



Parasites and Other Infectious Agents in Non-human Primates of Argentina

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Abstract

Purpose of Review In Argentina, there are five non-human primate (NHP) species: *Sapajus nigritus cucullatus*, *Sapajus cay*, *Alouatta caraya*, *Alouatta guariba clamitans*, and *Aotus azarae*. All of them inhabit protected and non-protected areas and face severe threats due anthropization. We aim to summarize the information available about parasites and infectious diseases of these NHPs and suggest further research on primate diseases in Argentina.

Recent Findings NHPs of Argentina are hosts of several parasites and pathogens important for conservation as well as public health. *Alouatta* species are lethally susceptible to yellow fever virus, which makes them suitable health sentinels of possible outbreaks. For other primate species, few parasite surveys have been carried out.

Summary Assessing the presence of infectious diseases and long-term surveillance on NHP allow the development of strategies to help in the early detection of pathogens that may threaten public health. Increasing the knowledge about parasites and infectious diseases and their consequences in NHP of Argentina is needed, considering a One Health approach.

Keywords Review · Primates of Argentina · Parasitology · Infectious diseases · Primatology · Pathogens

Introduction

Primates are the most important for biodiversity in tropical and subtropical forest ecosystems of the world [1]. Although humans have always shared habitats with NHP, the dynamics of human–primate interactions have changed dramatically in the recent past [2]. Anthropogenic environmental changes (such as the expansion of agriculture and cattle ranching, logging, urbanization, and pet trade) are driving primate species to extinction [3]. Many primates today are forced to live in mosaics of farmland, human settlements,

and forest fragments and in isolated protected areas [4]; as a consequence, approximately 60% of NHP of the world are threatened with extinction [2].

Infectious disease outbreaks are also a significant threat to the conservation of wild populations of NHP [5]. In addition, our close phylogenetic relationship with primates creates a high potential for zoonotic transmissions. Clear examples are the Ebola outbreaks and HIV/AIDS pandemic [6–8]. As humans and primates continue to come into direct contact in developed areas, understanding factors that influence disease occurrence in wildlife will be increasingly important for predicting disease emergence at a regional scale. Knowing the distribution of infectious diseases in wild primates, routes of contact, and transfer between primates and humans might help predict future pathogen exchanges and risk factors for human disease emergence [5].

Parasites represent a large part of the species diversity on Earth [9] and are usually ignored in ecological studies [10]. Infectious pathogens including parasites are common components of wildlife and produce major impacts on host physiology, ecology, and evolution [11]; understanding the factors that underlie patterns of parasite diversity is vital to identifying ecological principles controlling biodiversity

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[12]. Studying parasites has particular relevance in wild primates given their ecological significance in tropical and subtropical forests [13]. Knowing about host geographic distribution, ecology, feeding habits, and parasite diversity contributes to applying for better conservation programs when they are needed.

In Argentina, there are five species of NHPs, the black-horned capuchin monkey (*Sapajus nigritus cucullatus*), the brown-capped capuchin (*Sapajus cay*), the black and gold howler monkey (*Alouatta caraya*), the brown howler (*Alouatta guariba clamitans*), and the owl monkey (*Aotus azarae*). They inhabit in the remaining of Montana, Pedomontana (at the Yungas mountains), and Paranaense forests and in a complex of forests of the Humid Chaco region in the north of the country (Fig. 1), and their populations are declining facing severe threats.

Argentina has a long history of studies both in laboratory and field environments and rich scientific production in primatology [14]. A spike of interest has been seen in recent years, after the yellow fever outbreak in 2007 and 2008, in which NHP populations were severely decimated [15]. Here, we aim to summarize the knowledge available on parasites and other infectious agents of each primate species

in Argentina (see Table 1). We hope this review will support primatology studies with conservation and public health focus.

Alouatta caraya (Black and Gold Howler Monkey)

The genus *Alouatta* inhabits the widest range of habitats of any Neotropical primate species; they extend from Southern Veracruz State in Mexico, through Central and South America, to northern Argentina [21]. Northern Argentina and north Uruguay comprise the boundary of the southern distribution of the black and gold howler monkey [22, 23]. They occupy diverse habitats including continuous forest, gallery forest, and flooded forests of the Chaco region and Parana forest [22, 24]. Among primates, howlers are well-known for their ecological flexibility, which makes them “pioneers” able to exploit borderline habitats. Because of this flexibility, the species is an excellent model to study the dynamics of infectious disease transmission [25]. In fact, the ability to adapt and survive in modified environments, such as habitats with human contact [26], suggests that howler populations in fragmented forests can carry a more diverse community of parasites [27, 28]. Interestingly, the number of

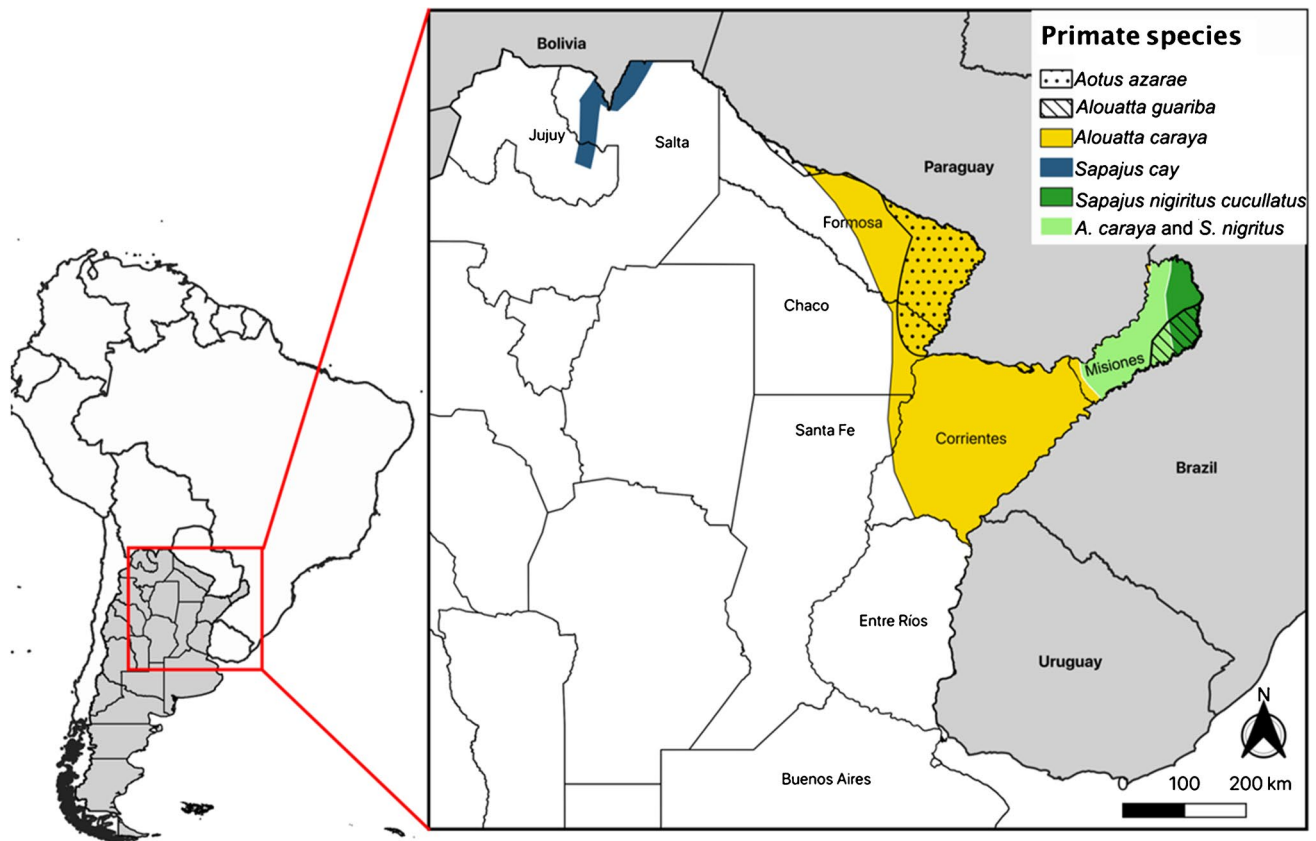


Fig. 1 Geographical distribution of *Alouatta caraya*, *Alouatta guariba guariba*, *Sapajus nigritus cucullatus*, *Sapajus cay*, and *Aotus azarae* in Argentina [16–20]

Table 1 Reported parasites and other infectious agents found in primates in the wild and captivity of Argentina

Primate species	Disease	Etiological agent	Prevalence (%)	Citation
Viral				
<i>Alouatta caraya</i>	UNAV (Una virus) MAYV (Mayaro virus)	Alphavirus	73 (61/84)	[48]
	Venezuelan equine encephalitis		57.1 (4/7)	[47]
	Bussuquara virus	Flavivirus	1 (1/108)	[45]
	Dengue		2 (1/108 DENV-1, 1/108 DENV-3)	[45]
	Ilheus virus		1 (1/108)	[45]
	Saint Louis encephalitis		37 (37/105)	[46]
			57.1 (4/7)	[47]
			11 (11/108)	[45]
	West Nile virus		24 (24/108)	[45]
			Unspecified Flavivirus	43 (30/70)
<i>Alouatta guariba</i>	Papilloma virus	Papillomaviridae	4.2 (1/24)	[50]
	Yellow fever	Flavivirus	-	[15]
<i>Sapajus</i> spp.	Papilloma virus	Papillomaviridae	14.3 (1/7) ²	[50]
Parasitic				
Endoparasites				
Protozoa				
<i>Alouatta caraya</i>	Chagas	<i>Trypanosoma</i> sp.	7 (2/29)	[28]
		<i>Trypanosoma cruzi</i>	46 (50/109)	[49]
	Malaria	<i>Plasmodium</i> sp.	3.45 (1/29)	[28]
	Giardiasis	<i>Giardia</i> sp.	54.4 (49/90)	[27]
			81.4 (22/27)	[34]
		<i>Giardia duodenalis</i>	3.6 (1/28)	[75]
	Cryptosporidiosis		70 (42/60)	[39]
			27.7 (14/50) ³	[39]
		<i>Cryptosporidium</i> sp.	100 (1/1) ³	[76]
	Amebiasis		100 (1/1)	[77]
		<i>Entamoeba coli</i>	65 (39/60)	[39]
	Coccidiosis		5.5 (3/50) ³	[39]
		<i>Eimeria</i> sp.	15 (9/60)	[39]
	Blastocystosis	<i>Blastocystis</i> sp.	77.7 (21/27)	[34]
		<i>Blastocystis hominis</i>	100 (60/60)	[39]
	Leishmaniasis		44.4 (22/50) ³	[39]
		<i>Leishmania</i> sp.	8.3 (9/109)	[49]
<i>Aotus azarae</i>	Blastocystosis	<i>Blastocystis</i> sp.	26 (14/49)	[61]
		<i>Endolimax nana</i>	23(12/49)	[61]
		23 (12/49)	[61]	
	Giardiasis	<i>Giardia</i> sp.	8 (4/49)	[61]
	Coccidiosis	<i>Isospora</i> sp.	45 (24/49)	[61]
Leishmaniasis	<i>Leishmania (Viannia)</i>	45 (4/9)	[62]	
	Unspecified amoeba	4 (2/49)	[61]	
	<i>Buxtonella</i> sp.	2 (3/158)	[68]	
<i>Sapajus nigritus</i>	Coccidiosis	Coccidia	25 (40/158)	[68]
	Amebiasis	<i>Entamoeba</i> sp.	4 (7/158)	[68]
Helminths				
Nematoda				
<i>Alouatta caraya</i>		<i>Strongyloides</i> sp.	10 (6/60)	[39]
		<i>Trypanoxyuris</i> sp.	7 (2/29)	[28]
		<i>Trypanoxyuris minutus</i>	22 (19/88)	[31]

Table 1 (continued)

Primate species	Disease	Etiological agent	Prevalence (%)	Citation		
<i>Aotus azarae</i>		<i>Uncinaria</i> sp.	17 (9/49)	[61]		
		<i>Strongyloides</i> sp.	30 (16/49)	[61]		
		<i>Taenia</i> sp.	2 (1/49)	[61]		
		<i>Trypanoxyrius</i> sp.	23 (12/49)	[61]		
		<i>Sapajus nigrinus</i>		<i>Ascaris</i> sp.	2.9 (1/35) ¹	[65]
				<i>Capillaria</i> sp.	3 (4/158)	[68]
				<i>Filariopsis</i> sp.	31.4 (11/35) ¹	[65]
					13 (20/158)	[68]
				<i>Strongyloides</i> sp.	11.4 (4/35) ¹	[65]
					15 (24/158)	[68]
				<i>Trichuris</i> sp.	2.9 (1/35) ¹	[65]
					9 (14/158)	[68]
				Unspecified Ascarididae	3 (4/158)	[68]
				Unspecified Nematoda	8 (13/158)	[68]
				Unspecified Physalopteridae	2.9 (1/35) ¹	[65]
		Unspecified Physalopteridae	4 (6/158)	[68]		
Unspecified Strongylida	1 (2/158)	[68]				
Unspecified Subuluridae	2.9 (1/35) ¹	[65]				
	2 (3/158)	[68]				
Cestoda						
<i>Alouatta caraya</i>	Bertelliasis	<i>Bertiella mucronata</i>	7 (6/84)	[31]		
			21 (6/29)	[28]		
			10 (6/60)	[39]		
			22.2 (11/50) ³	[39]		
			70.3 (564/802)	[40]		
<i>Alouatta guariba</i>	Bertelliasis	<i>Bertiella mucronata</i>	26 (11/40)	[40]		
			<i>Unspecified Hymenolepididae</i>	40 (14/35) ¹	[65]	
<i>Sapajus nigrinus</i>			12 (19/158)	[68]		
Trematoda						
<i>Sapajus nigrinus</i>		Unspecified Trematode	2.9 (1/35) ¹	[65]		
Filaria						
<i>Sapajus nigrinus</i>	Filariosis	<i>Dipetalonema robini</i>	-	[64]		
Ectoparasites						
Acari						
<i>Alouatta caraya</i>	Scabies	<i>Cebalges gaudi</i>	11 (3/29)	[28]		
Phthiraptera						
<i>Alouatta caraya</i>	Pediculosis	<i>Pediculus mjoebergi</i>	37 (111/302)	[31]		
			24 (7/29)	[28]		

¹Authors presented prevalence separated by season from 2012 to 2014. We selected data from 2013. ²Individuals in captivity. ³Individuals in semi-captivity

parasite species reported to infect howler monkeys is rather low. This is likely a result of their characteristic arboreality that may prevent contact with infections commonly found on the ground [29]. A high percentage of gastrointestinal parasites and all the blood-borne parasites found in howlers are also found in humans [30]. Different geographic and climate factors (e.g., precipitation, latitude, altitude, and human proximity) can influence parasite infection in howler

monkeys but the effect of each variable depends on the parasite category [29, 30].

To our knowledge, the first report of parasitology studies in *A. caraya* comes from Pope [31], who reported the presence of *Bertiella mucronata*, *Trypanoxyuris minutus*, and a louse *Pediculus mjoebergi* from the autopsy of 300 wild-caught howlers from Corrientes province. Studies from the early 2000 carried out in Corrientes province

and using non-invasive techniques, such as feces collection, provide the first reports of *Giardia* spp. and *Cryptosporidium* spp. In Argentina, two howler populations close to the junction of the Paraguay and Paraná Rivers have been a matter of study for several years, with monitoring of howler groups for over 30 years [32]. The sites are Isla Brasilera (27° 12' S, 58° 14' W) and Biological Station of Corrientes (EBCo) (27° 13' S, 58° 14' W) which, in the last 15 years, have served as the principal areas for infectious pathogens studies in *A. caraya*. Kowalewski et al. [27] studied in these two sites patterns of infection with *Giardia* and *Cryptosporidium* in black and gold howlers with different contact with humans (remote, rural, and village). From 90 samples analyzed, all of them were negative for *Cryptosporidium* sp. suggesting this parasite is not a natural component of the howler parasite communities at these sites and that current land-use patterns are not exposing Argentine black and gold howler monkeys to this parasite [27]. Conversely, *Giardia* sp. was present in howlers of all the sites but the infection was not significantly associated with the place of collection. When the quantitative technique was performed, the authors also found no significant association with sites. They also found that there was a higher prevalence at the site with the lowest primate density (1.04 howlers/ha for the rural site) and a lower prevalence at the site with the highest primate density (3.25 howlers/ha for Isla Brasilera). Infection prevalence seemed to be associated with factors such as the use of space or stress and not howlers' density. Regardless of the prevalence found among black and gold howlers, this parasite was not found associated with gastrointestinal signs or symptoms [27]. Based on molecular identification, in the rural area, *G. duodenalis* is shared between humans and domestic animals (Assemblage A) and between monkeys and domestic animals (Assemblage B), suggesting cross-species transmission, and may amplify baseline rates of infection in rural areas [33].

Alegre et al. [34] analyzed the relationship between the prevalence of *Giardia* sp. and *Blastocystis* sp. and host sex and age, with the hypothesis that adults NHP had higher protozoan parasite infections than juveniles (as studies with *Cebus capucinus* [35], *Alouatta pigra* [36], and *Mandrillus sphinx* [37] have shown). However, Alegre et al. [34], as in other studies, conclude that these biological factors do not affect the prevalence of these protozoans. Alegre et al. [34] worked with 27 individuals (13 juveniles, 14 adults) of both sexes from the EBCo site, finding an infection prevalence of 100% in juveniles and 78.5% in adults with 84.6% in males and 92.8% in females and no significant effects of age and sex in the infection prevalence. This study suggests that the high infection rates of protozoans may be due to the extent of deforestation and cattle interference howlers face at this site. Therefore, studies designed to examine age-sex effects

need to consider other potential infection risk factors, such as habitat disturbance (e.g., logging rates) [38].

The first report of gastrointestinal parasites from semi-captive *A. caraya* in Argentina was made by Milozzi et al. [39]. These authors studied intestinal parasites in wild *A. caraya* in a new area called “Las Lomas” and semi-captive howlers in a rescue center “Centro de Reeducción del Mono Aullador Negro” (CRMAN). They found that all individuals from both areas had infections of at least one type of gastrointestinal parasite. These infections included protozoans like *Blastocystis hominis*, *Giardia duodenalis*, *Eimeria* sp., and *Entamoeba coli* and helminths such as the cestode *Bertiella mucronata* and the nematode *Strongyloides* sp. They found significant variation in parasite prevalence between wild and semi-captive howlers, where the protozoan infection was higher in wild monkeys. These findings suggest that such variations might be due to environmental differences such as temperature and humidity that could be more favorable for the survival of infectious stages of some parasitic species, thus increasing the chances of infection [39].

Regarding *Bertiella mucronata*, *A. caraya* is considered the definitive host of this parasite with no reports of it in other howler species (except for *A. guariba* in areas of sympatry with *A. caraya*) [40]. Even local people in northern Argentina call this parasite “carayá taenia” due to its importance as a zoonotic pathogen. According to Kowalewski et al. [40], *B. mucronata* has a high prevalence in black and gold howler monkeys with infection patterns affected by seasonality and inter-habitat variability. However, it seems that *Bertiella* infection at moderate levels has no impact on the health status of the black and gold howlers. Although uncommon, human infections with *B. mucronata* are reported especially among children with epidemiological risk [41]. For this reason, its zoonotic potential cannot be ignored, and parasite infection is monitored in interface areas. There have been four cases of *Bertiella* sp. in humans in Argentina; the first case was in 1949 in a woman from Chaco Province; then, in 1983, two more cases were reported in Buenos Aires Province in a woman and a 2-year-old child [41]. The last report was in 2019, in a woman from Buenos Aires Province who worked as a howler monkey caretaker in a wildlife rehabilitation center for 20 years [41]. In this last report, the authors analyzed the feces from this woman and captive howlers and found the presence of *Giardia intestinalis* and *Cryptosporidium* sp. in howlers and *Blastocystis* sp. and *Bertiella* sp. in both the caretaker and monkeys. These results showcase how the possibilities of zoonotic parasite infection can increase with contact between humans and NHP.

When it comes to emerging infectious diseases, one of the greatest concerns in *A. caraya* is the yellow fever virus (YFV) outbreaks. YFV is an important re-emerging arboviral disease and a cause of severe illness and death in

A. caraya [42•]. In 1966, three howlers were found dead in Misiones Province and several yellow fever cases were reported in humans at that time [43]. In 2001, 80 howlers died of yellow fever near the Brazil–Argentina border [44], and between November 2007 and October 2008, YFV outbreaks seriously affected populations of the two howler monkey species in Argentina [15]. The susceptibility of monkeys to lethal infections of YFV in America has been considered a major indicator of enzootic disease outbreaks in forest areas [45]. This situation makes *A. caraya* a health sentinel, warning about possible YFV outbreaks that allow governments to strengthen vaccination [27]. However, the conservation of the black and gold howler monkeys may face drastic population reductions and genetic erosion if YFV continues to expand in South America [15]. For that reason, to ensure howler survival is necessary to continue human vaccination (as the only disease amplifier), implement education programs with local residents (in certain areas, there are beliefs howlers are the cause of the disease), correct management of protected areas to ensure the protection of howler habitats, and continue collaborative research projects on eco-epidemiology, mammals' roles in virus circulation, and conservation of howler monkeys [15].

YFV belongs to a genus of mosquito-borne viruses called *Flavivirus*. In recent years, studies detected the most important flavivirus in antibodies of howler monkeys in Argentina: Dengue virus (DENV), St. Louis encephalitis virus (SLEV), West Nile virus (WNV), Zika virus (ZIKV), Bussuquara virus (BSQV), and Ilheus virus (ILHV) [45]. In Asia and Africa, these flaviviruses tend to exist in a sylvatic cycle involving NHP and arboreal mosquitoes. However, in South America, the existence of sylvatic cycles of flaviviruses needs more exploration. In 2000, Contigiani et al. [46] studied serum samples from wild *A. caraya* and detected antibodies for SLEV in 35.2% while 11.4% of these samples were also positive for YFV, DENV, and ILHV [46]. In addition, Morales et al. [45] analyzed 108 serum samples of *A. caraya* in two areas from Corrientes Province, identifying antibodies against WNV (22.2%), SLEV (10.2%), DENV (1.85%) ILHV (0.93%), and BSQV (0.93%), while 30 samples were positive for undetermined flavivirus. Both studies found a high prevalence of SLEV suggesting that primates could play viral maintenance in nature but it needs more investigation. Morales et al. [45] had the first report of WNV in free-ranging NHPs from Latin America.

Another group of mosquito-borne viruses is the family *Togaviridae*. There is limited information about the circulation of these pathogens in wildlife in Argentina. Bottinelli et al. [47] detected for the first time the presence of Venezuelan equine encephalitis (VEE) in 4 serum samples from *A. caraya* of Chaco Province. Díaz et al. [48] analyzed 90 serum samples from *A. caraya* in Corrientes Province and reported the presence of Mayaro

virus (MAYV) and its subtype Una virus (UNAV) with a higher prevalence in adults than juveniles suggesting that the virus is endemic in the region.

Leishmaniasis is another vector-borne disease widely spread worldwide caused by protozoans of the genus *Leishmania*. In Argentina, *Leishmania braziliensis* and *L. infantum* are primarily transmitted in peridomestic settings and can infect a wide range of mammal species. The role of wild mammals in the cycle of *Leishmania* is still unknown. Martínez et al. [49] carried out the molecular analysis in blood samples of *A. caraya* and reported natural infections by *L. braziliensis*, *L. amazonensis*, and *L. infantum* in groups from Isla Brasilera (Chaco Province) and around the Biological Station of Corrientes. None of the howlers that were positive for *Leishmania* presented lesions or other symptoms. This suggests that the parasite may not affect the health of the howlers or that the sampling effort was not sufficient enough to detect symptomatic animals [49].

In Latin America, one of the most important parasitic diseases is Chagas disease as a result of *Trypanosoma cruzi* infection. Different studies suggest that NHP are naturally associated with *T. cruzi* I, *T. cruzi* II, and *T. cruzi* IV in the Atlantic and Amazonian forests. Martínez et al. [49] detected and characterized *T. cruzi* in blood samples of wild howler monkeys at four sites in northeastern Argentina. Analyzing 109 blood samples, this study—the first to describe *T. cruzi* infection in *A. caraya* from Argentina—found not only *T. cruzi* but also the closely related species *T. minasense*. The relevance of mammals as a reservoir of *T. cruzi* in endemic areas of Argentina has been documented very well, and howler monkeys are not the exception to the rule. If they are living in sympatry with other infested mammals or are bitten by their vectors kissing bugs, it is expected that they are positive for *T. cruzi*. The role of howler as a reservoir of Chagas disease needs further investigation, especially in regions where *T. cruzi* is hyperendemic and the human-animal interface is increasing.

Papillomaviruses (PV) are members of a highly diverse family of viruses (Papillomaviridae). Information about PV infection in Neotropical NHP species is scarce, with only four PVs identified in different species. Sanchez-Fernandez et al. [50] obtained genital and oral swabs from *A. caraya* at the Biological Station of Corrientes and “Paraje Santa Rita” in Chaco Province (26° 01' 32.46" S, 59° 58' 33.49" W). They found a positive result in an oral swab sample of a wild female *A. caraya* from Corrientes by using a PCR-CUT. This result is the first evidence of PV infection in *A. caraya* from northeastern Argentina, expanding the range of described hosts for these viruses and suggesting new scenarios for their origin and dispersal of PVs.

***Alouatta guariba clamitans* (Brown Howler Monkey)**

The brown howler monkey is endemic to the Atlantic Forest of Brazil and Argentina. Argentina has a small population in the eastern portion of Misiones Province. Some ecological studies started in 2005 in a protected area (El Piñalito Provincial Park 26° 30' S, 53° 50' W), but in 2008, after an outbreak of YFV, the studied monkeys died and the study was interrupted [51•]. In 2012, the species was classified as critically endangered in Argentina due to its highly restricted distribution, low population density, and decline caused by YFV outbreaks [51•]. Since then, studies on this species have been focused on its conservation. Special emphasis on YFV disease was developed to assess the risk of new outbreaks [15, 51•, 52–54]. Eighteen fecal samples were tested by PV, but none of them were positive [50].

Based on unpublished data presented by Kowalewski et al. [40], *Bertiella mucronata* was found in fecal samples of *A. guariba* in an area of sympatry with *A. caraya* in El Piñalito Provincial Park. Although there are studies of other parasites and infectious diseases on *A. guariba clamitans* (e.g., *Papillomavirus* [55], *Plasmodium* spp. [56], *Neospora caninum*, *Sarcocystis* spp., and *Toxoplasma gondii* [57]), these studies were developed in Brazilian populations of the species.

***Aotus azarae* (Owl Monkey)**

Monkeys of the genus *Aotus* are socially monogamous and are the only genus of Neotropical primates that are nocturnal, or cathemeral [58]. Owl monkeys' distribution ranges from Bolivia and Paraguay to Northern Argentina [59]. The Argentinian populations are found in Formosa and Chaco provinces [60]. Forest fragmentation, hunting, and illegal trade are the main threats of the species [60]. Since 1996, this species has been studied in a protected area of Formosa Province with a behavior, genetic, and ecology focus [59]. Parasites of free-ranging *A. azarae* are reported from a protected area (Estancia Guaycolec, 58° 11' W, 25° 58' S). In this area, Perea-Rodríguez et al. [61] aimed to report for the first time the gastrointestinal parasites of social groups and solitary individuals. Through a non-invasive survey, they collected 106 fecal samples of which 92% presented at least one parasite taxon and 60% of them presented multiple infections. They found parasites of the genera *Strongyloides* sp., *Uncinaria* sp., *Taenia* sp., *Trypanoxyrius* sp., *Entamoeba* sp., *Giardia* sp., *Endolimax nana*, *Isoospora* sp., and *Blastocystis* sp. Another study found the DNA of *Leishmania* (*Viannia*) in wild *A. azarae* [62] and also in Estancia Guaycolec. The authors highlight that although they found *L. (Viannia)* for the first time in free-ranging owl monkeys, additional works on eco-epidemiology and parasites are

needed to confirm whether this species is a reservoir or an incidental host.

***Sapajus nigrurus cucullatus* (Black-Horned Capuchin Monkey)**

Black-horned capuchin monkey populations are endemic to the Atlantic Forest and in Argentina, they are exclusive of Misiones Province. This species is usually found in protected and non-protected areas of Misiones, but most of the works has been focused on populations of the National Park Iguazú (PNI, 5° 40' S; 54° 30' W), a protected area of 670.000 has. The population of this site has been a matter of study since 1980, and recently, parasitology surveys have been implemented [63–66]. The first parasitological report of wild *S. nigrurus cucullatus* was published in 2017 by Vanderhoeven et al. [64]. The authors found the filaria *Dipetalonema robini* in the abdominal cavity of a monkey found dead. Up to the time of this writing, there are no reports of *Dipetalonema* species causing diseases in monkeys or humans. Filaroids in general are potentially pathogenic causing damage to the lymphatic system and present zoonotic potential. Consequently, the presence of *Dipetalonema robini* in capuchin monkeys or any other filaroid species could have consequences for human health [64] and monkey conservation. This work is a novel record of the parasite species in Argentina and in *Sapajus nigrurus cucullatus*.

Other parasitological studies have been undertaken with the same groups from PNI. First, a parasite survey was published by Agostini et al. [65]. In this survey, the authors collected 665 fecal samples from recognized individuals of two different groups. The study groups presented different interactions with tourists and access to human food. Through coprological techniques, they found eight helminth taxa *Filariopsis* sp., *Strongyloides* sp., *Trichuris* sp., *Ascaris* sp., an undetermined Subuluridae, an undetermined Physalopteridae, an undetermined Hymenolepididae, and an undetermined Trematode.

In parallel with Agostini et al. [65], studies about the interaction between parasites and nutrition [63] and behavior [66, 67] in the same wild groups of PNI have been published. This site receives hundreds of worldwide tourists on a daily basis, and some monkey groups are in high contact with tourists, with interactions that includes from physical contact to receiving human food. In this way, Agostini et al. [63] manipulated food provisioning and parasite burdens by applying antiparasitic drugs to evaluate if parasitism (parasite richness and loads) affected monkeys by comparing the physical conditions (body mass) in individuals dewormed and not dewormed. According to this work, there was no effect between parasitism and anthelmintic treatment on monkeys' physical condition, and the

authors suggested that parasitism in capuchin monkeys is negligible in normal environmental conditions.

When parasitism and food provisioning were evaluated with monkey's behavior, it was found that food provisioning had greater implication in group social dynamics than parasitism [66] but, when budget activities were analyzed, Agostini et al. [67] found that parasitism increased the time that capuchins dedicate to feeding on invertebrates, decreasing the time to rest. These works are the first parasitological experiments in wild capuchin monkeys.

A recent survey published by Illia et al. [68] analyzed the presence of parasites in the species in five anthropized and fragmented areas of Misiones. Contrary to the case in PNI where monkeys receive food from tourists, in these areas, contact with humans occurs due to forest patches overlapping with farms and cities. The authors found 14 parasite taxa from 158 fecal samples collected from five different study sites of Misiones. The parasites found were coccidia oocyst, *Entamoeba* sp., *Buxtonella* sp., an undetermined Hymenolepididae, *Strongyloides* sp., *Capillaria* sp., *Trichuris* sp., *Filariopsis* sp., an undetermined Ascarididae, an undetermined Strongylida, an undetermined Physalopteridae, an undetermined Subuluridae, and an undetermined Nematoda. The authors compared parasite taxa between sites with different human activities (ecotourism, agriculture and cattle ranching, forestry, rural establishments, and cities) and found a lower frequency in sites with ecotourism.

All the works mentioned above are studying free-ranging populations of monkeys, but parasitism in captive capuchin monkeys has also been studied (e.g., see [69]). Studies with captive monkeys are valuable, but they may not reflect the full range of host-parasite interactions in wild populations [30]. Additionally, until recent, *Sapajus nigritus* and *Sapajus cay* were considered as *Cebus apella* [70]. The available reports described their study models as “capuchin monkeys,” generally without describing the geographical origin of those monkeys. For all of these reasons, we decided not to include data from captive capuchin monkeys in this review. With this in mind, another recent finding related to the papillomavirus was made by Sanchez-Fernandez et al. [50] where they analyzed 15 fecal samples collected at the Iguazú National Park and one oral sample from a captive individual identified as *Sapajus* spp. from the ecological reserve “El Puma” in Misiones Province (27° 27' 36.5" S, 55° 48' 00.5" W). From the samples analyzed, only the sample that came from the captive animal was positive for PV and identified as the genus *Gammmapapillomavirus*. This finding is a novel report of PV in primates of Argentina and can help to understand other characteristics of the virus as its evolution and diversification.

Sapajus cay (Brown-Capped Capuchin Monkey)

The brown-capped capuchin monkey is distributed in Paraguay, southeast of Bolivia, Brazil, and northern Argentina [71]. In Argentina, the species is found in Salta, Jujuy, Chaco, and Formosa provinces [72]. Additionally, a study of the distribution of the Atlantic Forest primates reported *Sapajus cay* in several fragments of Paraguay, at the western border of the province of Misiones, where it inhabits *Sapajus nigritus* [73]. In captivity, *Sapajus nigritus* and *Sapajus cay* are commonly found in Misiones from individuals' victims of the pet trade and illegal capture. *Sapajus cay* captive individuals from the ecological reserve “El Puma” were analyzed for the presence of PV [50], but the geographical origin of those individuals was not mentioned by the authors. Despite that, samples were negative for PV. Until date, we have not found other works related to parasites and infectious diseases neither in captivity nor in free-ranging *Sapajus cay* in Argentina.

Conclusion

Records of parasite diversity and its interaction with primates and the environment are still scarce for the five species that inhabit Argentina. The difficulty to complete data sets and the scarce amount of information on parasitism are generalized to all the Neotropical primates [30]. Many Neotropical primate species and geographical regions are still unexplored [13]. But studies in parasitology are growing among primatologists in our country. Four out of the five species of NHP in Argentina have at least one study in parasitism or infectious diseases of free-ranging populations. The most studied species is *Alouatta caraya* similar to other *Alouatta* species of Latin America, being *Alouatta* the best-studied genus of Neotropical primates [13].

Moreover, if we examine the parasite groups (endoparasites and ectoparasites), there are more studies related to gastrointestinal parasites than blood parasites and ectoparasites. This scenario is repeated in Neotropical primates [13] and may be related to sampling methodology. While gastrointestinal parasite studies use non-invasive techniques (e.g., collecting fecal samples), studies with blood parasites or ectoparasites require capture and sedation of individuals. Different reasons may not enable animal capture. For example, the lack of information about parasites and other infectious pathogens (excluding YFV) in *Alouatta guariba clamitans* is related to its actual conservation status in the country, which makes it difficult to obtain data on its parasites and diseases. Fortunately, new techniques are emerging that allow the analysis of a new range of pathogens previously not considered for non-invasive surveys, for example, the detection of COVID-19 [74] and Herpesvirus-1 [79]

from fecal samples and the detection of viruses that are shed orally from plants discarded by monkeys during foraging [80]. Notwithstanding, given the impact of parasites and other pathogens, studies involving pathogens communities in NHP populations are important to understand primate–parasite associations and their implication on primate behavior, ecology, and transmission routes.

The phylogenetic relationship between humans and NHPs facilitates the possible exchange of parasites and other infectious agents. In Argentina, howlers are health sentinels of the ecosystem due to their lethal sensibility to YFV. This serves as an alert for potential YFV outbreaks that can compromise both human health and conservation of other threatened species living in sympatry. As such, knowledge regarding which parasites are present in primate populations allows a better understanding of wild populations and the ecology of diseases. At the same time, these efforts would provide essential information to assess well-designed conservation strategies and management for these species or forest regions. It is worth emphasizing that these species can be ambassadors of nature (*Alouatta caraya*, *A. guariba*, and *Aotus azarae* are natural monuments in Corrientes, Misiones, and Formosa provinces, respectively). Naming species as monuments gives them social value, creating awareness in people as to how important it is to conserve primates and their habitat.

The species *Sapajus nigritus cucullatus*, *Alouatta caraya*, and *Aotus azarae* have been the subject of long-term research programs. We encourage primatologists to continue with parasitological studies in the current long-term study sites and to take parasitological samples if sedation is needed for other ecological studies (e.g., captures for other reasons such as radio-collar placement). In addition, extend these study areas to work at a regional scale. If possible, include molecular techniques for a more sensitive and specific parasite identification thus enabling a better understanding of parasite ecology, transmission, and host-parasite association. When animals are found dead, we suggest performing necropsies to enhance surveys that use non-invasive techniques. In addition, we recommend including an analysis of parasite communities in areas where primates live in sympatry. Finally, it is crucial to enhance eco-epidemiological studies in all primate species of Argentina to assess populations' health status and vulnerabilities to pathogens with a particular focus on populations with a One Health approach. That is, primate health studies and conservation efforts must include environmental health monitoring and the involvement of human political and social policies.

Declarations

Conflict of Interest The authors declare that they do not have conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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