible explanation for why *P. melanotis* was the species with the highest number of individuals captured is that species of the *Peromyscus* genus are dominant species and good competitors against other species of genera such as *Microtus, Neotomodon,* and *Baiomys* (Barrera 1968).

The presence of Siphonaptera depends on the conditions provided by their host, but also on environmental parameters such as temperature and environmental humidity, which will then determine the conditions of the host's refuge (Krasnov *et al.* 1997). The results of this study suggest that flea assemblages in the Nevado de Toluca region are associated with host species exhibiting ecological adaptations to the environmental conditions characteristic of subalpine grasslands. Flea taxa of Nearctic origin were found to be dominant within these habitats. To date, only four species of fleas have been recorded in the Nevado de Toluca Flora and Fauna Protection Area (Ayala-Barajas *et* *al.* 1988; Table 2). Results indicated that there are seven species that are associated with rodents in this area, rather than five as previously documented in the literature. The flea species *Ctenophthalmus tecpin* and *Strepsylla villai* represent new records for the State of Mexico. Two of the species, *H. orophyla* and *R.* (*Actinophthalmus*) *mexicana*, have been previously reported in similar mountain environments and on the same hosts (Barrera 1968; Tipton & Mendez 1968). These fleas belong to two families (*Hystrichopsyllidae* and *Ctenophthalmidae*) that are considered to have Nearctic affinities (Acosta-Gutiérrez 2014).

The prevalence of the flea species collected in this study showed differences in two of the species of rodent hosts. The prevalence observed in the three species of *Plusaetis* is high in *M. mexicanus*, while in *P. melanotis* only one of them (*P. sibynus*) has a higher prevalence and abundance; this may be since it was the most captured rodent species during this study. Similar findings were observed in the works of Aguilar-Montiel *et al.* (2018) in La Malinche and Acosta *et al.* (2024) in Cerro del Mohinora. Morand & Poulin (1998) and Krasnov & Matthee (2010) mentioned that the population density of the hosts is an important factor that influences the dispersion and distribution of parasites among individuals, as well as the specific richness of ectoparasites.

On the other hand, *C. tecpin* was observed in both rodent species, but the highest prevalence (9.3%) was recorded in *M. mexicanus*, considered its primary host (Machado 1960; Morrone *et al.* 2000). This parasite-host association has also been reported in La Malinche, Popocatépetl, and Cerro El Potosí, which are mountain environments (Barrera 1968; Tipton & Méndez 1968; Acosta & Fernández 2006). The prevalence in the flea species *Hystrichopsylla orophila* and *Rhadinopsylla* (*Actinophthalmus*) *mexicana* was low (one individual per species); however, it aligned with what was found by Barrera (1968) and Tipton & Méndez (1968) for localities under similar elevations. Both species have been previously recorded in the Nevado de Toluca in the same rodent species (Ayala-Barajas *et al.* 1988).

The studies in Mexico that document the ectoparasite-host interaction in high mountain ecosystems such as Nevado de Toluca are limited, but relevant considering that these ecosystems are scarcely represented in Mexico and are sensitive to disappearing due to global warming. Studying this sensitivity is of great interest as hosts play a key role for ectoparasites by providing food, shelter and mating opportunities (Mize *et al.* 2011). In addition, the presence of ectoparasitic species is not only a host-parasite relationship, but also involves interaction of the habitat with the fleas (Krasnov *et al.* 2006).

Studies focused on mountain ecosystems, like the one conducted, help establish a baseline around the diversity of these ectoparasites and their host-parasite interaction (Acosta & Fernández 2015). However, more information is needed to describe their distribution patterns in these sites, since the characteristics of the environment may be gradually shifting the presence of fleas in their host, most likely due to changes in the microclimatic conditions within these localities (Krasnov 2006). Possible effects include the effect climate change may have on understudied microhabitats, such as the subalpine grassland, and the biodiversity present in the mountain systems of central Mexico. These questions suggest new lines of research around the possible effects of climate change on the biodiversity in these montane environments.

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