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What do we know about parasites of wildlife in high biodiversity areas with anthropogenic disturbance? The special case of Mexico

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Review

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Abstract

The continual rise of anthropogenic disturbance of ecosystems has been associated with an increasing incidence of emerging diseases. The largest amount of data on emerging diseases relates to bacterial and viral pathogens, but there is a lack of parasite data, especially from wildlife. Monitoring wildlife parasitic diseases should be considered a priority, especially in high biodiversity regions with strong anthropogenic impacts, like Mexico, where the wildlife/livestock/human interface is associated with increased risk of disease transmission. Mexico belongs to the top-ten megadiverse countries and is located between two biogeographic regions. This situation makes Mexico a favourable region for the spillover of animal pathogens to human beings, causing pandemics, such as the one recently caused by influenza virus A (H1N1). The current state of knowledge of Mexican wildlife parasites is scarce and focuses mainly in Neotropical fauna. Moreover, this knowledge is heterogeneous for different parasite groups, especially concerning their pathologic effects and epidemiology. The goals of this review are to compile information on Mexican wildlife parasites and to identify knowledge gaps in order to stimulate research on pending epidemiological, public health, ecological and pathological areas, and to encourage the creation of more specialized groups from the perspective of the One-Health concept.

Introduction

Changes in land use have led to the destruction of natural habitats and, consequently, produced significant modifications in the structure and functions of ecosystems. These anthropogenic disturbance activities increase rates of contact between humans, wildlife and domestic animals, and thus the risk of emerging zoonotic disease outbreaks rises (Brearley *et al.*, 2013), possibly because zoonotic pathogens are particularly prone to causing emerging diseases (Morse *et al.*, 2012). The facts that more than 50% of studies in disturbed wildlife habitats detected a rising of incidence and prevalence of disease (Gottdenker *et al.*, 2014) and that about 50% of human and domestic animal pathogens possess the capacity to infect other vertebrate hosts (Morse *et al.*, 2012), reinforce the above idea. Moreover, although some studies on pathogen transmission exist, this information is incomplete or nonexistent for 44% of human pathogens, and most of the information available relates to viral and bacterial agents (Miller *et al.*, 2013). In contrast, parasites have received less attention (Thompson *et al.*, 2009). However, parasites are no less important, because, according to Chomel (2008), of the 1415 species of pathogens described in humans, 287 are helminths and 66 are protozoans; further, many protozoans are classified as emergent or able to cause emerging zoonoses. There is high risk of spillover at the wildlife–human–domestic animal interface of protozoans and helminths such as *Giardia* spp., *Toxoplasma gondii*, *Trichinella* spp. and *Echinococcus* spp., with serious health consequences in some cases (Thompson, 2013).

Pathogen spillover events appear most frequently in high biodiversity regions where the interface between people, livestock and wildlife is pronounced and suffers large anthropogenic changes, which usually correlates with high human and/or domestic animal population densities. Thus, regions with high biodiversity are priority areas for epidemiological surveillance, where increasing knowledge about parasite aetiology, transmission and ecology will enable forecasting emerging pathogen outbreaks (Morse *et al.*, 2012). The scientific interest in these megadiverse areas is especially based on the paradigm that, from a general perspective, a high host diversity is accompanied by high parasite diversity (Lafferty, 2014), and possibly high transmission rates. For example, this was shown for (1) *Giardia* spp. and *Cryptosporidium* spp. affecting mountain gorillas (*Gorilla gorilla*) of Uganda, these parasites were genetically close or identical to those found in local farmers and their livestock (Graczyk *et al.*, 2001, 2002); (2) *Trypanosoma cruzi* II, a lineage common in the Chagas disease

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domestic cycle, has been detected in endangered golden lion tamarins (*Leontopithecus rosalia*) and golden-headed lion tamarins (*L. chrysomelas*) from Brazil, being attributed to the presence of this protozoan to the increasingly fragmented habitat of these host species (Kerr *et al*., 2016); (3) sarcoptic mange in Australian wombats (*Vombatus ursinus*) caused by *Sarcoptes scabiei*, var. *canis*, responsible for the drastic demographic decline of this marsupial species (Martin *et al*., 1998); (4) *Echinococcus granulosus* and *T. gondii* in wallabies (Macropodidae) in Australia, which are highly susceptible to these parasites that were introduced by European colonists, making wallabies more susceptible to predation (Abbott, 2006; Barnes *et al*., 2007); (5) *T. gondii* in fosa (*Cryptoprocta ferox*), the largest and endangered native carnivore from Madagascar, which suffered spillover from the introduced cat species *Felis catus* and *F. silvestris* (Pomerantz *et al*., 2016); (6) *Fasciola hepatica*, an Old World liver fluke introduced in America by European livestock, recently produced an outbreak with a mortality >90% in a Brazilian capybaras (*Hydrochoerus hydrochaeris*) population (Labruna *et al*., 2018); and (7) *Haemoproteus multipigmentatus*, which was introduced to the Galapagos archipelago with domestic rock pigeons (*Columba livia*) in the 1970s, was the origin of a spillover event in the endemic Galapagos dove (*Zenaida galapagoensis*), producing alterations in erythrocyte parameters (Santiago-Alarcon *et al*., 2010; Jaramillo *et al*., 2017). In spite of the eradication of rock pigeons from the archipelago in 2007, further spillover events from the Galapagos dove to at least six species of passerines indigenous to Galapagos, and the health consequences for the new hosts are still unknown (Phillips *et al*., 2012; Jaramillo *et al*., 2017).

Clearly, high biodiversity wilderness areas are a target for parasitic diseases of public health and veterinary importance across the world (Kutz *et al*., 2004). Parasites can affect the health and well-being of human beings and animals, and can also impact the fitness and the dynamics of wildlife populations, particularly of endangered species (Pedersen and Fenton, 2015). Therefore, it is imperative to identify parasitic agents and assess their impact on wildlife health. Unfortunately, this is a major challenge in many highly biodiverse areas of the world where little or no information about parasites, their life cycles and their hosts exists. Scientists urge to increase efforts to generate knowledge in these areas through field studies that combine traditional and molecular diagnostic techniques with an epidemiological approach, in order to elucidate the effect of parasites on hosts, at the individual and the population levels (Davidson *et al*., 2011). This demands a greater effort to train and support research groups that embrace these issues from a One-Health perspective (Thompson, 2013).

Pathogen monitoring in wild animals

During the past decade, pathogen surveillance in wild animals has increased exponentially. The main reasons are: (a) wildlife have been identified as reservoirs of emerging disease agents; (b) pathogens that infect wild animals may also affect livestock and cause a significant negative economic impact; (c) the eradication of diseases in farm animals may be impeded considerably if wildlife reservoirs persist; and (d) diseases in endangered and geographically restricted species may enhance their chances of extinction (Guberti *et al*., 2014).

According to Mörner *et al*. (2002), the countries that have conducted infectious disease surveillance programmes in wild animals are better prepared to protect their human, wildlife and domestic animal populations, because those countries improve their understanding of the epidemiology of emerging zoonoses. In fact, the surveillance of wildlife pathogens and their effects are a topic of increasing importance (Grogan *et al*., 2014). In Europe, Canada and the USA, wildlife disease monitoring programmes have been implemented for decades; however, in other countries such as Mexico, those programmes are non-existent or scanty. The lack of programmes in this American country can be explained in three ways. (1) The economic consequences of detecting and reporting new pathogens that provoke trade restrictions; in this sense, Mexico seeks to preserve the economic value of animal production systems, investing 2.9% of the total national budget. (2) The limited public resources available to environmental management, which amount to 0.94% of Mexico's national budget compared with 32.2% of this budget dedicated to economic development. (3) Investment in scientific research is extremely low, only 0.5% of Mexico's gross domestic product (Presupuesto de Egresos de la Federación para el Ejercicio Fiscal 2014, 2014; Interinstitutional Group of Mexican Postgraduate Students, 2017).

In spite of the efforts of some countries, wildlife disease surveillance is not a worldwide priority. Wildlife disease surveillance is hindered by a set of problems difficult to overcome, notably: (a) lack of social and political will, (b) the inherent complexity of environment–pathogen–host interactions, and (c) the high costs of implementing long-term disease monitoring programmes in free-ranging wildlife (Grogan *et al*., 2014). Besides, some diseases can be under-represented in such programmes, particularly those affecting rare wild species or, in other cases, animal species that lack charisma in our society. Moreover, following the recognition of a particular problem in wildlife, society may show indifference or unwillingness to act (Grogan *et al*., 2014). A key element of surveillance is to detect, predict and define the impact of pathogens across space and time. According to the study objective, the researcher can opt to carry out active or passive surveillance (Mörner *et al*., 2002).

Because, there is low governmental willingness to invest in wildlife disease surveillance in Mexico, passive surveillance is the more affordable way for local researchers to detect parasitic infections in wildlife animals. Because passive surveillance is based on the opportunistic collection of samples, a substantial reduction in field costs can be achieved through collaboration and building networks that incorporate interdisciplinary researchers, legal hunters and members of local government, and encouraging citizens to report on animals found sick or dead, which are a major source of biological samples to investigate infections in wildlife (Mörner *et al*., 2002; Rhyan and Spraker, 2010). In addition, passive surveillance facilitates the detection of cryptic, subclinical or previously unknown diseases, because these diseases are insufficiently monitored by active surveillance for the cryptic or non-charismatic nature of the hosts, lack of basic knowledge of pathogens and the remote nature of the location (Grogan *et al*., 2014). Therefore, the detection of pathogens with these epidemiological traits is important and makes passive surveillance on a large temporal and spatial scale a priority (Mörner *et al*., 2002; Lawson *et al*., 2015). In contrast, active surveillance is based on monitoring for specific pathogens, mainly those that affect people or livestock, and provides detailed epidemiological information allowing investigation of environmental factors associated with disease events (Mörner *et al*., 2002; Sleeman *et al*., 2012). However, active surveillance entails a great economic investment and is time consuming. Thus, it is recommended to perform passive

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surveillance first and progress to active surveillance after a specific pathogen or sick or dead animals are identified, in order to conduct an epidemiologic follow-up study (Mörner *et al.*, 2002).

Other useful places to monitor wildlife pathogens are wildlife rescue and rehabilitation centres, which provide unique opportunities to study wild animals and their pathogens, especially under sinanthropic circumstances. These centres compile a wide variety of autochthonous wildlife species, sometimes from remote regions. They facilitate the collection of samples, the follow-up of disease stages, the study of the circumstances that favour morbidity and mortality and, moreover, permit carrying out pathological examinations prior to and after death or euthanasia (Randall *et al.*, 2012; Lawson *et al.*, 2015).

Biodiversity and anthropogenic perturbation in Mexico

Mexico belongs to the top-ten megadiverse countries, with more than 30% of its land under closed forest (Shi *et al.*, 2005). This country possesses most climate types and has a complex topography derived from an intense geological history. Mexico is a terrestrial eco-region with high values on species richness, endemisms, taxon rarity, unusual ecological and evolutionary phenomena, and a global singularly of habitat types. In fact, Mexico is the only country of the American continent in which two biogeographic regions converge, the Nearctic and the Neotropical zones (Olson *et al.*, 2001). Also, it is a region in which human pandemic health emergencies have originated in animals, such as the influenza A (H1N1) pandemic caused by a viral strain that resulted from a genetic combination of bird, pig and human influenza viruses (Pérez-Padilla *et al.*, 2009).

In spite of its great biodiversity, most remains to be described, including wildlife parasite species (Paknia *et al.*, 2015). Moreover, illegal wildlife trade, illegal hunting, anthropogenic disturbance and infectious diseases seriously threaten Mexican biodiversity. Some facts related to this include:

(a) The illegal traffic of a great number of psittacines (parrots). Each year an estimate of 65,000–78,000 birds are illegally trapped in Mexico, and nearly 75% die before being acquired by a private buyer (Weston and Memon, 2009).
(b) The widespread increase of urbanization especially in tropical areas. For example, the state of Tabasco, located in southeastern Mexico, currently has the highest rate of deforestation in the country. It is related to human population growth, attributed to the local oil boom, which doubled from 1,062,961 to 2,238,603 people from 1980 to 2010. During 2010, 470,000 barrels of crude oil were produced daily in Tabasco state, positioning it as the largest oil-producing Mexican state (Pinkus-Rendón and Contreras-Sánchez, 2012). Nevertheless, despite the economic success, governmental and public environmental interest is virtually nonexistent. Indeed, no official data related to the loss of species associated to oil exploitation exist, even though it is well known that many native wildlife species have been forced to coexist with human populations due to habitat encroachment (Gordillo-Chávez *et al.*, 2015; Hidalgo-Mihart *et al.*, 2016). Some of the most affected species are Mexican howler monkeys (*Alouatta palliata* and *A. pigra*), opossums (*Didelphis virginiana*, *D. marsupialis* and *Philander opossum*), anteaters (*Tamandua mexicana*), procyonids (*Nasua narica* and *Procyon lotor*), several bat species and manatees (*Trichechus manatus*). The species listed are commonly observed in urban and peri-urban areas (Hidalgo-Mihart *et al.*, 2016; Martínez-Hernández *et al.*, 2016).
(c) The expansion of the road network. Between 2006 and 2012, the Mexican government spent $17.6 billion on road modernization and built 3000 km of new roads. Such modernization has produced profound landscape changes and ecosystem fragmentation (Flores-Rangel, 2015), and resulted in the increase of wildlife road kills. As a matter of fact, in some tropical Mexican regions, some authors reported up to four daily road-kill wild animals on a 1.2 km study section (Grosselet *et al.*, 2009); moreover, it is estimated that 13.16% of road-killed animals in the studied areas are endangered species (Pozo-Montuy and Pozo-Juárez, 2008).
(d) The effects of pathogens on the wild host species are virtually unexplored, because most research is focused on pathogen diagnosis, and the impact of pathogens on the population dynamics of wildlife host communities is unknown (Vander Wal *et al.*, 2014).

The importance of parasitological research

Parasites constitute a group of living organisms where any numerical approximation about their biodiversity would probably be an underestimation. In fact, it is well known that almost any living organism has at least one form of parasite, inside or outside of its body (Pérez-Ponce de León and García-Prieto, 2001; Lafferty, 2014).

According to Pérez-Ponce de León *et al.* (2011), animal protozoa, helminths and arthropods have been erroneously perceived as having an irrelevant role in ecosystem functions, dynamics and pathogenicity in some cases. Nevertheless, parasites may play a more important ecological role than previously thought, particularly taking into account that almost 50–70% of all animal species are parasites (Sukhdeo, 2012). In addition, some parasitic diseases such as human helminthoses may have serious consequences for risk groups, particularly pregnant and breastfeeding women, children the elderly, and immunosuppressed people. Human helminthoses are classified as neglected diseases, because they have traditionally received comparatively little scientific and public health attention, and an insufficient budget has been dedicated to their control; concretely, only 1% of the worldwide science budget is invested in research on helminthoses, in spite of the high prevalence of these parasites (Hotez *et al.*, 2008). It is for these reasons that WHO recommended increasing the number of studies to assess the prevalence and intensity of helminth infections in humans and domestic animals (Hotez *et al.*, 2008).

Parasites from wild animals can be zoonotic emergent or re-emergent pathogens, posing a risk for human and animal health and thus causing a negative impact on global and local economies (Pérez-Ponce de León *et al.*, 2011; Gómez and Nichols, 2013). Further, parasites can produce negative impacts on endangered wildlife species, making them more susceptible to extinction by inducing behavioural changes, altering demographic and migration patterns and affecting their reproduction, and energetic balance by depleting host nutrients and inducing appetite loss (Gómez and Nichols, 2013). In contrast, some parasitic species can favour a long lifespan in the host population by reducing the mortality, hence modifying the ecosystem structure and function (Lafferty *et al.*, 2008).

Biological researchers proposed to study parasites and host–parasite interactions as a key to understanding ecosystem functions and structure. It is known that parasites can be indicators

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of the food chains and the evolutionary and demographic history of their host; moreover, they can point to migratory patterns, and host origin and distribution (Lafferty *et al.*, 2008; Gómez and Nichols, 2013). Parasites can also highlight environmental changes, they control host populations, and they play a large role on the maintenance of the genetic diversity and structure of communities (Pérez-Ponce de León *et al.*, 2011). Parasites have also been identified as having some beneficial effects for their hosts; for example, infections with enzootic, low pathogenic parasites can induce cross-immunity to related and more pathogenic parasites; moreover, some parasites can protect their host by removing heavy metals because they are able to bio-accumulate high quantities of them (Gómez and Nichols, 2013).

Current knowledge of parasites in Mexican wildlife

There is little information on the richness and diversity of wildlife parasites in Mexico, and it is especially scant in terms of epidemiological surveys. There are quite a few reasons for the lack of information. In the first place, because host biodiversity is great and this probably translates into a similarly high parasite richness and biodiversity. Secondly, because there is a lack of studies on most animal hosts (Pérez-Ponce de León and García-Prieto, 2001). In fact, it is probable that many parasite species will become extinct before they are discovered, and this is partly due to the insufficient numbers of local researchers dedicated to parasitology, compared with the high biodiversity of parasite.

In Mexico, helminths are the group of parasites that have received the most attention. Helminth richness is twice as high in the Neotropical compared with the Nearctic region. But it is important to mention that there also have been more studies in the Neotropical than in the Nearctic region (Pérez-Ponce de León and García-Prieto, 2001; García-Prieto *et al.*, 2010). The second parasitic group most frequently studied in Mexico is the arthropods, with records going back to the early 20th century (Whitaker and Morales-Malacara, 2005; Acosta-Gutiérrez, 2014). In contrast, descriptive studies on wildlife protozoans have historically attracted little attention in this country, which is reflected in the fact that there are no protozoa inventories and a lack of specialized scientific groups, except for protozoan species of medical importance, for example, the newly described *Blastocystis* sp. in Mexican howler monkeys (Villanueva-Garcia *et al.*, 2017*a*).

Helminthological studies in Mexican wildlife

Helminths have been intensively studied for 80 years by the local group of researchers of the Biology Institute of the Universidad Nacional Autónoma de México. Until 2011, 21% of Mexican vertebrate fauna – about 1145 animal species, including fishes – had been studied in search of helminths. One of the most interesting results was that each of the vertebrate species investigated was infected by at least one helminth species, and the total number of adult helminths registered was 1,900 (Pérez-Ponce de León *et al.*, 2011). However, the proportion of non-infected animals was not recorded in most studies, and for this reason, it was not possible to estimate helminth prevalence. Notwithstanding, it was estimated that animals had an average of 1.66 helminth specimens per individual host (Pérez-Ponce de León *et al.*, 2011; Lafferty, 2014). The number of helminth subgroups included 634 digenea, 271 cestodes, 538 nematodes and 87 acanthocephala. Fish are the most studied group of vertebrates with 1,039 helminth species identified, followed by mammals, birds, reptiles and amphibian with 308, 268, 241 and 162 helminth species, respectively. However, excluding fish (25.0% of 2,692 fish species have been studied), mammals are the most frequent group investigated (22.6% of 535 registered species), followed by reptiles (19% of 804 registered species), amphibian (17.5% of 361 registered species) and birds (12.2% of 1,096 registered species). Moreover, after fish, birds are the vertebrate group with the most numerous helminth species recorded, despite being the least studied host group (Pérez-Ponce de León *et al.*, 2011), which leads us to believe that such group has large helminth richness.

The majority of helminth studies have been carried out in central and southern Mexico, and the greatest sampling effort has been for digenetic trematodes (Pérez-Ponce de León *et al.*, 2007). In contrast, acanthocephala – included within the helminths group – is the subgroup that has received the least attention. According to García-Prieto *et al.* (2010), the total number of acanthocephalan species registered so far is 54 species, and another 22 species have not been classified. Acanthocephalan specimens have been found in 213 vertebrate host species, representing only 3.66% of the total Mexican vertebrates described. Again, infection prevalence is unknown because many of the studies do not indicate the number of wild animals analysed. Most records of the acanthocephala (49 species) occur in fishes, as it is the case with other helminth subgroups (García-Prieto *et al.*, 2010). The preponderance of fish studies is attributed to several reasons like fish having high commercial value, fish being the most diverse vertebrate group and fish are relatively easy to obtain and analyse in the laboratory (Pérez-Ponce de León *et al.*, 2011).

The increasing risk of extinction of many animal species has encouraged the development of the new scientific field named 'parasite conservation', which aims at investigating the co-extinction of parasitic taxa as a consequence of host extinction (Rózsa and Vas, 2014). In fact, some authors have pointed out that parasites can become extinct before their hosts, because some of them occur only in part of the host range and, in cases in which transmission is density-dependent, the host population drops below the threshold density required for the parasite to persist (Lafferty, 2014). In Mexico, this topic has become relevant, because two cases of co-extinctions of arthropod parasites have been registered (Mey and González-Acuña, 2000; Rózsa and Vas, 2014). Still, no helminth extinctions have been recorded, though the risk is ever-present, due to the intense loss of host species, most dramatically among amphibians and reptiles.

Mexico has 10% of worldwide reptiles and amphibian biodiversity (693 and 285 species, respectively), and 60.7% of amphibian and 53.7% of reptile species are indigenous. Until 2002, a total of 119 amphibian and 239 of reptile species were of recent description in Mexico, and 26 and 31.8% of them, respectively, were endemic species (Pérez-Ponce de León *et al.*, 2002). It is most likely that a great number of their helminth species are also endemic to Mexico.

Arthropod parasite studies in Mexican wildlife

The study of arthropods has mostly focused on those affecting mammals. Until 2005, at least 52.5% of all Mexican mammal species had been described as having one or more ectoparasite species. The most recent survey of ectoparasites was done by Whitaker and Morales-Malacara (2005), who mention 681 arthropod species, including 328 mesostigmatid and prostigmatid mite species, 47 ticks (Ixodoidea), 2 true bugs (Hemiptera), 141 fleas

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(Siphonaptera), 39 sucking lice (Psocodea: Anoplura), 70 chewing lice (Psocodea: Mallophaga), 48 bat flies (Diptera: Streblidae and Nycteribiidae) and one oestrid fly species (Diptera: Oestridae).

One of the best-studied arthropod parasites of Mexican vertebrate wildlife is the order Siphonaptera. Until 2014, 172 species had been registered, representing 6.8% of total flea species in the world. Most have been recorded in mammals, specifically in rodents. In the case of birds, all the flea species registered belong to the Ceratophyllidae family, and were found on Apodiformes and Galliformes (Acosta-Gutiérrez, 2014).

Finally, it must be noted that two chewing lice species from Mexican birds are considered to have become extinct. The first case corresponds to the louse *Aquiliogogus caracarensis* from the Guadalupe Caracara (*Polyborus lutosus*), an island raptor bird that was extinct in 1900. The second louse was *Colpocephalum californici* from the California condor (*Gymnogyps californianus*), which can only be found currently in captivity; this louse species became extinct due to ectoparasite treatments used as part of the *ex situ* condor conservation programme (Íñigo, 1999; Lafferty, 2014; Rózsa and Vas, 2014).

Protozoan parasite studies in Mexican wildlife

It is noticeable that no inventories of the protozoan group exist and the country lacks specialist scientific groups committed to the description of new protozoan species. The most common protozoan records are related to three zoonotic parasite species of medical importance, *T. gondii*, *T. cruzi* and *Leishmania mexicana*.

The protozoan *T. gondii* has been mainly investigated in rodents and wild felid species, probably because these hosts are of great importance in its life cycle. Antibodies to *T. gondii* were detected by the complement fixation test in opossums (*D. virginiana*), rock squirrels (*Spermophilus variegatus*), ringtails (*Bassariscus astutus*) and skunks (*Spilogale gracilis*) on a Mexico City natural reserve (Suzan and Ceballos, 2005). In northern Mexico, using an in-house indirect ELISA, antibodies were detected in two wild rodents (*Sigmodon hispidus* and *Liomys irroratus*) of five species analysed (Rendón-Franco *et al*., 2014*c*). Using the latex agglutination test, parasite antibodies were detected in two wild felid species (*Leopardus wiedii* and *Lynx rufus*), two wild canids (*Canis latrans* and *Urocyon cinereoargenteus*), a procyonid (*N. narica*) and an opossum (*Didelphis* sp.), and not in a feline species, *P. yagouaroundi* (Rendón-Franco *et al*., 2014*a*).

Infection by the trypanosomatids *T. cruzi* and *L. mexicana* has been investigated in several wild species. For example, *T. cruzi* was isolated in *D. virginiana* from Yucatan Peninsula, and was also detected by PCR in two procyonid hosts, *P. lotor* and *N. narica*, from Tabasco state (Ruiz-Piña and Cruz-Reyes, 2002; Martínez-Hernández *et al*., 2014). Moreover, *Trypanosoma* antibodies were detected in Mexican howler monkeys, by ELISA and by IFAT, and in a grey fox population (*U. cinereoargenteus*), by ELISA, from southern and central Mexico, respectively (Rovirosa-Hernández *et al*., 2013; Zamora-Ledesma *et al*., 2016). With regards to *Leishmania* spp., *L. mexicana* was detected by PCR in 13 of 41 bat species (*Pteronotus personatus*, *Artibeus jamaicensis*, *A. lituratus*, *Dermanura phaeotis*, *Carollia sowelli*, *Choeroniscus godmani*, *Desmodus rotundus*, *Glossophaga commissarisi*, *G. soricina*, *Leptonycteris curasoae*, *Phyllostomus discolor*, *Sturnira lilium* and *S. ludovici*) from six states of Mexico, and antibodies were detected by ELISA also on the two previously mentioned howler monkey species and grey fox population (Rovirosa-Hernández *et al*., 2013; Berzunza-Cruz *et al*., 2015; Zamora-Ledesma *et al*., 2016).

Blastocystis, a protozoan that recently gained medical importance (Vargas-Sanchez *et al*., 2015), was detected in the two above-mentioned Mexican howler monkeys in southern Mexico (Villanueva-Garcia *et al*., 2017*a*). It is also worthy of attention that a new *Entamoeba* clade has also recently been described in these primate species (Villanueva-Garcia *et al*., 2017*b*). Finally, a study in a wild rodent community revealed *Eimeria* spp. as the most common parasites in the faeces of six host species (*Baiomys taylori*, *Neotoma albigula*, *Onychomys arenicola*, *O. leucogaster*, *Perognathus flavus* and *Peromyscus maniculatus*) from northern Mexico (Rendón-Franco *et al*., 2014*b*).

Conclusions

In high biodiversity countries like Mexico, further wildlife parasitological studies are urgently needed to help prevent the emergence of new diseases in human and domestic animal populations, to avoid negative impacts on the fitness and dynamics of wild animal populations, and to mitigate co-extinction of endemic host and parasite species. The implementation of epidemiological studies of parasitic infections, by means of active and passive surveillance of wildlife populations will increase our knowledge and ability to design adequate programmes to improve human and animal health, biodiversity conservation programmes and international trade in Mexico. Research should focus on parasite biology and on the clinical implications of parasitic infections. Efforts should be directed toward geographic areas and parasite groups that have been least explored, such as the Nearctic zone and protozoans, respectively. For this to occur, it is essential to promote the development of research in parasitology and parasitic diseases through public funding following the One-Health approach.

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