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Review / Artículo de revisión

Parasitism in the Ringtail cat (*Bassariscus astutus*): a systematic review

El parasitismo en el Cacomixtle (*Bassariscus astutus*): una revisión sistemática

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ABSTRACT

The ringtail cat (*Bassariscus astutus*) is a small mammal native to North America, whose role as a host for parasites is poorly understood. The present study aimed to use the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist to systematically collect and analyze the species that parasitize *B. astutus*. 55 species were identified from 23 scientific studies published between 1945 and 2021. 83.3 % of these were arthropod ectoparasites, mainly from the Ixodidae and Pulicidae families. It was identified that the louse *Neotrichodectes thoracicus* and the cestode *Taenia pencei* could present some type of specificity towards *B. astutus*. On the other hand, the Chao1, Chao2, Jack1, Jack2, and Bootstrap estimators were used to estimate parasite richness, which showed that the species inventory is still incomplete. We expect our results to be helpful in exposing the lack of information about the species that parasitize *B. astutus*, especially endoparasites.

KEY WORDS: *Bassariscus astutus*, Ringtail cat, Parasites, Endoparasites, Ectoparasites.

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RESUMEN

El cacomixtle (*Bassariscus astutus*) es un pequeño mamífero nativo de Norteamérica, cuyo rol como hospedero de parásitos es poco conocido. El presente estudio tuvo como objetivo utilizar la lista de verificación PRISMA para recopilar de manera sistemática y analizar a las especies que parasitan *B. astutus*. Se identificaron a 55 especies provenientes de 23 estudios científicos publicados entre 1945 al 2021. El 83.3 % de estas fueron ectoparásitos artrópodos, principalmente de las familias Ixodidae y Pulicidae. Se identificó que el piojo *Neotrichodectes thoracicus* y el cestodo *Taenia pencei* podrían presentar algún tipo de especificidad hacia *B. astutus*. Por otro lado, se utilizaron los estimadores Chao1, Chao2, Jack1, Jack2 y Bootstrap para estimar la riqueza de parásitos, los cuales mostraron que el inventario de especies continúa incompleto. Se espera que estos resultados sean útiles para exponer la falta de información sobre las especies que parasitan a *B. astutus*, en especial de los endoparásitos.

PALABRAS CLAVE: *Bassariscus astutus*, Cacomixtle, Parásitos, Ectoparásitos, Endoparásitos.

Introduction

Altered ecosystem dynamics and the increasing interaction between humans, domestic animals, and wildlife are an important source of zoonotic diseases (Bengis *et al*., 2004; Polley, 2005, Myers *et al*., 2013; Rizzoli *et al*., 2019; Magouras *et al*., 2020). These are defined as those infectious illnesses of animal origin that can affect humans. Worldwide, parasites serve as transmission vectors for 35 % of these afflictions (Vélez-Hernández *et al*., 2014), where the probability of acquisition is defined by ecological (Gibb *et al*., 2020) and biological factors of humans, the disease, the vector, and its host (Polley, 2005; Rizzoli *et al*., 2019; Sooksawasdi Na Ayudhya & Kuiken, 2021).

Among mammals, the order Carnivora harbors the largest number of zoonotic pathogens and parasites. Especially the taxonomic family of procyonids, which has been recognized for its role in the transmission of various pathogens of parasitic origin to humans (Han *et al*., 2021). There is information about the coati *Nasua narica* (Linnaeus, 1766) and the raccoon *Procyon lotor* (Linnaeus, 1758), whose wide distribution, proximity to human settlements, omnivorous diet, dispersal capacity over long distances, and the use of latrines, contribute to the health hazard. However, there are few reports of zoonoses by other procyonid species, such as the ringtail cat *Bassariscus astutus* (Lichtenstein, 1830), despite having a similar life history and behavior. There is little information on the ecology and biology of this species, as well as its role as a vector or

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reservoir of parasites. For this reason, this study aimed to compile and synthesize the available information on the species that parasitize the ringtail cat. This information will make it possible to identify areas of opportunity for future studies on the species, its parasites, and the interactions they have with other organisms, including humans.

Material and Methods

A systemic review of the metazoan species that parasitize *B. astutus* was carried out based on the PRISMA checklist (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Page *et al*., 2021). The registered parasites were divided into two categories: ectoparasites and endoparasites. For the former, the arthropod phylum was investigated, which includes most of the organisms that infect mammals (Balashov, 2006). While for endoparasites, various taxonomic groups were included, such as helminths (Acanthocephali, cestodes, trematodes, nematodes, etc.) and protists (Apicomplexa, Euglenozoa, etc.).

The data search was carried out in scientific journals, university newsletters, documents of scientific societies, technical reports, and books published between 1900 and 2021. Initially, it was carried out in the databases of Google Scholar, EBSCOhost, JSTOR, ScienceDirect, PubMed, and Scielo Scientific Library. In which, the following keywords were entered in independent searches: "*Bassariscus astutus*", "ringtail cat", "cacomixtle" "cacomiztle", "mammals", "carnivores", "wildlife" and "parasites", "host – parasites", "ectoparasites", "endoparasites", "Ixodes", "ticks", "fleas", "Helminths", "infectious disease", "*T. cruzi*", "Toxoplasmosis" and "Mexico", "Arizona, "New Mexico", "Texas", "California", "Nevada", "Utah, "Colorado". The same keywords were translated and used in Spanish.

The information on the parasite species reported and cited within the studies was used to build a table, which included the following qualitative variables: year of publication, study area, phylum, type of parasite (endoparasites/ectoparasites), habitat (tract gastrointestinal, lungs, heart, blood, epidermis, etc.) and if it acts as the causative agent or vector of any disease of medical interest considered by the Pan American Health Organization (PAHO, 2003). Once the information was collected, a map and a line graph were used to evaluate the trend in the location and number of documents published every five years since 1900 and to identify the most studied parasite phyla in *B. astutus*. The relative frequency for the type of habitat was calculated and a Chi-square test was performed to analyze if there were significant differences between ectoparasites and endoparasites. Additionally, a species accumulation curve was built considering each publication as a sampling unit; The EstimateS program (version 9.1.0) was used to randomize the information and calculate the biodiversity estimators Chao1, Chao2, Jack1, Jack2, and Bootstrap, and R (R Core Team 2019) to build a curve for each estimator.

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Results and Discussion

A total of 23 publications about the species that parasitize *Bassaricus astutus* were identified and included in the present review (Appendix 1). Of the evaluated literature, four texts explicitly contained the name of *B. astutus* or its common name within the title; 14 alluded to ectoparasites, specifically ticks, the genus *Ixodes*, and/or their hosts; and five to *T. cruzi* and diseases in wild mammals. However, at least one species of parasite present in *B. astutus* was mentioned. The results presented a bias towards more recent studies, some works published at the beginning of the 20^{th} century were not possible to find and include in the present review (i.e., Neumann (1911) cited by Cooley & Kohls (1945); Mac-Callum (1921), and Price (1928) cited by Pence & Willis (1978)). Thus, the information corresponded to a period of 76 years, with an average of 1.5 publications every 5 years, with an increase in number between 1970-1975 and 2000-2005 (Figure 1). Regarding their origin, they came mainly from the United States (n=17; 70 % in Texas, 15 % in Nevada, Arizona, and New Mexico, and 11 % without a specific location within the country), followed by Mexico (n=7; 28 % in Nuevo León, 28 % in Mexico City and the rest in Baja California Sur, Guanajuato and Guerrero) as can be seen in Figure 2.

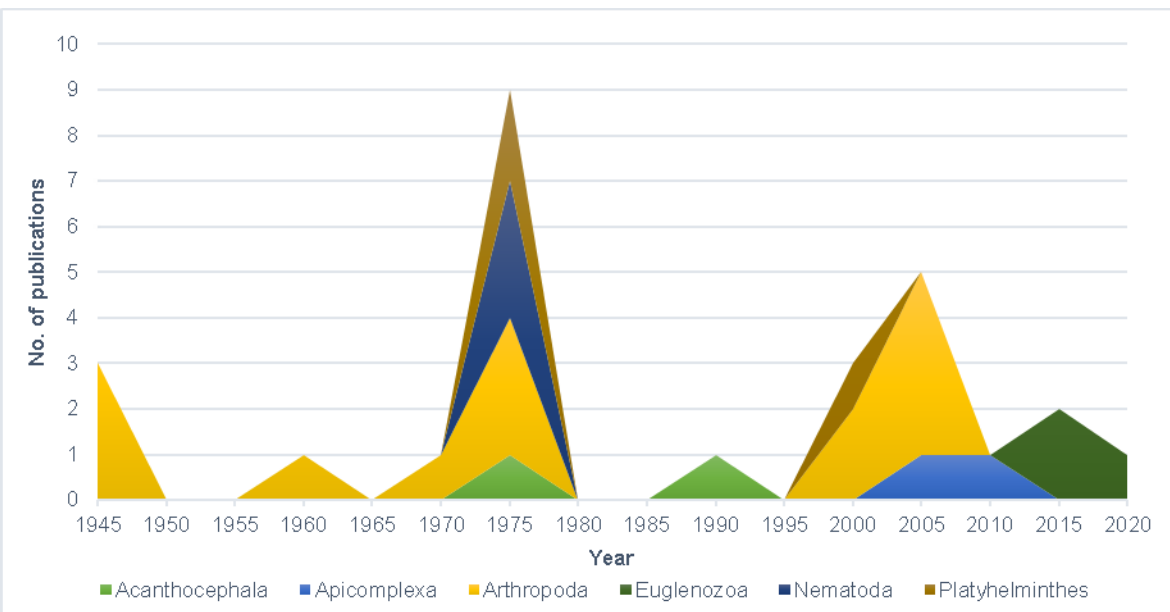

Figure 1. Publications related to *B. astutus* parasites from different phyla from 1945 to 2021.

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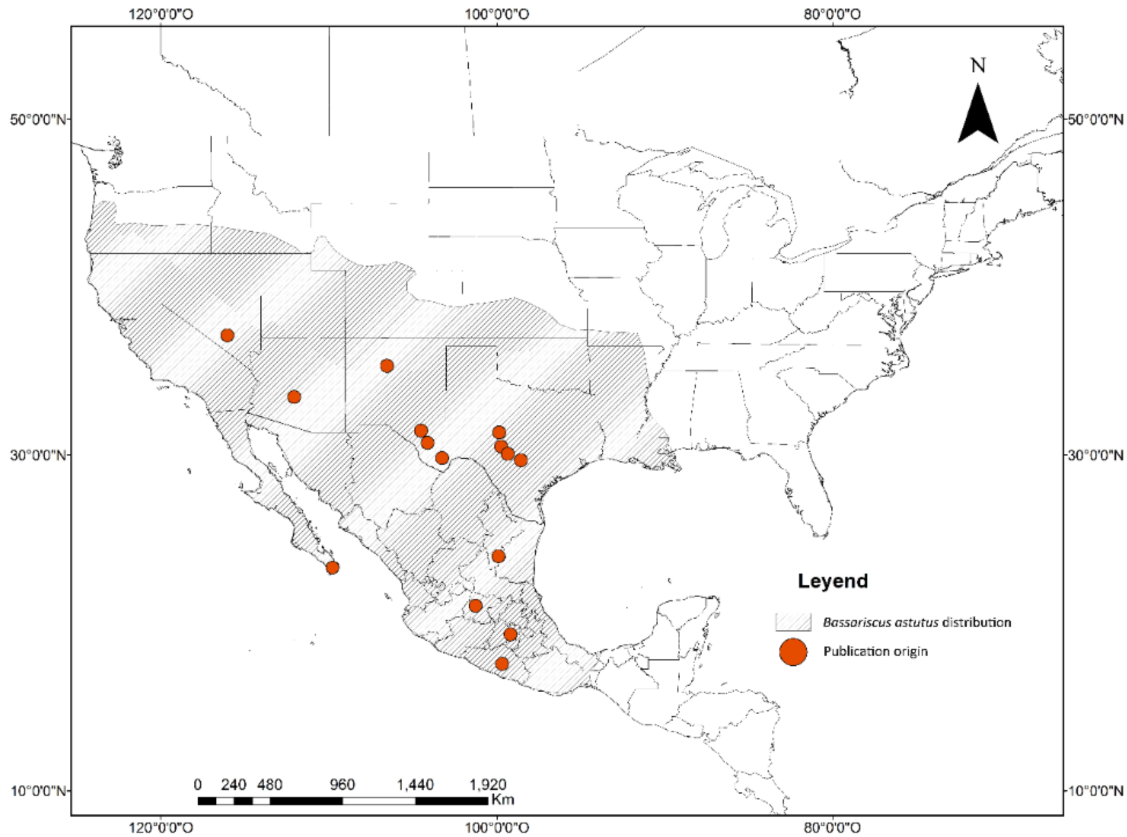

Figure 2. Origin of published papers on *B. astutus* parasites.

Data was gathered on the occurrence of 55 parasite species belonging to the following phylum: Acanthocephala (1), Apicomplexa (1), Arthropoda (46), Euglenozoa (1), Nematoda (3) and Platyhelminthes (3); with a significant difference between the studies of ectoparasites and endoparasites ($\chi^2(22, N=23) = 59.08$, $p > 0.05$), where 83 % of the species were arthropod ectoparasites present in the epidermis and fur of *B. astutus*, with few others distributed in other body areas (Figure 3). This bias could be since most of the reports came mainly from ectoparasite-host lists, where *B. astutus* was not usually the study subject (for example: Beck *et al*., 1963; Montiel-Parra *et al*., 2007 and Guzmán-Cornejo *et al*., 2009). Furthermore, the limited number of publications on endoparasites, which account for only 16 % of the species, may be attributed to the challenges associated with accessing samples. This difficulty arises due to the non-random distribution of *B. astutus* latrines, which are typically found in hard-to-reach locations with steep slopes or elevated positions (Barja & List, 2006). Additionally, the activity patterns and habitat

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preference of *B. astutus* can make it difficult to capture for biopsies (Ryser-Degiorgis, 2013). The reduced number of publications, added to the few places where they were made, leave aside species of parasites that could be associated with a particular ecoregion (Kresta *et al*., 2009), and do not show the temporal and spatial fluctuation that could exist among parasitic communities. Therefore, it is highly probable that there are more than 55 species of parasites in *B. astutus* (Appendix 1).

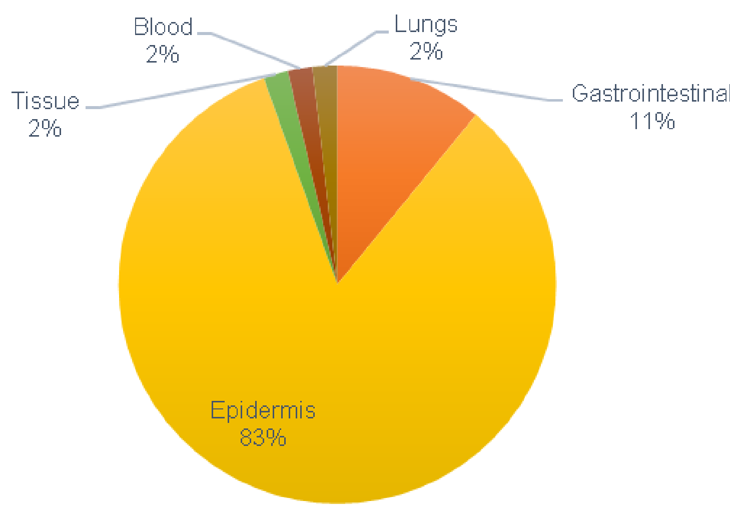

Figure 3. Body distribution of the parasites present in *B. astutus*.

Of the reported parasites, the most cited taxonomic families were Ixodidae and Pulicidae. This could be partially explained because they have complex life cycles that require different hosts and that generally do not present specificity when infecting other species (Cañizales & Guerrero, 2017). The presence of the *Ctenocephalides felis* flea could be considered anomalous in *B. astutus* since this species usually resides in the domestic cat, although it has also been found in other mammals (Durden & Traub, 2002). In contrast, the louse *Neotrichodectes thoracicus* and the cestode *Taenia pencei* have only been reported on *B. astutus* so far (Osborn, 1902; Ewing, 1936; Emerson & Roger, 1985; Rausch, 2003; Kelley & Horner, 2008), which could indicate some level of specificity of both parasites.

In relation to the diversity of parasite species, it was determined that, both in the observed and estimated species, the asymptotic number was not reached (Figure 4). Hence, the parasite inventory of this work can be considered incomplete. The Jack1, Jack2 and Chao2 estimators overestimated species richness and presented greater bias. For example, Chao2 predicts that more than 70 species remain to be reported to reach the total asymptote of the curve. On the other hand, the Chao1 and Bootstrap estimators presented less bias and were more precise. Both estimators predict that around 20 species remain to be inventoried for the census to be complete. The behavior of the estimators coincides with that reported by Poulin (1998), Romero-Tejeda *et al*. (2008) and Bautista-Hernández *et al*. (2013); who, for parasitology studies, mention that the most recommended wealth estimator is Bootstrap.

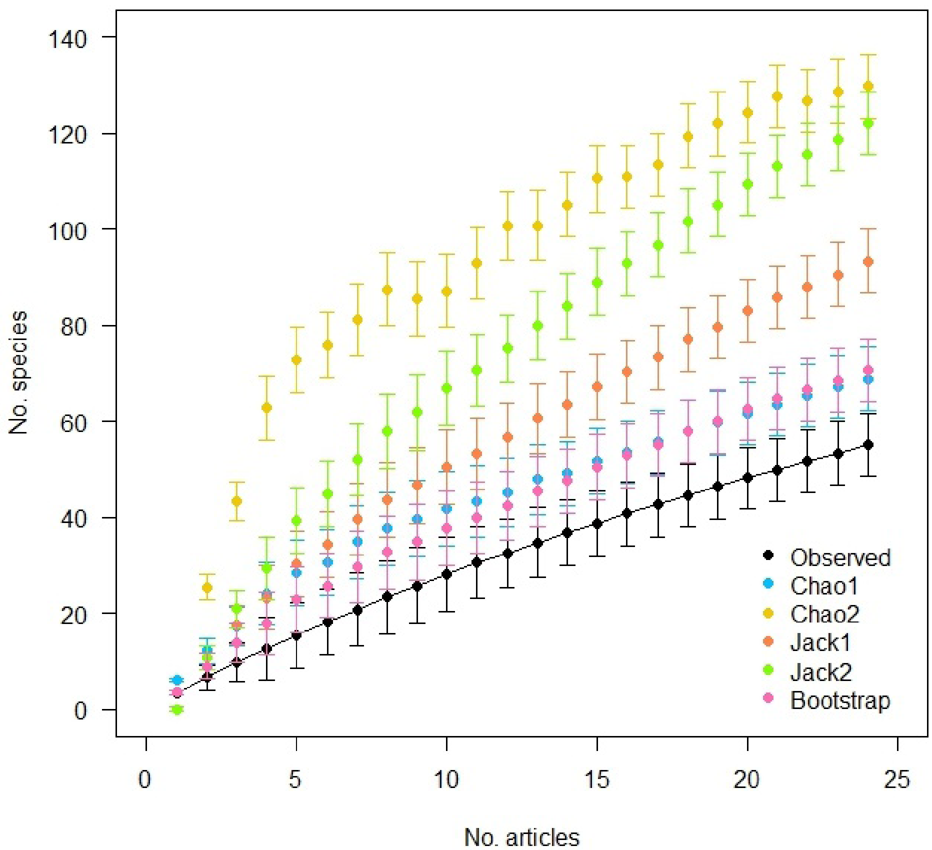

Figure 4. Observed and estimated parasite species accumulation curve of *B. astutus*.

Eight parasite species were identified in *B. astutus*, which cause or serve as a vector for 14 zoonoses considered by PAHO (2003). 14.28 % of them are caused by protists, 28.57 % by cestodes, and 57.14 % by ticks of the Ixodidae family. The reported seroprevalence for *Toxoplasma gondii* in *B. astutus* in suburban environments was 20 % (Suzán & Ceballos, 2005) and in South Texas for Chagas disease 100 % (Kramm *et al*., 2019). However, *B. astutus* is not considered to be a reservoir for either of these two protozoa since the reports are scarce and come from few samples. In relation to helminthiasis, the most noteworthy are coenurosis, taeniasis, and mesocestoidiasis, caused mainly by the genera *Taenia* and *Mesocestoides*. The prevalence of *Mesocestoides* of 20 % found by Pence & Willis (1978) could indicate that *B. astutus* serves as the definitive host for these organisms, since according to Chelladurai & Brewer (2021) the prevalence of *Mesocestoides* in intermediate hosts is 7.09 % and in definitive hosts 21.72 %. Regarding pathologies caused by arthropods, to date it has not been investigated whether *B. astutus* plays any role in the natural history of these pathogens. However, it is important to highlight that ticks of the genera *Haemaphysalis, Dermacentor, Ixodes,* and *Amblyomma* (all identified in *B. astutus*) are responsible for the storage and transmission of most zoonoses among arthropods (Sosa-Gutierrez *et al*., 2016; Rizzoli *et al*., 2019). Although the dynamics between *B. astutus* and zoonoses remain unknown, the species could be considered as an indicator of the parasites present in an ecosystem (Han *et al*., 2021). This is important as, among wildlife-transmitted zoonoses, the discovery rate of new parasites is low relative to bacteria and viruses (Polley, 2005).

Conclusions

Information was collected on 55 species that parasitize *B. astutus* from 23 scientific articles published for more than 76 years. The collected data showed a bias towards ectoparasites, which means that greater research effort towards endoparasites is required. We identified that the louse *Neotrichodectes thoracicus* and the cestode *Taenia pencei* may present some type of specificity towards *B. astutus*. The species accumulation curve showed that more than 20 taxa still need to be identified to complete the inventory of parasites of the species. Finally, more information is needed to identify temporal and spatial patterns between *B. astutus* and its parasites as well as to recognize whether *B. astutus* plays a role as a reservoir or vector of zoonotic diseases.

Author contribution

Conceptualization of the work, MGDI; development of the methodology, MGDI; software management, MGDI; experimental validation, JMMC; results analysis, MGDI, JMMC; Data Management, MGDI; writing and preparation of the manuscript, MGDI, JMMC; writing, proofreading and editing, MGDI, JMMC; project manager, MGDI, JMMC; fundraising, MGDI, JMMC. “All authors of this manuscript have read and accepted the published version of it.”

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Conflict of interest

The authors declare no conflict of interest.

Appendix 1. *Bassariscus astutus* parasites

Class	Order	Family	Species	Zoonosis	Reference
Archiacanthocephala	Oligacanthorhynchida	Oligacanthorhynchidae	*Macracanthorhynchus ingens*		13
Conoidasida	Eucoccidiorida	Sarcocystidae	*Toxoplasma gondii*	Toxoplasmosis	22
Arachnida	Ixodida	Ixodidae	*Amblyomma americanum*	Tularemia (*Francisella tularensis*), Ehrliquiosis (*Ehrlichia spp.*), Rocky Mountain spotted fever (*Rickettsia rickettsii*)	5, 11, 14, 19
Arachnida	Ixodida	Ixodidae	Dermacentor parumapertus		8
Arachnida	Ixodida	Ixodidae	*Dermacentor variabilis*	Tularemia (*F. tularensis*), Rocky Mountain spotted fever (*Rickettsia rickettsii*)	14
Arachnida	Ixodida	Ixodidae	*Haemaphysalis leporispalustris*		14
Arachnida	Ixodida	Ixodidae	*Ixodes angustus*		20
Arachnida	Ixodida	Ixodidae	*Ixodes conepati*		14, 20
Arachnida	Ixodida	Ixodidae	*Ixodes cookei*	Encephalitis (*Flavivirus spp.*)	4, 11, 19, 23
Arachnida	Ixodida	Ixodidae	*Ixodes dampfi*		29
Arachnida	Ixodida	Ixodidae	*Ixodes kingi*		8, 11
Arachnida	Ixodida	Ixodidae	*Ixodes rubidus*		1, 7
Arachnida	Ixodida	Ixodidae	*Ixodes scapularis*	Babiosis (*Babesia microti*), Lyme disease(*Borrelia burgdorferi*)	19
Arachnida	Ixodida	Ixodidae	Ixodes sculptus		4
Arachnida	Ixodida	Ixodidae	*Ixodes texanus*		5, 11, 24, 25

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Class	Order	Family	Species	Zoonosis	Reference
Arachnida	Mesostigmata	Hirstionyssidae	*Hirstionyssus breviseta*		14
Arachnida	Mesostigmata	Hirstionyssidae	*Hirstionyssus staffordi*		14
Arachnida	Mesostigmata	Laelapidae	*Androlaelaps circularis*		16
Arachnida	Mesostigmata	Laelapidae	*Androlaelaps fahrenholzi*		14
Arachnida	Sarcoptiformes	Glycyphagidae	*Homopus hypudaei*		14
Arachnida	Trombidiformes	Cheyletidae	*Cheyletus eruditus*		14
Arachnida	Trombidiformes	Cheyletidae	*Eucheyletia hardyi*		14
Arachnida	Trombidiformes	Trombiculidae	*Euschoengastia eadsi*		14
Arachnida	Trombidiformes	Trombiculidae	Microtrombicula fisheri		10
Arachnida	Trombidiformes	Trombiculidae	*Microtrombicula tragulata*		10
Arachnida	Trombidiformes	Trombiculidae	*Pseudoschoengastia apista*		14
Insecta	Phthiraptera	Trichodectidae	*Neotrichodectes thoracicus*		6, 14
Insecta	Siphonaptera	Ceratophyllidae	*Dactylopsylla percernis*		19
Insecta	Siphonaptera	Ceratophyllidae	*Malaraeus sinomus*		14, 15
Insecta	Siphonaptera	Ceratophyllidae	*Monopsyllus wagneri*		15
Insecta	Siphonaptera	Ceratophyllidae	*Orchopeas neotomae*		15
Insecta	Siphonaptera	Ceratophyllidae	*Orchopeas sexdentalus*		14, 19
Insecta	Siphonaptera	Ceratophyllidae	*Oropsylla montana*		15
Insecta	Siphonaptera	Ceratophyllidae	Thrassis aridis		15
Insecta	Siphonaptera	Hystrichopsyllidae	*Anomiopsyllus novomexicanensis*		15
Insecta	Siphonaptera	Hystrichopsyllidae	*Anomiopsyllus nudatus*		14
Insecta	Siphonaptera	Hystrichopsyllidae	*Atyphloceras echis*		15
Insecta	Siphonaptera	Hystrichopsyllidae	*Epitedia stanfordi*		15
Insecta	Siphonaptera	Hystrichopsyllidae	*Megarthroglossus bisetis*		15
Insecta	Siphonaptera	Hystrichopsyllidae	*Meringis arachis*		15

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Class	Order	Family	Species	Zoonosis	Reference
Insecta	Siphonaptera	Hystrichopsyllidae	*Micropsylla sectilis*		15
Insecta	Siphonaptera	Hystrichopsyllidae	*Stenistomera alpina*		15
Insecta	Siphonaptera	Pulicidae	*Ctenocephalides felis*		9
Insecta	Siphonaptera	Pulicidae	Echidnophaga gallinacea		14, 15,18, 19
Insecta	Siphonaptera	Pulicidae	*Hoplopsyllus affinis*		11
Insecta	Siphonaptera	Pulicidae	*Pulex irritans*		11, 17
Insecta	Siphonaptera	Pulicidae	*Pulex simulans*		14, 15, 18, 19
Insecta	Siphonaptera	Rhopalopsyllidae	*Polygenis gwyni*		14
Kinetoplastea	Trypanosomatids	Trypanosomatidae	*Trypanosoma cruzi*	Chagas disease	26, 27, 28
Chromadorea	Rhabditida	Ancylostomatidae	*Placoconus lotoris*		3, 13
Chromadorea	Rhabditida	Pneumospiruridae	*Pneumospirura bassarisci*		12, 13
Secernentea	Spirurida	Physalopteridae	*Physaloptera sp*		13
Cestoda	Cyclophyllidea	Mesocestoididae	*Mesocestoides bassarisci*	Mesocestoidiasis	2
Cestoda	Cyclophyllidea	Mesocestoididae	*Mesocestoides sp*	Mesocestoidiasis	13
Cestoda	Cyclophyllidea	Taeniidae	*Taenia pencei*	Coenurosis, Taeniasis	21

Source: Fuente: [1] Neumann (1911) quoted by Cooley y Kohls (1945), [2] MacCallum (1921) quoted by Pence y Willis, (1978), [3] Price (1928) quoted by Pence y Willis (1978), [4] Bishopp y Trembley (1945), [5] Brennan (1945), [6] Wiseman (1959) quoted by Mayberry *et al*. (2000), [7] Hoffmann (1962) quoted by Whitaker y Morales-Malacabra (2005), [8] Beck *et al*. (1963), [9] Barrera (1968) quoted by Whitaker y Morales-Malacabra (2005), [10] Webb y Loomis (1970), [11] Toweill y Price (1976), [12] Pence y Stone (1977), [13] Pence y Willis (1978), [14] Custer y Pence (1979), [15] Eads *et al*. (1979), [16] Bassols (1981) quoted by Whitaker y Morales-Malacabra (2005), [17] Morales-Muciño y Llorente-Bousquets (1986) quoted by Whitaker y Morales-Malacabra (2005), [18] Ayala-Barajas *et al*. (1988) quoted by Whitaker y Morales-Malacabra (2005), [19] Richerson *et al*. (1992), [20] Samuel *et al*. (2001), [21] Rausch (2003), [22] Suzán y Ceballos (2005), [23] Montiel-Parra *et al*. (2007), [24] Gordillo-Perez *et al*. (2009), [25] Guzmán-Cornejo *et al*. (2009), [26] Brown *et al*. (2010), [27] Curtis-Robles *et al*. (2018), [28] Kramm *et al*. (2019) y [29] Sánchez-Montes *et al*. (2021).

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