



What do we know about the epidemiology of infectious diseases and parasites of free-ranging Neotropical ungulates? Needs and priorities

Review Article


Cite this article: Trillanes-Flores CE, Naranjo EJ, Ramírez-Marcial N, Pérez-Jiménez JC, Perera-Marín JG, Rojas-Maya S, Chávez C (2025) What do we know about the epidemiology of infectious diseases and parasites of free-ranging Neotropical ungulates? Needs and priorities. *Animal Health Research Reviews*, 1–11. <https://doi.org/10.1017/S1466252325000040>

Received: 31 January 2023
Revised: 26 February 2025
Accepted: 27 February 2025

Keywords:

deer; emerging infectious diseases; Latin America; peccaries; tapirs

Corresponding author: Eduardo J. Naranjo;
Email: enaranjo@ecosur.mx

Carlos E. Trillanes-Flores^{1,2}, Eduardo J. Naranjo¹ , Neptali Ramírez-Marcial¹, Juan Carlos Pérez-Jiménez³, José Gerardo Perera-Marín⁴, Susana Rojas-Maya⁴ and Carlos Chávez⁵

¹Departamento de Conservación de la Biodiversidad, El Colegio de la Frontera Sur, San Cristóbal de Las Casas, CS, México; ²Departamento de Ciencias de la Sustentabilidad, El Colegio de la Frontera Sur, Lerma, CM, México; ³Departamento de Reproducción, Facultad de Medicina Veterinaria y Zootecnia, Universidad Nacional Autónoma de México, Coyoacan, CX, México; ⁴Zoológico Regional Miguel Álvarez del Toro, Gobierno del Estado de Chiapas Secretaría de Medio Ambiente e Historia Natural, Tuxtla Gutiérrez, CS, México and ⁵Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Chiapas, Tuxtla Gutiérrez, CS, México

Abstract

Our analysis covers 122 scientific publications about health issues in free-ranging Neotropical ungulates produced between 1990 and 2022, with an emphasis on the epidemiology of infectious diseases and parasites. Most studies focus on parasitology (43.4%) and bacteriology (15.6%), while body condition (0.8%), toxicology (1.6%), virology (6.6%), and health assessments (6.6%) are less studied. Brocket deer (*Mazama americana* and *M. gouazoubira*), followed by peccaries (*Pecari tajacu* and *Tayassu pecari*), and the lowland tapir (*Tapirus terrestris*) were the most frequent species surveyed (61.4% of all publications). We detected considerably higher numbers of studies and health topics covered in Brazil ($n = 64$; 52.5% of the total) compared to other Latin American countries. We emphasize the need for further research focused on poorly known health aspects of Neotropical ungulates that have received little attention in the past, especially the Chacoan peccary (*Catagonus wagneri*), taruca deer (*Hippocamelus antisensis*), Northern pudu (*Pudu mephistopheles*), and the least known *Mazama* species. Ecotoxicology and pathology studies are necessary to evaluate the impact of agrochemicals and other human disturbances on Neotropical ungulate populations in the wild. We encourage further research on the human impacts and trends of change in the epidemiology of infectious diseases, parasites, and health status of Neotropical wild ungulate populations.

Introduction

The health of ungulate populations may be affected by three main processes (Deem *et al.*, 2001): (1) landscape transformation, (2) shifts in population dynamics, and (3) changes in the ecology of diseases. The first is related to land-use change, which contributes to habitat fragmentation, habitat loss, macro- and microclimatic change, and environmental pollution. These factors favour interactions among humans, livestock, and wildlife, which in turn contribute to increased disease transmission across species (Daszak *et al.*, 2000; Harvell *et al.*, 2002). The indirect effects of land-use change consist of environmental changes related to human activities (e.g., temperature increase and shifts in precipitation regimes) and stress on wildlife populations, making them more vulnerable to either known or new diseases (Deem *et al.*, 2001; Harvell *et al.*, 2002).

The second process affecting the health of wildlife species consists of shifts in population dynamics due to human activities such as high hunting pressure, illegal trade, and translocation of animals (Cunningham *et al.*, 2003; Kruse *et al.*, 2004). Careless wild species translocations and releases of domestic animals (potential asymptomatic hosts) may help disseminate new pathogens and diseases in locations where native populations lack immunity. Wildlife markets constitute ideal scenarios for epidemic outbreaks because diverse animal species from multiple locations usually are kept in small and filthy cages, where secretions, excretions, food, water, and parasites are exchanged among them (Aguirre *et al.*, 2020; Galindo, 2022). The risk of zoonosis increases as animals are killed, sold, and transported from these markets to nearby cities and villages, as probably happened with the recent Covid-19 pandemic (Galindo, 2022). Another possibility is that the animals arriving in a new habitat may not have the natural defences against endemic diseases (Cunningham *et al.*, 2003; Daszak *et al.*, 2000; Kruse *et al.*, 2004). The third main process consists of changes in disease ecology occurring when the equilibrium among the

© The Author(s), 2025. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.



host, the etiological agent, and their environment modifies. This can lead to 'endemic stability' loss, resulting in clinical disease (Deem *et al.*, 2001). The three processes described coupled with rapid human population growth, social inequality, deficient education, and weak environmental policies cause direct impacts on wildlife health and conservation (Valdez, 2014). These processes have synergic effects leading to increased poverty in rural communities, undervaluation, and higher demand for natural resources, resulting in higher impacts on wild populations, their habitats, and the environmental services they provide (Challenger and Dirzo, 2009).

The three families of Neotropical ungulates considered in this review (Cervidae, Tapiridae, and Tayassuidae) include 22 species, most of them frequently hunted for food and other purposes where they occur (Gallina, 2019). These species may be either recipients or transmitters of numerous parasitic, bacterial, and viral diseases with livestock, which could represent a conservation problem for wild populations (Kruse *et al.*, 2004; Romero *et al.*, 2008). The risk of global disease spread highlights the relevance of maintaining epidemiological vigilance and research on ungulate populations (Daszak *et al.*, 2000). This review aims to synthesize the state of knowledge on the epidemiology of infectious diseases, parasites, and health conditions of Neotropical ungulates. We offer evidence on information gaps and suggest directions for future research on their conservation.

Materials and methods

For this review, we compiled available information published on health aspects of Neotropical ungulate species between 1990 and 2022. We considered species distributed in the tropical areas of Mexico, Central America, South America, and the Antilles (Morrone, 2017). We excluded South American camelids (family Camelidae) from this analysis. We included papers in scientific journals, books and book chapters, theses and dissertations, proceedings of conferences and workshops, and technical reports. We also considered studies carried out in extensive Wildlife Conservation Units (UMA, in Spanish) and protected areas across Mexico. Our bibliographic searches were done using the resources available in the Web of Science, Scielo, Google Scholar, Research Gate, the National Consortium of Scientific and Technological Information (CONRICYT-Mexico), and the El Colegio de la Frontera Sur's library information system (SIBE-ECOSUR). The keywords used in our searches were: *Blastocercus*, *Catagonus*, *Dicotyles*, *Hippocamelus*, *Mazama*, *Neotropical*, *Odocoileus*, *Ozotoceros*, *Parachoerus*, *Pecari*, *Peccary*, *Pudu*, *Subulo*, *Tapirella*, *Tapirus*, *Tayassu*, and *Ungulates*. These keywords were linked through Boolean connectors (AND, OR, NOT) with the terms: *Body Condition*, *Conservation Medicine*, *Cortisol*, *Disease*, *Emerging Infectious Disease*, *Health Assessment*, *Microbiology*, *Parasite*, *Stress*, *Toxicology*, *Virus*, and their correspondent terms in Spanish and Portuguese.

We retrieved a total of 457 scientific publications, of which we discarded those focused on chemical contention, taxonomy, systematics, ecology (e.g., density, distribution, habitat use, and interactions, among others), papers in press or under review, and unfinished theses and dissertations. Although we considered publications including feral populations of domestic ungulates, we excluded studies done with captive animals or collection specimens unless they were very relevant to the discussion. After applying the above criteria, our final analyses consisted of 122 documents (see References and complementary list in Appendix S1).

The following data were retrieved from the documents reviewed: authors, year and type of publication, species, countries where the study took place, and topics covered. For studies carried out in Mexico, where both the Nearctic and the Neotropical regions converge, we only took those done in areas with Neotropical affinity (Morrone, 2014). The topics covered in publications were classified into seven categories: parasitology, bacteriology, virology, toxicology, pathology, body condition, and multi-themed studies. The publications titled 'health assessments' (those including hematic biometry, blood chemistry, and urine tests) were assigned to only one of the seven categories used. Studies including more than one topic (e.g., parasitology and bacteriology) were classified as 'multi-themed'. Our analysis incorporated studies documenting both the presence and absence of infectious agents. Finally, we discussed the needs and prospects for future research on health issues of Neotropical ungulates, with emphasis on cervids, peccaries, and tapirs.

Results

Of the 122 studies (1990–2022; see Table S1 in Supplementary material) on health issues of free-ranging Neotropical ungulates retrieved, 83 (68%) were published between 2011 and 2022, while 34 (27.9%) corresponded to the period 2001–2010, and only 5 (4.1%) were produced between 1990 and 2000 (see References and complementary list in Appendix S1). Most of the papers ($n = 101$; 55.5%) focused on deer species (Cervidae), while peccaries (Tayassuidae) and feral pigs (Suidae) were included in 45 studies (24.7%), and tapirs (Tapiridae) in 36 (19.8%). Two thirds ($n = 82$; 67.2%) of these publications covered more than one species, although only 15 (12.3%) covered more than one family. There were 19 ungulate species included in the studies reviewed, of which the red brocket deer (*Mazama americana*, $n = 27$; 14.8%), the brown brocket deer (*M. gouazoubira*, $n = 27$; 14.8%), the collared peccary (*Pecari tajacu*, $n = 20$; 11%), the lowland tapir (*Tapirus terrestris*; $n = 19$; 10.4%), and the white-lipped peccary (*Tayassu pecari*, $n = 19$; 10.4%) were the most frequent (Fig. 1).

Over a half of the published research on the health of free-ranging Neotropical ungulates between 1990 and 2022 was done in Brazil ($n = 64$; 52.5%), followed by Mexico ($n = 11$; 9%), Chile ($n = 9$; 7.4%), Argentina ($n = 7$; 5.7%), and Peru ($n = 7$; 5.7%). These five countries accounted for about 80% of all publications, while other eight countries (Bolivia, Colombia, Costa Rica, Ecuador, Guatemala, Trinidad, Uruguay, and Venezuela) and the territory of French Guiana produced the remainder (Fig. 2). No studies conducted in Belize, El Salvador, Guyana, Honduras, Nicaragua, Panama, Paraguay, Suriname, and the Antilles (except for Trinidad) were retrieved in our searches.

The majority (82.8%) of the reports were published in scientific journals, while dissertations and theses represented 8.2%. The remainder 9% was composed of book chapters, proceedings of conferences and workshops, and technical reports. The most frequent themes covered in the publications reviewed were parasitology ($n = 53$; 43.4%), bacteriology ($n = 19$; 15.6%), multi-themed studies ($n = 17$; 13.9%), and pathology ($n = 14$; 11.5%). Studies focused on health assessment, virology, toxicology, and body condition accounted for the remainder 15.5% (Table 1). The bacteria *Leptospira* spp. and *Brucella* spp., ticks, helminths, and bluetongue virus were the most frequently recorded organisms in Neotropical ungulates (Table 2, see References and complementary list in Appendix S1).

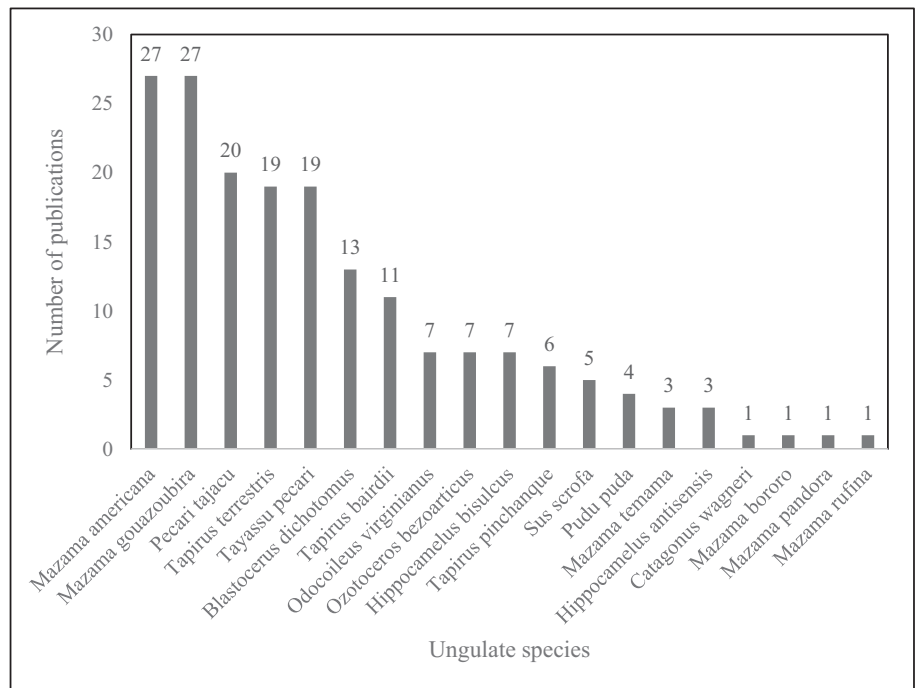


Figure 1. Number of publications on the health of free-ranging Neotropical ungulates in which each species appears ($N = 122$, 1990–2022). Most publications (67.2%) included more than one species.

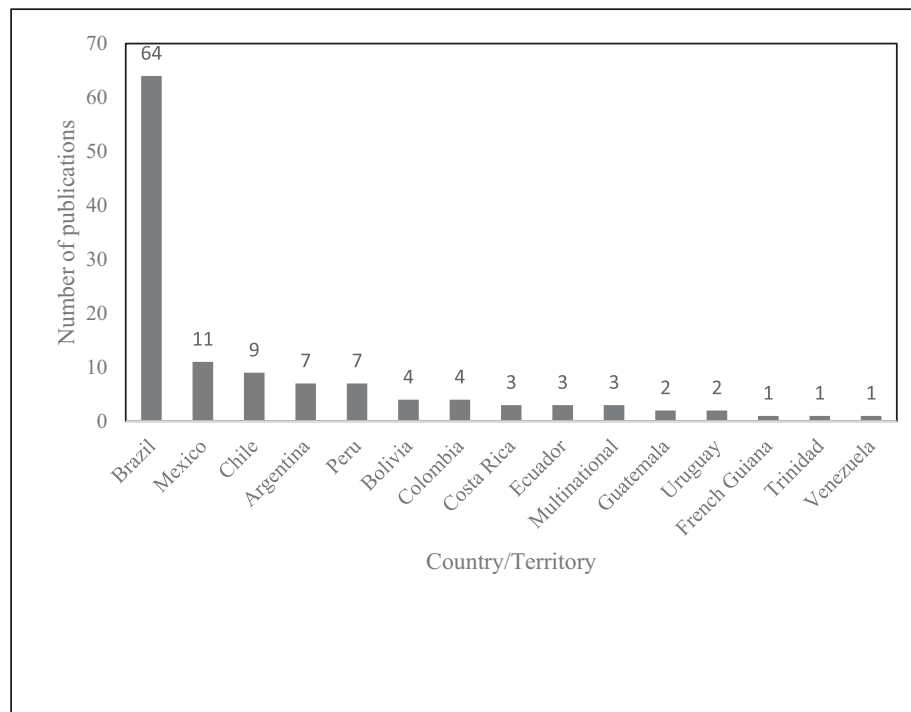


Figure 2. Number of publications on the health of free-ranging Neotropical ungulates by country/territory ($N = 122$, 1990–2022).

Tapirs (*Tapirus spp.*)

The lowland tapir (*T. terrestris*) has been widely surveyed across Brazil, including health assessments of free-ranging populations, the seroprevalence of infectious diseases (Fernandes *et al.*, 2020; May-Junior, 2011; Medici *et al.*, 2014), and parasite evaluations (Lima *et al.*, 2013; Malzoni *et al.*, 2010; May-Junior, 2011). At least two long-term surveys (1996–2021) have been conducted on tapirs in the Brazilian Atlantic Forest, the Cerrado, and the Pantanal

(Labruna *et al.*, 2021; Medici *et al.*, 2014). Fernandes *et al.* (2020) compared the results of these surveys to their own obtained in the Brazilian Cerrado, showing that the tapirs of this region had more health problems than those of the Atlantic Forest and the Pantanal, probably due to a higher human disturbance present in the Cerrado. *Leptospira* spp., helminths (*Agriostomum* spp., *Parascaris* spp., *Strongyloides* spp., *Trichostrongylus* spp., *Strongylus* sp.), ticks (*Amblyomma* sp., *Haemaphysalis* sp., *Rhipicephalus* sp.), bluetongue virus (Reoviridae), *Trypanosoma terrestris*, and *Toxoplasma gondii*

Table 1. Number of publications on the health of free-ranging Neotropical ungulates by theme ($N = 122$, 1990–2022)

Theme	<i>N</i>	%
Parasitology	53	43.4
Bacteriology	19	15.6
Multi-themed	17	13.9
Pathology	14	11.5
Health assessment	8	6.6
Virology	8	6.6
Toxicology	2	1.6
Body condition	1	0.8
Total	122	100

Table 2. Etiological agents and frequent diseases recorded in publications on the health of free-ranging Neotropical ungulates (1990–2022)

Etiological agent	<i>Cervidae</i>	<i>Tayassuidae</i>	<i>Suidae</i>	<i>Tapiridae</i>
<i>Brucella</i> sp.		x		
<i>Leptospira</i> sp.	x	x	x	x
Protozoans	x	x	x	x
Helminths	x	x	x	x
Ticks		x	x	x
AD		x		
BT				x
EEE				x
FMD	x			
IBR				x
PCT-2		x		
PP				x
VS		x		
WEE				x

AD = Aujeszky's disease; BT = bluetongue; EEE = East equine encephalitis; FMD = foot and mouth disease; IBR = infectious bovine rhinotracheitis; PCT-2 = porcine circovirus type 2; PP = porcine parvovirus; VS = vesicular stomatitis; WEE = West equine encephalitis.

have been the most frequently detected etiological agents in the lowland tapir (Malzoni *et al.*, 2010; May-Junior, 2011; Lima *et al.*, 2013; Navas *et al.*, 2019; Table 2).

The only published assessment of parasites present in free-ranging mountain tapirs (*T. pinchaque*) was done by Bernal *et al.* (2008) in the Nevados National Park in the Central Andes of Colombia. These authors collected blood samples for haematology and identified the ticks *Amblyomma multi-punctum* and *Ixodes scapularis*. For Baird's tapirs (*T. bairdii*), parasitological evaluations have revealed the presence of the nematods *Lacandoria* sp., *Neomurshidia* sp., *Bunostonum* sp., *Agriostomum* sp., *Brachylumulus* sp., *Strongylus* sp., *Trichostrongylus* sp., *Nematodirus* sp., *Tapironema* sp., *Trichonema* sp., *Tziminema unachi*, and the protozoans *Eimeria* sp. and *Balantidium* sp. (Cruz *et al.*, 2006; Güiris *et al.*, 2017; Méndez, 2017; Pérez-Flores *et al.*, 2019; Romero *et al.*, 2008).

There have been few pathology assessments describing diseases on free-ranging tapirs. Navas *et al.* (2019) published a study recording their findings on the pathology of 35 tapirs killed on roads of the Brazilian Cerrado. They found degeneration in adrenal glands, necrosis, and loss of fascicular and reticular cells with replacement by fibrosis and cortical atrophy, interstitial pneumonia, glossitis, lung anthracosis, colitis, cholangitis, and pericholangitis in several of the individuals examined. Intestinal parasitosis seems to be common in wild tapirs (Navas *et al.*, 2019). Tapirs killed in collisions along roads have also been subject of toxicological studies in Mato Grosso do Sul, Brazil (Fernandes *et al.*, 2018). Among the main toxic compounds detected in these ungulates are the organochlorines, organophosphates, pyrethroids, carbamates, and minerals such as lead, copper, manganese, and cadmium. In a second study, the same authors found pesticides and heavy metals linked to commercial farming in the Cerrado (Fernandes *et al.*, 2020). No other published surveys on this matter were found for tapirs across the Neotropics.

Peccaries (*Catagonus wagneri*, *Pecari tajacu*, and *Tayassu pecari*) and feral pigs (*Sus scrofa*)

Research on the epidemiology of peccary species has been done particularly in Brazil and other South American countries (see References and complementary list in Appendix S1). *Leptospira* spp., *Brucella* spp., helminths, and ticks have been the more frequently studied infectious agents in peccaries of Bolivia, Brazil, and Colombia (Ferreira, 2008; Karesh *et al.*, 1998; Montenegro *et al.*, 2018; Table 2). The seroprevalence of leptospirosis was reported in white-lipped peccaries of the Brazilian Pantanal, where these ungulates interacted with livestock (De Freitas *et al.*, 2010). Brucellosis has also been detected in white-lipped peccaries of the Pantanal (Real *et al.*, 2010) and Quedas do Iguaçu, Brazil (Mangini *et al.*, 2004). These surveys were focused not only on peccaries but also on feral pigs, cows (*Bos indicus*), dogs (*Canis lupus familiaris*), jaguars (*Panthera onca*), sheep (*Ovis aries*), horses (*Equus caballus*), and domestic pigs that tested positive to brucellosis and leptospirosis in Pontal do Paranapanema, Brazil (Ferreira, 2008).

Montenegro *et al.* (2018) detected leptospirosis in collared peccaries (prevalence = 78%) and feral pigs (prevalence = 100%) at several study sites in Colombia, while Lord and Lord (1991) isolated *Brucella* spp. from lymph nodes and spleens of collared peccaries from Venezuela. Other bacteria found in lung tissues of white-lipped peccaries and collared peccaries from Brazil were *Pasteurella multocida* and *Mycoplasma hyopneumoniae* (Martins *et al.*, 2014). Regarding viral diseases, Montenegro *et al.* (2018) detected classic porcine fever, porcine circovirus type 2, and vesicular stomatitis in peccaries and feral pigs of Colombia. However, they did not find Aujeszky's disease in their samples. In Brazil, Mangini *et al.* (2004), Paes *et al.* (2013), and Martins *et al.* (2014) found porcine circovirus type 2, porcine herpesvirus type 1, and Aujeszky's disease in both peccaries and feral pigs.

In Bolivia, Karesh *et al.* (1998) examined the parasites and infectious diseases present in white-lipped peccaries at Noel Kempff National Park. They found evidence of *Leptospira* sp., *Mycoplasma hyorhinus*, Aujeszky's disease, vesicular stomatitis, vesicular exanthema of the pig, and San Miguel's marine lion virus. All peccaries (both white-lipped and collared) sampled by Karesh *et al.* (1998), and by Rodríguez *et al.* (2019) in Bolivia were infested by ticks (*Amblyomma* sp.). A similar case was reported for the Chacoan peccary (*Catagonus wagneri*) in Salta, Argentina, where Nava *et al.* (2009) detected *Amblyomma boeroi* in 14 carcasses. Helminths in

peccaries have only been reported by Carlos *et al.* (2008) in Peru, who identified *Ascaris* sp., Ancylostomatidae, spiruroid type, and the trematode *Paragonimus* sp.

In Mexico, Romero *et al.* (2008) detected the nematodes *Globocephalus usosubulatus*, *Parabronema pecariae*, and *Texicospirura turki*; the trematode *Paramphistomum* sp., and the cestode *Moniezia benedeni* in both collared peccaries and white-lipped peccaries of the Lacandon Forest. The only protozoans reported for wild peccaries, collared peccaries, and feral pigs in the Neotropics are *Trypanosoma cruzi* and *T. evansi*, which were identified by Herrera *et al.* (2008) in Brazil. These authors concluded that the parasitemia by *T. evansi* could have been due to the stress resulting from prolonged droughts and habitat loss. Being social species, peccaries and pigs may be good reservoirs of these parasites in both natural and humanized settings. Finally, the only survey to assess the presence of toxic compounds in peccaries was conducted by Karesh *et al.* (1998) in Bolivia, with negative results.

Cervids (*Blastocerus dichotomus*, *Hippocamelus* spp., *Mazama* spp., *Odocoileus virginianus*, *Ozotoceros bezoarticus*, and *Pudu* spp.)

Several epidemiological studies on free-ranging deer of South America were published between 1990 and 2022 (see References and complementary list in Appendix S1). Deem *et al.* (2004) reported the presence of *Amblyomma* spp. ticks, *Lipoptena mazamae* (Hippoboscidae) flies, and an unknown louse species in grey brocket deer (*Mazama gouazoubira*) of Bolivia. These authors reported the presence of *Leptospira interrogans*, bovine respiratory syncytial virus, and probably, the epizootic haemorrhagic disease virus (EHDV). The nematodes, cestodes, and protozoans *Trichuris ovis*, *Paramphistomum* spp., *Schistosoma* sp., *Moniezia* sp., and *Eimeria* sp. have also been found in grey brocket deer of Bolivia (Beltrán *et al.*, 2009; Deem *et al.*, 2004). In Brazil, Szabó *et al.* (2003) found that the parasitic load and the number of tick species increased in pampas deer (*Ozotoceros bezoarticus*) after their habitat shrunk because of the flooding caused by the Puerto-Primavera dam. The nematodes *Physocephalus sexalatus*, *P. lassancei*, *Texicospirura turki*, and *Pygarginema verrucosa* have also been detected in brocket deer (*Mazama americana* and *M. gouazoubira*), and the pampas deer of the Brazilian Pantanal (Hoppe *et al.*, 2010; Silva *et al.*, 1999). Polymerase Chain Reaction (PCR) tests have allowed determining the incidence of *Theileria* sp., *Babesia* sp., *Anaplasma* sp., *Brucella abortus* y *Leptospira interrogans* in wild brocket deer (*M. gouazoubira*), pampas deer, and swamp deer (*Blastocerus dichotomus*) in Brazil (Da Silveira *et al.*, 2011; Mathias *et al.*, 1999; Mongruel *et al.*, 2017). Regarding virology assessments, the bluetongue virus and the deer chronic wasting disease were detected in Brazil by Mazzoni *et al.* (2018), and Ribeiro *et al.* (2017). Similarly, pathological retrospective studies and clinical cases in free-ranging Brazilian cervids have been published by Cunha *et al.* (2014), Echenique *et al.* (2018), and Navas *et al.* (2019). No publications on the epidemiology or parasites of *Mazama bricenii*, *M. chunyi*, and *M. nana* were found in our searches.

Some studies have been done about parasites and diseases of the huemul deer and the taruca deer (*Hippocamelus* spp.). Analysing faeces of the Patagonian huemul deer (*Hippocamelus bisulcus*) collected in the Aysen and Magallanes regions of southern Chile, Hinojosa *et al.* (2019) found eggs of *Moniezia* sp., *Nematodirus* sp., *Eimeria* spp., and Strongyle-type nematods. In the same area

and for the same deer species, Vila *et al.* (2019) observed foot disease probably caused by poxvirus, and Hernandez *et al.* (2019) isolated the bacteria *Echinococcus granulosus* from pulmonary tissue and found larvae of *Taenia hydatigena*. Previously, Hinojosa *et al.* (2014) observed in the same area a huemul female with numerous melanotic tumours diagnosed as fibroma, while Morales *et al.* (2017) detected the presence of *Corynebacterium pseudotuberculosis* in abdominal abscesses of two huemul specimens. In southern Argentina, Reissig *et al.* (2020) identified the protozoan *Sarcocystis* sp., while Flueck and Smith-Flueck (2017) documented severe osteopathologies and muscle atrophy in seven huemul deer, probably due to a selenium and iodine-deficient diet. The only study retrieved about parasites of the taruca deer (*Hippocamelus antisensis*) was conducted by Gomez-Puerta *et al.* (2016) who identified the helminths *Trichostrongylus axei*, *Mazamastrongylus* sp., and *Taenia hydatigena* in a specimen from the southern Peruvian Andes.

Considerably fewer publications exist on the Southern pudu (*Pudu pudu*). Oyarzun *et al.* (2018) found the nematode *Dictyocaulus eckerti* in lungs of pudu from southern Chile, while recently, Santodomingo *et al.* (2022) detected the protozoan *Babesia* sp. and the bacteria *Borrelia* sp. in pudus of Chiloé Island. In Argentina, Reissig *et al.* (2020) identified infection by the protozoan *Sarcocystis* sp. on pudus from the Patagonian National Parks. The only virological study on wild pudus was conducted by Hidalgo *et al.* (2022), who found caprine herpesvirus-2 present in samples of dead animals from southern Chile. No publications on the epidemiology or parasites of the Northern pudu (*Pudu mephistophiles*) were retrieved from our searches.

Several surveys on the infectious diseases and parasites of cervids have been done in Mexican extensive wildlife management units (UMA). González (2001) and Barranco (2016) detected protozoans and nematodes of the genus *Eimeria* sp., *Otertagia* spp., *Cooperia* spp., *Moniezia* spp., *Haemeonchus* spp., *Trichostrongylus* spp., *Trichuris* spp., and *Capillaria* spp. in white-tailed deer. Mukul *et al.* (2014) identified the presence of the nematode *Strongylus* sp., ticks (*Amblyomma cajennense*), fleas (*Pulex irritans*), lice (*Gliricola porcelli*), and flies (*Lipoptenena* sp.) in brocket deer (*M. temama*) and white-tailed deer of the Yucatan Peninsula. In the same region, Ojeda *et al.* (2019) detected *Ehrlichia chaffeensis*, *Anaplasma phagocytophilum*, *A. odocoilei*, *Amblyomma mixtum*, *A. parvum*, *A. cf. oblongoguttatum*, *Ixodes affinis*, *Ripicephalus microplus*, *R. sensu lato*, and *Haemaphysalis juxtakochi* in brocket deer and white-tailed deer.

Discussion

In the context of increasing demand to feed the global human population, interactions between wildlife and livestock are becoming more frequent, which heightens the risk of pathogen transmission among wild animals, livestock, and humans (Gordon IJ, 2018; Jones *et al.*, 2013). Effective biosecurity measures that are cost-effective are required to control various risks (Jori *et al.*, 2021). The emergence of virus-borne diseases such as AIDS, Ebola, Avian Influenza, and antibiotic-resistant bacteria during the twentieth century, and more recently, the COVID-19 pandemic highlight the need for cooperative work among physicians, veterinarians, economists, sociologists, anthropologists, environmentalists, and other specialists (Cook *et al.*, 2004; Daszak *et al.*, 2000). In 2004, the Wildlife Conservation Society (WCS) emphasized the relevance of understanding the ecology of emerging wildlife diseases

under the 'One World-One Health' approach. This approach proposes the integration of medicine and ecosystem health through 12 'Manhattan Principles' seeking to prevent disease and maintain ecosystem health for the benefit of society, wildlife, and livestock (Gibbs, 2014). Neotropical wildlife species are food sources for rural societies throughout Latin America (e.g., Naranjo *et al.*, 2004; Ojasti, 2010); therefore, we need to understand the relationship between the health issues of wildlife, livestock, and people.

Although the majority (68%) of available publications on the epidemiology, parasites, and health conditions of Neotropical ungulates were produced in the last decade (2012–2022), knowledge is clearly uneven among topics, species, and countries. Out of the 33 countries in Latin America and the Antilles, research on the subjects of this review in free-ranging ungulates has been conducted in only 13 countries. Among these, Brazil, Mexico, Chile, Argentina, and Peru have produced 80% of all publications. The studies done in Brazil (52.5% of the total) have included parasitology, bacteriology, virology, and toxicology (Fernandes *et al.*, 2020, 2018; Lima *et al.*, 2013; Malzoni *et al.*, 2010; May-Junior, 2011; Medici *et al.*, 2014). Parasitology has been the most frequent field of study in Mexico (Cruz *et al.*, 2006; Güiris *et al.*, 2017; Romero *et al.*, 2008). In Argentina, Bolivia, Chile, and Colombia, researchers have covered a wider array of topics, such as general health assessments, bacteriology, virology, and parasitology in peccaries and deer (e.g., Bernal *et al.*, 2008; Deem *et al.*, 2004; Flueck and Smith-Flueck, 2017; Hinojosa *et al.*, 2019; Karesh *et al.*, 1998; Montenegro *et al.*, 2018; Rodríguez *et al.*, 2019; Suárez *et al.*, 2008).

It is unclear if the differences in government spending on healthcare and research explain the inequality in the number and thematic coverage of retrieved publications because each country recognizes different priorities (Arriagada *et al.*, 2005). In most countries, human health institutions are still separated from animal health agencies despite the potential benefits of the One Health approach (Gibbs, 2014; Zinsstag *et al.*, 2009). This makes it more difficult to determine if research funding for zoonotic diseases is sufficient.

Studies on free-ranging wildlife have logistic constraints (i.e., capture and handling of animals, hiring of specialized field guides, access to the study area, and sample collection and transport; De Thoisy *et al.*, 2003). Besides, epidemiologic monitoring of zoonotic diseases in wild host species may be difficult to apply in Neotropical countries because of the need for multidisciplinary task forces including veterinary doctors, ecologists, zoologists, epidemiologists, geographers, and mathematicians, among others (Gil and Samartino, 2001). The lack of continuity in political and financial incentives to train and update specialists makes it difficult for many Latin American countries to be self-sufficient in the generation of information about the health of their wildlife species (Schütz *et al.*, 2008). Considering the above, it looks pivotal to identify the drivers of emerging infectious diseases and establishing an epidemiological monitoring system on wildlife populations across the Neotropics.

Most research and publications on wild ungulates in Brazil have been done in public universities and research centres such as São Paulo University, Oswaldo Cruz Foundation, Institute of Ecological Research (IPE, in Portuguese), the Brazilian Institute of Conservation Medicine, and the IUCN Tapir Specialist Veterinary Group. Perhaps the outstanding biodiversity and large size of Brazil's tropical ecosystems (especially the Amazon) draw more interest and funding for research by national and international agencies, which favours higher scientific output. In other Latin American countries, almost all research on the health of ungulates

has been done in public institutions. On the other side, remarkable differences in the distribution and density of Neotropical ungulate populations across species and habitats could be playing important roles in the amount of research devoted to assessing their epidemiology of infectious diseases, parasites, and general health conditions. This may help to explain why only four widely distributed species (red brocket deer, collared peccary, white-lipped peccary, and lowland tapir) have received more attention (54.7% of the publications reviewed) than the other 18 Neotropical ungulate species combined. After our review, we identified the following information gaps and needs for further studies on the health of Neotropical ungulates.

Tapirs

The environmental factors and the complex biological cycles determining the selective presence of certain pathogens in some wildlife species have not yet been fully understood. For example, there are places where peccaries and tapirs coexist with livestock. However, brucellosis has been detected in peccaries, but not in tapirs. Similarly, antibodies against diseases such as leptospirosis and toxoplasmosis have been found in coexisting tapirs and livestock (Malzoni *et al.*, 2010; Mangini *et al.*, 2012). Because of that, it is required that future epidemiological research initiatives consider the size of habitat fragments as well as ungulate and livestock population densities. This could help identifying why certain ungulate species are more prone than others to get infected by pathogens. For both Baird's and mountain tapirs, it will be needed to investigate the seroprevalence or isolation of infectious agents similarly to what has been done with the lowland tapir.

The priority diseases to be investigated in Neotropical ungulates should be those that are relevant for public health, the conservation of wild species, and those present in livestock at a regional scale (Quse and Fernandes, 2014). For example, leptospirosis is transmitted where livestock interacts with free-ranging ungulates and has been detected in tapirs of Brazil and Costa Rica (De Freitas *et al.*, 2010; Hernandez-Divers *et al.*, 2005). Thus, it should be a priority to assess the effects of these diseases in tapirs across Latin America. Other diseases potentially threatening tapir populations occurring nearby human settlements are encephalitis (i.e., Nile, East equine, and West equine), whose vector is present in southeastern Mexico and may affect equines and humans (Ulloa *et al.*, 2009). Horses have been used as sentinels of the Equine infectious anaemia in Guatemala and a potential threat for Baird's tapirs has been identified (Lepe *et al.*, 2018). Therefore, the search for antibodies against this disease in wild tapirs may constitute a good opportunity for doing research.

Few studies have focused on the analysis of the relationship between disease intensity and habitat features, for instance, the parasite composition on tapir faeces and their relationship with the vegetation cover (Alvarado, 2018). The environment can play a fundamental role in preserving certain parasites and commensals in tapir droppings (Güiris *et al.*, 2009). This is an opportunity to do relevant research for conserving these ungulates, especially in highly disturbed sites.

Peccaries and feral pigs

Feral pigs have received attention as potential disease vectors for livestock and wild ungulates in Brazil because many of them were introduced during the Paraguay War (Medici *et al.*, 2014; Paes *et al.*, 2013). Similarly, Montenegro *et al.* (2018) found evidence

of transmission of leptospirosis between feral pigs and peccaries in Colombia. Nonetheless, no epidemiological studies have been done on feral pigs in Mexico, even though this species is already present in the southeastern part of the country (Hidalgo-Mihart *et al.*, 2014; Weber, 1995). In contrast, Mérida (2015) found presence of brucellosis (30% of the samples) and leptospirosis (34%) in white-lipped peccaries and feral pigs of Uaxactún, northern Guatemala. All feral pigs examined were heavily infested by ticks. The ecological and sanitary impact of these pigs on wild ungulate populations and their habitats across southern Mexico and Central America would constitute another research need to be attended to whenever possible.

Toxicological research on peccaries and feral pigs has been barely done in Latin America. Peccaries, tapirs, and deer sometimes feed on corn, soy, and other plantations across Latin America (Lima *et al.*, 2019; Romero *et al.*, 2006; Ruiz *et al.*, 2014; Serrano *et al.*, 2021), so they could be exposed to toxic compounds such as glyphosate and other pesticides. Therefore, there is a high probability to detect these toxic compounds in free-ranging ungulates across Colombia, where great amounts of herbicides were used since the mid-1980s to eradicate illegal crops (Idrovo, 2015). On the other side, analyses of hormones as stress indicators in ungulates have been applied in captive peccaries to assess the effects of density and space availability on their levels of cortisol (Mangini *et al.*, 2012; Montes *et al.*, 2009, 2012; Nogueira-Filho *et al.*, 2012). However, there are no published surveys of these hormones on peccaries in the wild.

Cervids

There have been evidences of ectoparasites, endoparasites, bacteria, and viruses, such as the bovine respiratory syncytial virus, and the EHDV in South American cervids (see Beltrán *et al.*, 2009; Da Silveira *et al.*, 2011; Deem *et al.*, 2004; Hoppe *et al.*, 2010; Mayor *et al.*, 2007; Mongruel *et al.*, 2017, and many other references in Appendix S1). Nevertheless, research describing shifts in the parasite composition after human disturbance, and pathological studies on Neotropical cervids are very scarce (Cunha *et al.*, 2014; Echenique *et al.*, 2018; Hinojosa *et al.*, 2014; Navas *et al.*, 2018; Szabó *et al.*, 2003).

In the case of Mexico, closeness to the United States, climatic conditions, and socio-economic factors impose remarkable differences in natural resource management between the north and the south of the country. While large numbers of private ranches and extensive UMAs (many with exotic ungulate species for sport hunting) prevail in the north, communal land ownership, subsistence hunting, and a complex sociocultural environment are more frequent in the south, which complicates the functioning of the UMA system originally designed for the north (Weber *et al.*, 2006). This disparity is mirrored in the body of published information about Mexican ungulates, where the white-tailed deer and the mule deer (*Odocoileus hemionus*) have been a lot more studied in northern Mexico than all wild ungulate species in the Neotropical portion of the country.

In northern Mexico, the bluetongue virus, *Boophilus* sp. ticks, EHDV, bovine diarrhoea virus, protozoans (*Theileria cervi*), and the bacteria *Borrelia burgdorferi*, *Brucella abortus*, *Brucella melitensis*, and *Leptospira* sp. have been found in mule deer and white-tailed deer populations (Cantu *et al.*, 2008; Contreras *et al.*, 2007; Martinez *et al.*, 1999; Pavón *et al.*, 2020). Although the work by Cantu *et al.* (2008) on white-tailed deer was not done within

the Neotropical region, it is one of the few in which some environmental factors were analysed as drivers of the host's response to an etiological agent.

In contrast, in central and southern Mexico, there have been a very few reports of ectoparasites, endoparasites, and rickettsiae in both free-ranging and UMA deer (Barranco, 2016; González, 2001; Mukul *et al.*, 2014; Ojeda *et al.*, 2019; Romero *et al.*, 2008). Hence, it is necessary to increase the quest for etiological agents that have already been described in the north of the country to create an epidemiological map of them.

Prospects for future research

While there have been many publications on health issues of Neotropical free-ranging ungulates, most of them have only focused on describing microorganisms or their seroprevalence. However, there are still important information gaps that need to be addressed, particularly in fields like environmental toxicology. Even diseases that are traditionally considered relevant for wildlife, livestock, and humans, such as rabies, require further study in this region. According to an epidemiological study based on official databases, only 2.6% of the 1,037 cases of rabies detected between 2001 and 2013 were found in white-tailed deer (Bárceñas *et al.*, 2015). However, these authors concluded that rabies had been under-registered and had spread to new areas. Castellanos and Venegas (2015) photographed a lowland tapir being bitten by false vampire bats (*Desmodus rotundus*) in Yasuni National Park, Ecuador, showing that wild ungulates may be exposed to rabies at any time.

Orta *et al.* (2018) discovered that red brocket deer, collared peccaries, and lowland tapirs consumed soil contaminated with oil in the Peruvian Amazon. Since these animals are hunted for food in the region, it is crucial to investigate whether geophagy could be a means through which humans are exposed to highly toxic substances such as heavy metals, radioactive isotopes, and hydrocarbons. Therefore, investigating the impact of the oil industry and pesticides on the health of wildlife and people in the Neotropics is highly relevant.

Accessing free-ranging ungulates for clinical examination and sampling is a primary challenge in their health research, leading to many surveys utilizing hunted specimens. (Deem *et al.*, 2004; Lord and Lord, 1991; Romero *et al.*, 2008). An alternative to this limitation would be studying livestock populations as models of infectious diseases in conditions like those of wild ungulates, considering the adaptability of the microorganisms to their hosts. In order to better understand the dynamics of diseases, nomadic and free-ranging livestock herds can serve as useful models for monitoring, as suggested by various studies (Abril-Galve *et al.*, 1994; Alberghini, 2019; Centelles *et al.*, 2021).

In southeastern Mexico, Díaz (2006) and Martínez-Mota *et al.* (2007) found higher cortisol levels in the faeces of black howler monkeys (*Alouatta pigra*), jaguars (*Panthera onca*), and pumas (*Puma concolor*) occupying disturbed habitats compared to those using pristine areas. These kinds of studies have not yet been done in Neotropical ungulates that require large tracts of tropical forest in relatively good condition (e.g., tapirs and white-lipped peccaries; Naranjo *et al.*, 2015). Further research is necessary to determine the impact of habitat variables and human disturbance on parasitic load and physiological stress in these species.

In this review, we found that most of the research published between 1990 and 2022 corresponded primarily to parasitological, bacteriological, multi-themed, and pathological surveys on deer,

peccaries, and tapirs. We emphasize the need for further research focused on poorly known epidemiological aspects of Neotropical ungulates that have received little attention in the past, especially the Chacoan peccary, the taruca deer, pudus, the least known *Mazama* species (i.e., *M. bororo*, *M. bricenii*, *M. chunyi*, *M. nana*, and *M. rufina*) and wild camelids (i.e., *Lama guanicoe* and *Vicugna vicugna*). In particular, ecotoxicological and pathological studies are needed to assess the effects of agrochemicals and other human disturbances (e.g., feral species) on wild ungulate populations throughout the Neotropical region. It is also important to increase the reach and depth of epidemiological knowledge for wild ungulates out of Brazil. Funding for research and training of local specialists (especially virologists) will be essential for that purpose. Nonetheless, modest surveys on the parasitology, bacteriology, and haematology of local ungulate populations could be promoted in the short term in countries such as Belize, Cuba, Dominican Republic, El Salvador, Guyana, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Puerto Rico, and Suriname, where some research groups and basic infrastructure already exist. Those studies would help to better understand the roles of ecological mechanisms and anthropic processes influencing the health of these mammals. Improving and expanding our knowledge on these elements, particularly in species and countries with the highest information gaps, should be a priority for their sustainable management and conservation.

Supplementary material. The supplementary material for this article can be found at <https://doi.org/10.1017/S1466252325000040>.

Acknowledgements. We would like to express our gratitude to Mexico's National Council for Science and Technology (CONACYT) and El Colegio de la Frontera Sur (ECOSUR) for providing the first author with a scholarship to pursue doctoral studies. Two anonymous reviewers provided insightful comments to improve this manuscript and Gregory Jones edited the English.

Competing interests. The authors declare none.

Disclosure statement. The authors report there are no competing interests to declare.

References

- Abril-Galve F, Lozano MV and Martínez E (1994) Estudio epidemiológico de la enfermedad Visna-Maedi en ganado ovino en la zona veterinaria de Cedrillas (Teruel). *Mundo Ganadero* 2, 46–50.
- Aguirre AA, Catherina R, Frye H and Shelley L (2020) Illicit wildlife trade, wet markets, and COVID-19: Preventing future pandemics. *World Medical Health Policy* 12(3), 256–265.
- Alberghini JP (2019) Caracterización de enfermedades del ganado para su control y prevención, en productores trashumantes de la provincia de Neuquén. Master's thesis, Universidad Nacional del Comahue, Rio Negro, Argentina.
- Alvarado MC (2018) Presencia de parásitos gastrointestinales en la danta centroamericana (*Tapirus bairdii*) y la relación de la composición de parásitos en sus letrinas con variables ambientales en la región noreste de la cordillera de Talamanca, Costa Rica. PhD Dissertation, Universidad Nacional de Costa Rica, Heredia, Costa Rica.
- Arriagada I, Aranda V and Miranda F (2005) *Políticas Y Programas de Salud En América Latina. Problemas Y Propuestas*. Santiago, Chile: CEPAL, UN.
- Bárceñas I, Loza-Rubio E, Zendejas-Martínez H, Luna-Soria H, Cantó-Alarcón GJ and Milián-Suazo F (2015) Comportamiento epidemiológico de la rabia parálitica bovina en la región central de México, 2001–2013. *Revista panamericana de Salud pública/Panamerican Journal of Public Health* 38(5), 396–402.
- Barranco SG (2016) *Frecuencia de parásitos gastrointestinales en heces de venado cola blanca (Odocoileus virginianus) pertenecientes a unidades de manejo para la conservación de la Vida Silvestre (UMA) del estado de Morelos*. Cuernavaca, Mexico: Universidad Autónoma del Estado de Morelos.
- Beltrán LF, Angulo S and Gonzales JL (2009) Uso de metodologías de censos muestrales indirectos de fecas para evaluar endoparásitos en mamíferos silvestres: Un ensayo en la Reserva Privada de San Miguelito, Santa Cruz, Bolivia. *Ecología en Bolivia* 44(1), 56–61.
- Bernal LA, Orjuela-Acosta D, Rodríguez A and Lizcano DJ (2008) Chemical restraint, hematology and blood parasites of free ranging mountain tapirs in the central Andes of Colombia. In Medici EP, Mendoza A, Shoemaker A, Holst B, Ríos-Castillo E, Russo K and Angell G (eds), *Fourth International Tapir Symposium*. Quintana Roo, Mexico: Xcaret, IUCN/SSC Tapir Specialist Group, 43.
- Cantu A, Ortega JA, Mosqueda J, García-Vazquez Z, Henke SE and George JE (2008) Prevalence of infectious agents in free-ranging white-tailed deer in northeastern Mexico. *Journal of Wildlife Diseases* 44(4), 1002–1007.
- Carlos NE, Tantaleán M, Leguía PV, Alcázar GP and Donadi SR (2008) Frecuencia de helmintos en huanganas silvestres (Tayassu pecari Link, 1795) residentes en áreas protegidas del Departamento de Madre de Dios, Perú. *Neotropical Helminthology* 2(2), 48–53.
- Castellanos A and Venegas G (2015) Vampire bats bite lowland tapirs in Yasuni National Park, Ecuador. *Tapir Conservation* 24, 7.
- Centelles I, Martínez A, Cabrera R, Castillo B and Larroza M (2021) Evaluación de la efectividad del Triclabendazol como fasciolicida en caprinos de la provincia de Neuquén, Argentina. *FAVE* 20(2), 76–80.
- Challenger A and Dirzo R (2009) Factores de cambio y estado de la biodiversidad. In Dirzo R, González R and March IJ (eds), *Capital Natural de México*. México, DF: CONABIO, 37–73.
- Contreras J, Mellink E, Martínez R and Medina G (2007) Parásitos y enfermedades del venado bura (*Odocoileus hemionus fuliginatus*) en la parte norte de la Sierra de San Pedro Mártir, Baja California, México. *Revista Mexicana de Mastozoología* 11, 8–20.
- Cook RA, Karesh WB and Osofsky SA (2004) The Manhattan Principles on “One World, One Health”. In: One World, One Health. Available at <http://www.oneworldonehealth.org/> (accessed 5 January 2024).
- Cruz E, Lira I, Güirris D, Osorio D and Quintero M (2006) Parásitos del tapir centroamericano *Tapirus bairdii* (Perissodactyla: Tapiridae) en Chiapas, México. *Revista de Biología Tropical* 54(2), 445–450.
- Cunha AC, Assunção LW, Jackson M, Souza AJ and Valente LR (2014) Compressive myelopathy in a free-ranging red brocket (*Mazama americana*) caused by a lumbar paraspinal abscess with accompanying spondylodiscitis. *Acta Scientiae Veterinariae* 42(Suppl 1), 53.
- Cunningham AA, Daszak P and Rodríguez JP (2003) Pathogen pollution: Defining a parasitological threat to biodiversity conservation. *Journal of Parasitology* 89(Suppl.), S78–S83.
- Da Silveira JA, Rabelo EM and Ribeiro MF (2011) Detection of *Theileria* and *Babesia* in brown brocket deer (*Mazama gouazoubira*) and marsh deer (*Blastocercus dichotomus*) in the state of Minas Gerais, Brazil. *Veterinary Parasitology* 177, 61–66.
- Daszak P, Cunningham AA and Hyatt AD (2000) Emerging infectious diseases of wildlife: Threats to biodiversity and human health. *Science* 287(5452), 443–449.
- De Freitas T, Keuroghlian A, Eaton DP, Barbosa E, Figueiredo A, Nakazato L, Oliveira J, Miranda F, Paes RC, Carneiro LA, Lima JV, Neto AA, Dutra V and De Freitas JC (2010) Prevalence of *Leptospira interrogans* antibodies in free-ranging *Tayassu pecari* of the Southern Pantanal, Brazil, an ecosystem where wildlife and cattle interact. *Tropical Animal Health and Production* 42, 1695–1703.
- De Thoisy B, Demar M, Aznar C and Carme B (2003) Ecological correlates of *Toxoplasma gondii* exposure in free-ranging neotropical mammals. *Journal of Wildlife Diseases* 39, 456–459.
- Deem SL, Andrew J, Marcela M and William B (2004) Disease survey of free-ranging grey brocket deer (*Mazama gouazoubira*) in the Gran Chaco, Bolivia. *Journal of Wildlife Diseases* 40, 92–98.
- Deem SL, Karesh WB and Weisman W (2001) Putting theory into practice: Wildlife health in conservation. *Conservation Biology* 15(5), 1224–1233.
- Díaz M (2006) Niveles de cortisol y estado endoparasitario en heces de jaguar (*Panthera onca*) y puma (*Puma concolor*) de vida libre en el ejido Caobas,

- Quintana Roo, México. Master's thesis, El Colegio de la Frontera Sur, San Cristóbal de Las Casas, Mexico.
- Echenique JVZ, Soares MP, Uzal FA, Ladeira SRL, Albano APN, Bandarra PM and Schild AL** (2018) Blackleg in a free-range brown brocket deer (*Mazama gouazoubira*). *Pesquisa Veterinaria Brasileira* **38**(12), 2262–2265.
- Fernandes RC, Medici EP, Testa-José C and Canena AC** (2018) Impacto de agrotóxicos e metais pesados na anta brasileira (*Tapirus terrestris*) no estado do Mato Grosso do Sul, Brasil, e implicações para saúde humana e ambiental. Mato Grosso do Sul. Campo Grande, Brazil: Technical report, Instituto de Pesquisas Ecológicas.
- Fernandes RC, Medici EP, Testa C and Micheletti T** (2020) Health assessment of wild lowland tapirs (*Tapirus terrestris*) in the highly-threatened Cerrado biome, Brazil. *Journal of Wildlife Diseases* **56**(1), 34–46.
- Ferreira A** (2008) Espécies sentinelas para a Mata Atlântica: as conseqüências epidemiológicas da fragmentação florestal no Pontal do Paranapanema, São Paulo. PhD dissertation, Universidade de São Paulo, Sao Paulo, Brazil.
- Flueck WT and Smith-Flueck AM** (2017) Troubling disease syndrome in endangered live Patagonian huemul deer (*Hippocamelus bisulcus*) from the Protected Park Shoonem: Unusually high prevalence of osteopathology. *BMC Research Notes* **10**, 739.
- Gallina S** (2019) *Ecology and Conservation of Tropical Ungulates in Latin America*. Cham, Switzerland: Springer.
- Galindo J** (2022) Live animal markets: Identifying the origins of emerging infectious diseases. *Current Opinion in Environmental Science & Health* **25**, 100310.
- Gibbs EPJ** (2014) The evolution of one health: A decade of progress and challenges for the future. *Veterinary Record* **174**, 85–91.
- Gil AD and Samartino L** (2001) Zoonosis en los sistemas de producción animal de las áreas urbanas y periurbanas de América Latina. *Livestock Policy Discussion Paper* **2**(2), 65.
- Gomez-Puerta LA, Pacheco J and Angulo J** (2016) Sobre algunos helmintos parásitos de la taruca, *Hippocamelus antisensis* (Mammalia: Artiodactyla) Filo: Nematoda, Orden: Rhabditida, Familia: Trichostrongylidae. *Revista Peruana de Biología* **23**, 329–334.
- González AP** (2001) Presencia de nemátodos gastrointestinales en diferentes especies de ciervos en México. PhD dissertation, Universidad Nacional Autónoma de México, Mexico City.
- Gordon IJ** (2018) Review: Livestock production increasingly influences wildlife across the globe. *Animal* **12**(2), s372–382.
- Güiris D, Rojas N, Berovides-Álvarez V, Cruz-Aldán E, Chávez-Hernández C, Moguel-Acuña J, Pérez-Escobar M and Palacios-Mendoza G** (2009) Primer registro de *Probstmayria tapiri* (Nematoda: Atractidae) en *Tapirus bairdii* (Gill, 1865) de la Sierra Madre de Chiapas, México. *Acta Zoologica Mexicana* **25**(1), 83–91.
- Güiris M, Ocegüera-Figueroa A, Osorio-Sarabia D, Pérez-Escobar ME, Nieto-López MG, Rojas-Hernández NM and García-Prieto L** (2017) *Tziminema unachi* n. gen., n. sp. (Nematoda: Strongylidae: Strongylinae) parasite of Baird's tapir *Tapirus bairdii* from Mexico. *Journal of Helminthology* **5**, 1–8.
- Harvell CD, Mitchel CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS and Samuel MD** (2002) Climate warming and disease risks for terrestrial and marine biota. *Science* **296**, 2158–2162.
- Hernandez F, Verdugo C, Cardenas F, Sandoval R, Morales N, Olmedo P, Bahamonde A, Aldridge D and Acosta-Jamett G** (2019) *Echinococcus granulosus* in the endangered Patagonian huemul (*Hippocamelus bisulcus*). *Journal of Wildlife Diseases* **55**(3), 694–698.
- Hernandez-Divers SM, Aguilar R, Leandro D and Foerster CR** (2005) Health evaluation of a radiocollared population of free-ranging Baird's tapirs (*Tapirus bairdii*) in Costa Rica. *Journal of Zoo and Wildlife Medicine* **36**(2), 176–187.
- Herrera HM, Abreu UGP, Keuroghlian A, Freitas TP and Jansen AM** (2008) The role played by sympatric collared peccary (*Tayassu tajacu*), white-lipped peccary (*Tayassu pecari*), and feral pig (*Sus scrofa*) as maintenance hosts for *Trypanosoma evansi* and *Trypanosoma cruzi* in a sylvatic area of Brazil. *Parasitology Research* **103**, 619–624.
- Hidalgo E, Cabello J, Novoa I, Celis S, Ortiz C, Kemeç I, Lagos R, Verasay J, Mansell M, Moreira D, Vergara PM, Millán J and Esperón F** (2022) Molecular detection and characterization of hemoplasmas in the Pudu (*Pudu puda*), a native cervid from Chile. *Journal of Wildlife Diseases* **58**, 8–14.
- Hidalgo-Mihart M, Pérez D, Pérez LA, Contreras F, Angulo J and Hernández J** (2014) Primer registro de una población de cerdos asilvestrados en el área de la Laguna de Términos, Campeche, Mexico. *Revista Mexicana de Biodiversidad* **85**, 990–994.
- Hinojosa A, Blumer E, Camacho A, Silva A, Quezada M and Brevis C** (2014) First report of fibroma in huemul (*Hippocamelus bisulcus* Molina 1782). *Gayana* **78**, 127–129.
- Hinojosa A, Pérez M, López R, Rubilar L, Llanos S and González D** (2019) Diagnosis of parasites in huemul (*Hippocamelus bisulcus*) feces from south and central Chile. *Revista MVZ Cordoba* **24**(2), 7268–7272.
- Hoppe L, Tebaldi J and Nascimento AA** (2010) Helminthological screening of free-ranging grey brocket deer *Mazama gouazoubira* Fischer, 1817 (Cervidae: Odocoileini) from Brazilian Pantanal wetlands, with considerations on *Pygarginema verrucosa* (Molin, 1860) Kadenatzii, 1948 (Spiroceridae: Ascaropsin). *Brazilian Journal of Biology* **70**(2), 417–423.
- Idrovo AJ** (2015) De la erradicación de cultivos ilícitos a la erradicación del glifosato en Colombia. *Revista de la Universidad Industrial de Santander Salud* **47**(2), 113–114.
- Jones BA, Grace D, Kock R, Alonso S, Rushton J et al.** (2013) Zoonosis emergence linked to agricultural intensification and environmental change. *Proceedings of the National Academy of Sciences* **110**, 8399–8404.
- Jori F, Hernandez-Jover M, Magouras I, Dürr S and Brookes VJ** (2021) Wildlife–livestock interactions in animal production systems: What are the biosecurity and health implications? *Animal Frontiers* **11**(5), 8–19.
- Karesh WB, Uhart MM, Painter RLE, Wallace RB, Braselton WE, Thomas LA, House C, Mcnamara TS and Gottdenker N** (1998) Health evaluation of white-lipped peccary populations in Bolivia. Proceedings AAZV AAWV Jt Conf.: 445–449.
- Kruse H, Kirkemo AM and Handeland K** (2004) Wildlife as source of zoonotic infections. *Emerging Infectious Diseases* **10**(12), 2067–2072.
- Labruna MB, Martins TF, Acosta IC, Serpa MC, Soares HS, Teixeira RH, Fernandes RC and Medici EP** (2021) Ticks and rickettsial exposure in lowland tapirs (*Tapirus terrestris*) of three Brazilian biomes. *Ticks and Tick-borne Diseases* **12**(3), 101648.
- Lepe M, García R, Fountain NM, Ponce G, Gonzalez M and Escobar LE** (2018) Domestic horses within the Maya Biosphere Reserve: A possible threat to the Central American tapir (*Tapirus bairdii*). *Caldasia* **40**(1), 188–191.
- Lima I, Pereira A, Nunes PH, Naegeli MF, Gatti A, Rossi J, Solange M and Marcili A** (2013) Morphological and molecular characterization and phylogenetic relationships of a new species of trypanosome in *Tapirus terrestris* (lowland tapir), *Trypanosoma terrestris* sp. nov., from Atlantic Rainforest of southeastern Brazil. *Parasites and Vectors* **6**(349), 1–12.
- Lima M, Peres CA, Abrahams MI, Junior Ca da S, Costa G DM and Santos RC** (2019) The paradoxical situation of the white-lipped peccary (*Tayassu pecari*) in the state of Mato Grosso, Brazil. *Perspectives in Ecology and Conservation* **17**(1), 36–39.
- Lord VR and Lord RD** (1991) *Brucella suis* infections in collared peccaries in Venezuela. *Journal of Wildlife Diseases* **27**(3), 477–481.
- Malzoni M, De-Almeida-Jácomo TA, Kayo-Kashivakura C, Mundim-Tórres N, Marvulo FV, Ragozo AM, Pereira-De-Souza LS, Ferreira JS, Vasconcellos SA, Morais MZ et al.** (2010) Serologic survey for selected infectious diseases in free-ranging Brazilian tapirs (*Tapirus terrestris*) in the Cerrado of central Brazil. *Journal of Zoology* **41**(1), 133–136.
- Mangini PR, Gazino-Joineau ME, Carvalho-Patricio MA, Fortes MAT, Goncalves MLL, Margarido TCC, Kluczkovsky A and Klemz C** (2004) Estudo da ocorrência de soros positivos para doenças infecto contagiosas em populações selvagens e cativas de *Tayassu pecari* na Região de Quedas do Iguçu-PR. *Archives of Veterinary Science* **4**(1), 2.
- Mangini PR, Medici EP and Fernandes RC** (2012) Tapir health and conservation medicine. *Integrative Zoology* **7**, 331–345.
- Martínez-Mota R, Valdespino C, Sánchez MA and Serio-Silva JC** (2007) Effects of forest fragmentation on the physiological stress response of black howler monkeys. *Animal Conservation* **10**(3), 374–379.

- Martinez A, Salinas A, Martinez F, Cantu A and Miller DK (1999) Serosurvey for selected disease agents in white-tailed deer from Mexico. *Journal of Wildlife Diseases* 35(4), 799–803.
- Martins A, Brombila T, García J, Sousa H, Oliveira S, Hamad A, Ogata R, Gennari M and Richtzenhain L (2014) Swine infectious agents in *Tayassu pecari* and *Pecari tajacu* tissue samples from Brazil. *Journal of Wildlife Diseases* 50(2), 1–7.
- Mathias LA, Girio RJ and Duarte JM (1999) Serosurvey for antibodies against *Brucella abortus* and *Leptospira interrogans* in Pampas deer from Brazil. *Journal of Wildlife Diseases* 35(1), 112–114.
- May-Junior JA (2011) Avaliação de parâmetros e epidemiológicos da população de anta brasileira (*Tapirus terrestris*, Linnaeus, 1758) na Mata Atlântica do Parque Estadual Morro do Diabo, Pontal do Paranapanema, São Paulo. Master's thesis, Universidade de São Paulo, São Paulo, Brazil.
- Mayor P, Guimaraes DA, Le Pendu Y, Da Silva JV, Jori F and López M (2007) Reproductive performance of captive collared peccaries (*Tayassu tajacu*) in the eastern Amazon. *Animal Reproduction Science* 102, 88–97.
- Mazzoni MH, Câmara JC, Diniz AC, Cubas Z, Coelho S, Maldonado MI, De Moraes W, Oliveira MJ, Angelo DF, Portela IZ and Nunes A (2018) Multiple bluetongue virus serotypes causing death in Brazilian dwarf brocket deer (*Mazama nana*) in Brazil, 2015–2016. *Veterinary Microbiology* 227, 143–147.
- Medici EP, Mangini PR and Fernandes RC (2014) Health assessment of wild lowland tapir (*Tapirus terrestris*) populations in the Atlantic Forest and Pantanal biomes, Brazil (1996–2012). *Journal of Wildlife Diseases* 50(4), 817–828.
- Méndez ID (2017) Evaluación de la carga parasitaria en las poblaciones de tapir (*Tapirella bairdii*) del biotopo protegido San Miguel, La Palotada el Zotz, y del Parque Nacional Laguna Lachuá. BSc thesis, Universidad de San Carlos, Ciudad de Guatemala.
- Mérida SA (2015) Epidemiological survey on peccaries (*Tayassu pecari*) and pigs (*Sus scrofa*) in the Community Forestry Concession of Uxactún, Maya Reserve Biosphere, Guatemala. PhD dissertation, University of Veterinary Medicine Hannover, Hannover, Germany.
- Mongruel CA, Benevenuto JL, André MR, De Oliveira A, Zacarias R and Seki MC (2017) Molecular characterization of *Anaplasma* sp. in free-living gray brockets (*Mazama gouazoubira*). *Vector-Borne Zoonotic Diseases* 17(3), 165–171.
- Montenegro OL, Roncancio N, Soler D, Cortés J, Contreras J, Sabogal S, Acevedo LD and Navas PE (2018) Serologic survey for selected viral and bacterial swine pathogens in colombian collared peccaries (*Pecari tajacu*) and feral pigs (*Sus scrofa*). *Journal of Wildlife Diseases* 54(4), 700–707.
- Montes JC, Melo LK, Mukul JM, Segura JC and Castro FG (2012) Efecto del espacio por animal sobre los niveles de cortisol, conductas agonísticas y su relación con el ciclo ovárico del pecarí de collar (*Pecari tajacu*) en cautiverio. *Archivos Latinoamericanos de Producción Animal* 20(3–4), 80–86.
- Montes JC, Solís AL, Yokoyama J, Mukul JM and Segura JC (2009) Evaluación de estrés en *Pecari tajacu* sometidos a dos densidades de población. *Archivos de Zootecnia* 58(223), 463–466.
- Morales N, Aldridge D, Bahamonde A, Cerda J, Araya C, Muñoz R, Saldias ME, Lecocq C, Fresno M, Abalos P and Retamal P (2017) *Corynebacterium pseudotuberculosis* infection in Patagonian huemul (*Hippocamelus bisulcus*). *Journal of Wildlife Diseases* 53(3), 621–624.
- Morrone JJ (2014) Biogeographical regionalisation of the Neotropical region. *Zootaxa* 3782(1), 1–110.
- Morrone JJ (2017) *Neotropical Biogeography: Regionalization and Evolution*. Boca Raton, USA: CRC Press.
- Mukul JM, Zapata R, Montes RC, Rodríguez RI and Torres JF (2014) Parasitos gastrointestinales y ectoparásitos de ungulados silvestres en condiciones de vida libre y cautiverio en el trópico mexicano. *Revista Mexicana de Ciencias Pecuarias* 5(4), 459–469.
- Naranjo EJ, Amador SA, Falconi FA and Reyna RA (2015) Distribución, abundancia y amenazas a las poblaciones de tapir (*Tapirus bairdii*) y pecarí de labios blancos (*Tayassu pecari*) en México. *Therya* 6(1), 227–249.
- Naranjo EJ, Guerra MM, Bodmer RE and Bolaños JE (2004) Subsistence hunting by three ethnic groups of the Lacandon Forest, Mexico. *Journal of Ethnobiology* 24, 233–253.
- Nava S, Mangold AJ, Mastropaolo M, Venzal JM, Oscherov EV and Guglielmo AA (2009) *Amblyomma boeroi* n. sp. (Acari: Ixodidae), a parasite of the Chacoan peccary *Catagonus wagneri* (Rusconi) (Artiodactyla: Tayassuidae) in Argentina. *Systematic Parasitology* 73, 161–174.
- Navas P, Díaz J, Matushima ER, Fávero CM, Sánchez AM, Sacristán C, Ewbank AC, Marques A, Barbanti JM, Dos Santos C, Cogliati B, Mesquita L, Maiorka PC and Catão JL (2018) A retrospective pathology study of two Neotropical deer species (1995–2015) of Brazil: Marsh deer (*Blastocerus dichotomus*) and brown brocket deer (*Mazama gouazoubira*). *PLoS One* 13(6), e0198670.
- Navas PE, Díaz J, Fernandes RC, Testa C, Silva R, Sansone M, Medici EP and Catoa JL (2019) Pathological findings in lowland tapirs (*Tapirus terrestris*) killed by motor vehicle collisions in the Brazilian Cerrado. *Journal of Comparative Pathology* 170, 34–45.
- Nogueira-Filho SLG, Carvalho H, Silva HPA, Fernandes LC and Nogueira SC (2012) Stress assessment in white-lipped peccaries (*Tayassu pecari*). *Suiform Soundings* 11(2), 21–28.
- Ojasti J (2010) Prólogo. In Guerra MM, Calmé S, Gallina S and Naranjo EJ (eds), *Uso Y Manejo de Fauna Silvestre En El Norte de Mesoamérica*. Xalapa, Mexico: INECOL, 15–18.
- Ojeda MM, Rodríguez RI, Esteve MD, Pérez A, Modarelli JJ and Villegas S (2019) Molecular detection of rickettsial tick-borne agents in white-tailed deer (*Odocoileus virginianus yucatanensis*), mazama deer (*Mazama temama*), and the ticks they host in Yucatan, Mexico. *Ticks and Tick-borne Diseases* 10(2), 365–370.
- Orta M, Rosell A, Cartró M, O'Callaghan C, Moraleda N and Mayor P (2018) First evidences of Amazonian wildlife feeding on petroleum-contaminated soils: A new exposure route to petrogenic compounds? *Environmental Research* 160, 514–517.
- Oyarzun P, Muñoz P and Valenzuela G (2018) Southern pudu (*Pudu puda*) (Artiodactyla: Cervidae) as an additional host for *Dictyocaulus eckerti* (Strongylida: Dictyocaulidae). *Revista Mexicana de Biodiversidad* 89, 301–305.
- Paes RC, Fonseca J, LARC M, Jardim GC, Piovezan U, Herrera HM, Mauro RA and Vieira-da-motta O (2013) Serological and molecular investigation of the prevalence of Aujeszky's disease in feral swine (*Sus scrofa*) in the subregions of the Pantanal wetland, Brazil. *Veterinary Microbiology* 165, 448–454.
- Pavón AJ, Cárdenas A, Rábago JL, Barrón CA and Mosqueda J (2020) First molecular evidence of *Theileria cervi* infection in white-tailed deer (*Odocoileus virginianus*) in Mexico. *Veterinary Parasitology: Regional Studies and Reports* 22, 1–4.
- Pérez-Flores J, Lagunas O, González D and Ocegüera A (2019) First molecular characterization of *Linguatula recurvata* (Pentastomida) and first record in Baird's tapir (*Tapirus bairdii*) from Calakmul, Mexico. *Comparative Parasitology* 86(2), 135–141.
- Quise V and Fernandes RC (2014) *Manual Veterinario Del Tapir*, 2nd Edn. Buenos Aires, Argentina: IUCN/SSC Tapir Specialist Group.
- Real VV, Dutra V, Nakazato L, Freitas TP, Keuroghlian A, Almeida AD and Souza RL (2010) PCR de *Salmonella* spp., *Streptococcus suis*, *Brucella abortus* e circovirus suíno tipo 2 em taiaassuídeos de vida livre e cativo. *Revista Brasileira de Saúde E Produção Animal* 11(3), 858–864.
- Reissig EC, Helman E and More G (2020) *Sarcocystis* spp. infection in South American deer huemul (*Hippocamelus bisulcus*) and pudu (*Pudu puda*) from Patagonian National Parks, Argentina. *Parasitology Research* 119, 3915–3922.
- Ribeiro CB, De Melo I, Barbanti L, Duarte M, Mendes RJ, Torres RA, Wanderley AM, Gomes JE and Garcia JE (2017) Are Brazilian cervids at risk of prion diseases? *Prion* 11(1), 65–70.
- Rodríguez EV, Mollericono JL and Nallar R (2019) Garrapatas del género *Amblyomma* (Acari: Ixodidae) parasitando a tayasuidos silvestres (*Tayassu pecari* y *Pecari tajacu*) en la Reserva de la Biosfera Pilon Lajas, Beni-Bolivia. *Ecología en Bolivia* 54(2), 96–106.
- Romero KG, Naranjo EJ, Morales HH and Nigh RB (2006) Daños ocasionados por vertebrados silvestres al cultivo de maíz en la Selva Lacandona, Chiapas, México. *Interiencia* 31(4), 276–283.

- Romero S, Ferguson BG, Güiris D, López S, Paredes A and Weber M** (2008) Comparative parasitology of wild and domestic ungulates in the Selva Lacandona, Chiapas, Mexico. *Comparative Parasitology* **75**(1), 115–126.
- Ruiz J, Castro R, Rivero N, Bello R and Sánchez D** (2014) Occurrence of glyphosate in water bodies derived from intensive agriculture in a tropical region of southern Mexico. *Bulletin of Environmental Contamination and Toxicology* **93**, 289–293.
- Santodomingo A, Robbiano S, Thomas R, Parrague C, Cabello J, Vera F, Valencia C, Moreira D, Moreno L, Hidalgo E and Muñoz S** (2022) A search for piroplasmids and spirochetes in threatened pudu (*Pudu puda*) and associated ticks from Southern Chile unveils a novel *Babesia* sp. and a variant of *Borrelia chilensis*. *Transboundary and Emerging Diseases* **00**, 1–12. doi:10.1111/tbed.14743
- Schütz G, Hacon S, Silva H, Moreno AR and Nagatani K** (2008) Principales marcos conceptuales aplicados para la evaluación de la salud ambiental mediante indicadores en América Latina y el Caribe. *Revista Panamericana de Salud Publica* **24**(4), 276–285.
- Serrano I, Reyna RA, Molina D and Naranjo EJ** (2021) Baird's tapir: Predicting patterns of crop damage surrounding the Calakmul Biosphere Reserve, Campeche, Mexico. *Revista Mexicana de Biodiversidad* **92**(2021), e923520.
- Silva MIS, Nascimento AA, Bonuti MR, Mapeli EB and Arantes IG** (1999) Ascaropsinae (Alicata & McIntoch, 1933) parasites of deer from the lowlands region of the state of Mato Grosso Do Sul, Brazil. *Revista Brasileira de Parasitologia Veterinaria* **8**(2), 133–136.
- Suárez JA, Lizcano DJ and Orjuela D** (2008) Basic physiological variables of five free ranging mountain tapirs in the central Andes of Colombia. Xcaret, Mexico: Conference report, IUCN/SSC Tapir Specialist Group.
- Szabó MPJ, Labruna MB, Pereira MC, Duarte MB, Labruna MB, Pereira MC and Szabo MPJ** (2003) Ticks (Acari: Ixodidae) on wild marsh-deer (*Blastocerus dichotomus*) from southeast Brazil: Infestations before and after habitat loss. *Journal of Medical Entomology* **40**(3), 268–274.
- Ulloa A, Ferguson HH, Méndez JD, Danis R, Casas M, Bond JG, García JC, Orozco A, Juárez JA, Farfan JA, García JE, Rosado EP, Edwards E, Komar N, Hassan HK, Unnasch TR and Rodríguez MA** (2009) West Nile virus activity in mosquitoes and domestic animals in Chiapas, México. *Vector-borne and Zoonotic Diseases* **9**(5), 555–560.
- Valdez R** (2014) Perspectivas del manejo y conservación de fauna en México. In Valdez R and Ortega JA (eds), *Ecología Y Manejo de Fauna Silvestre En México*. Texcoco, Mexico: Colegio de Postgraduados, 21–40.
- Vila AR, Briceño C, McAloose D, Seimon TA, Armién AG, Mauldín EA, Be NA, Thissen JB, Hinojosa A, Quezada M, Paredes J, Avendaño I, Silva A and Uhart MM** (2019) Putative parapoxvirus-associated foot disease in the endangered huemul deer (*Hippocamelus bisulcus*) in Bernardo O'Higgins National Park, Chile. *PLoS One* **14**(4), e0213667.
- Weber JM** (1995) La Introducción del jabalí europeo a la Reserva de la Biosfera La Michilia, Durango: Implicaciones ecológicas y epidemiológicas. *Revista Mexicana de Mastozoología* **1**, 69–73.
- Weber M, García G and Reyna R** (2006) The tragedy of the commons: Wildlife Management Units in southeastern Mexico. *Wildlife Society Bulletin* **34**(5), 1480–1488.
- Zinsstag J, Schelling E, Bonfoh B, Schelling E, Bonfoh B, Fooks AR, Kasymbekov J, Waltner D and Tanner M** (2009) Towards a 'One Health' research and application tool box. *Veterinaria Italiana* **45**, 121–133.