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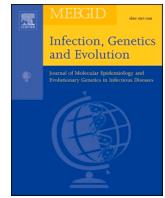
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Research paper

## Diversity of parasites in two captive chimpanzee populations in southern Gabon

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### ABSTRACT

Captive chimpanzees living in confined environments like sanctuaries or primatology centers are frequently affected by gastrointestinal parasites. Some of these are likely to be transmitted to humans and may seriously affect public health. However little information is currently available on the gastrointestinal parasites of primates living in such environments. Here, we characterize the diversity and prevalence of gastrointestinal parasites in two populations of captive chimpanzees living in south-eastern Gabon. Our study reveals that at least nine parasite species infect the chimpanzees with high prevalence, including several helminths (*Ascaris* spp., *Enterobius* spp., *Strongyloides* spp., *Trichuris* spp., *Hymenolepis* spp., *Mammomonogamus* spp), three protozoa (*Balantoides* spp., *Entamoeba* spp. and *Troglodytella* spp) and several unidentified parasites. All the parasite taxa we identified had previously been identified in other primates, including humans. Age, sex and site type may influence infection rates and/or parasite diversity found in a particular host.

### 1. Introduction

Habitat destruction, logging, and bushmeat trade are significant threats to wild primates (Estrada et al., 2017; Etiendem et al., 2013). Once their habitats destroyed, primates are easily killed and survivors are occasionally taken for sale (Nellemann et al., 2010). Sanctuaries offer protection to these survivors (Beck et al., 2007; Macfie and Williamson, 2010) and various species of non-human primates are maintained in captivity in primatology centers and sanctuaries (Harrison et al., 2008; Hosey, 2005).

Parasitic infections are the most common causes of gastrointestinal diseases in captive nonhuman primates (McPherson, 2013; Tangtrongsup et al., 2019). Because these animals are receptive to gastrointestinal parasites which naturally infect humans (Wolfe et al., 1998), they are potential reservoirs for human parasites (Mafuyai et al., 2013; Soulsby, 1982). Great apes maintained in captivity cannot easily be reintroduced to the wild safely (Guynup, 2017; Robins et al., 2019); living in close contact with humans and in confined environments

facilitates the exchange of infectious agents (Nunn and Hare, 2012). This makes it important to assess gastrointestinal parasite prevalence and diversity in such animal populations.

In this preliminary study we investigate two populations of rescued chimpanzees: one housed in a primatology center and the other in a sanctuary, both in south-eastern Gabon. We evaluated the diversity and prevalence of gastrointestinal parasites in these two confined environments. As far as possible, we also assessed the influence of sex, age, season and site on the presence of intestinal parasites.

### 2. Material and methods

#### 2.1. Ethics statement

All faecal samples were collected outside national parks and protected areas, using non-invasive methods, as recommended by the National Ethics Committee of Gabon and with the authorization of the Gabonese Ministries of Water and Forestry, Higher Education, Scientific

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## 2.2. Study sites

We conducted research on gastro-intestinal parasites from February 2017 to March 2018 (13 months) on two populations of chimpanzee: the primatology center at CIRMF (CDP) and the private Lékédi park, both in the Haut-Ogooué province in south-east Gabon (Fig. 1).

Close to the city of Franceville, the CDP environment is strongly impacted by human activities. The CDP houses more than 350 non-human primates of 10 different species, including 54 chimpanzees, 250 mandrills (*Mandrillus sphinx*) and other species of Cercopithecidae. A team of 30 permanent employees and volunteers takes care of the animals, feeding and monitoring them. At night, security agents and dogs guard the center. During this study, we collected faecal samples from 47 chimpanzees during routine health surveys. The other 7 were not included in this study because of their health status: 3 were in quarantine and 4 in retirement.

Lékédi Park is near the town of Bakoumba, approximately 100 km from Franceville; the park covers about 14,000 ha and is completely fenced. Three different types of vegetation are found there: primary forest, secondary forest and savannah, making it a suitable site to receive

chimpanzees and gorillas (*Gorilla gorilla*) seized by the Ministry of Waters and Forest during anti-poaching operations. Three groups of reintroduced chimpanzees being rehabilitated for release into the wild, live there in semi-free ranging conditions. They share the space with wild gorillas and chimpanzees living and circulating freely in the Park. A team of workers takes care of the animals (feeding, nursing, monitoring) from 08:00 h to 17:00 h every day; we collected faecal samples from a group of 23 young semi-free chimpanzees.

## 2.3. Faecal sample collection and examination

We collected samples at each site twice a year, once during the rainy season and once during the dry season. We collected samples <1 h after defecation and examined them the same day. We noted the site, age, sex and season for each sample. Overall, we collected and examined 140 faecal samples. Faecal samples were analyzed via sodium nitrate flotation and faecal sedimentation following the protocol described in Gillespie (2006). As previously described (Boundenga et al., 2018) the detection and counting of parasite eggs, larvae, and cysts was performed using a compound microscope (x10 objective). Egg pictures were captured using a microscope (Leica ICC50 HD) coupled with a computer and using the x40 and x100 objectives. Identification of parasites is based on the morphology and size of the egg shell, nucleus and larvae as

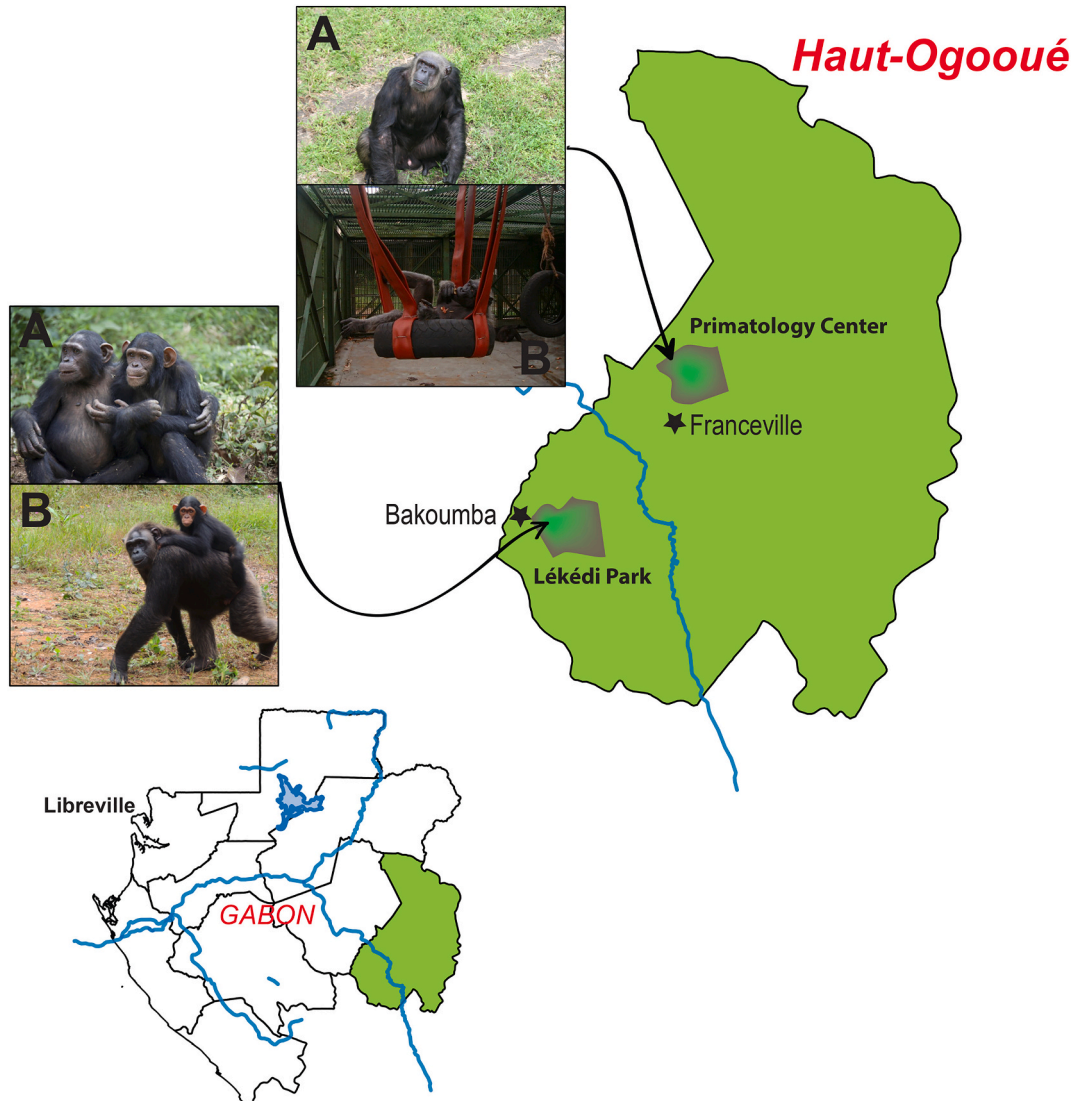


Fig. 1. Map of the study sites in South-east Gabon. This figure shows the different chimpanzees in their environments.

described by Chitwood and Chitwood (1950), Golvan (1990), Ashford and Crewe (2003) and Gillespie (2006). Information about the parasite biology and their host spectrum was obtained from the same sources and from Anderson (2000) and Combes (1996).

Identification using morphometric analysis precludes precise determination at the species level, so we identified positive samples to the genus level when possible. The genus name used is that of the parasite of the same type (order, suborder, family) found in other primates, including humans. When several diagnoses were possible, we chose the most probable based on the parasite's lifecycle and host taxonomy. For most of the parasites, the genus is likely to include several species, so we use the abbreviation "spp". The Strongylidae are a special case; when Strongylidae eggs are detected they are likely to be *Strongyloides* spp., *Oesophagostomum* spp., *Necator* spp. or other members of this group. Among these different taxa only the first one may be identified unambiguously and is therefore designated in the following as *Strongyloides* spp. Without any possibility of identification at the generic level the other Strongylidae are categorized as "strongylid" eggs.

#### 2.4. Statistical analyses

All statistical analyses were performed using R software. Prevalence between sites and sexes were compared using Chi-square ( $\chi^2$ ) tests. We compared seasons using the McNemar test. Differences were considered statistically significant at 0.05 confidence level.

### 3. Results

#### 3.1. Diversity and prevalence of parasite taxa

After examination of 140 faecal samples from chimpanzees, several genera of gastrointestinal parasites were identified (Fig. 2). **Helminths:** *Ascaris* spp., *Enterobius* spp., *Strongyloides* spp., *Trichuris* spp., *Hymenolepis* spp., *Mammomonogamus* spp.; strongylid eggs; unidentified eggs very similar to the eggs of *Toxocara* spp. **Protozoa:** *Balantioides* spp., *Entamoeba* spp. and *Troglodytella* spp.

Among the helminths, *Strongyloides* spp. was the most frequent with an overall prevalence of 67%, followed by "other" strongylid eggs, 57%, *Ascaris* spp. 44% and *Trichuris* spp. 24% (Table 1). For the other taxa, the overall prevalence varied 1–17% (Table 1). Among the protozoans, *Balantioides* spp. had the highest prevalence (66%), followed by *Entamoeba* spp. (48%), while *Troglodytella* spp. was found in 7% of samples (Table 1).

#### 3.2. Effect of site, season and host sex and age on infection prevalence

Infection levels (Table 1) are generally higher at Lékédi Park than at the CDP. Three parasite groups were significantly more frequent in LEK Park than in CDP: strongylid eggs, *Trichuris* spp. and *Mammomonogamus* spp. Two groups found at Lékédi Park, *Hymenolepis* spp. and *Troglodytella* spp., were not found in samples from the CDP. Conversely: *Ascaris* spp. was more frequent in samples from the CDP than from Lékédi Park. *Enterobius* spp. was identified only in samples from the CDP.

A significant difference in infestation rate was observed between the rainy and the dry season ( $p < 0.05$ ). At the CDP, six parasites had a higher prevalence during the rainy season: *Ascaris* sp. ( $p = 0.005$ ), *Strongyloides* spp. ( $p = 0.009$ ), *Enterobius* spp. ( $p = 0.004$ ), *Mammomonogamus* spp. ( $p = 0.023$ ), *Balantioides* spp. ( $p = 0.006$ ) and a group of strongylid eggs ( $p = 0.003$ ) (Table 2). At Lékédi Park, the same difference was observed for four parasite taxa: *Strongyloides* spp. ( $p = 0.006$ ); *Ascaris* spp. ( $p = 0.004$ ); *Trichuris* spp. ( $p < 0.001$ ) and *Mammomonogamus* spp. ( $p = 0.015$ ) (Table 2).

At the CDP, prevalence was significantly higher in males than females ( $p < 0.05$ ) for strongylid eggs, *Balantioides* spp., *Strongyloides* spp. and group of unidentified parasites (Table 3). At Lékédi Park, prevalence was generally higher in males than females but the differences were not

statistically significant (Table 3).

The effect of age could not be evaluated at the CDP because only adult individuals were examined. At Lékédi Park, the prevalence of *Trichuris* spp. and group of unidentified parasites were significantly higher among adults than young animals (Table 4). For other parasites, adults at Lékédi tended to have higher infection rates than young animals, although the comparison was not statistically significant (Table 4).

### 4. Discussion

Several recent studies have reported wide gastrointestinal parasite diversity in African non-human primates (Clough et al., 2010; Howells et al., 2011; Kalousová et al., 2014). With the exception of *Mammomonogamus* spp. all the gastro-intestinal parasites identified in this study had previously been recorded in chimpanzees.

#### 4.1. Helminth parasites

##### 4.1.1. *Strongyloides* spp.

With 67%, the highest prevalence was for *Strongyloides* spp. This prevalence is similar to that found in studies of wild chimpanzees, where *Strongyloides* prevalence was 74–100% (Gillespie et al., 2010; Krief et al., 2005) and higher than reported in several studies of captive chimpanzees (Howells et al., 2011; Landsoud-Soukate et al., 1995; Mbaya and Udendeye, 2011; Petrášová et al., 2010). The parasites identified in our study may be *Strongyloides fuelleborni*, recorded in chimpanzees from Gabon (Hasegawa et al., 2016); but because strongylid eggs are morphologically similar and overlap in size, they may also belong to *Oesophagostomum*, *Necator* or *Trichostrongylus*, which have also been identified in chimpanzees (Pačfo et al., 2019; Krief et al., 2005).

##### 4.1.2. *Ascaris* spp.

With a prevalence of 44%, *Ascaris* spp. has a higher prevalence than previously observed (Mbaya and Udendeye, 2011; Mul et al., 2007). Recent studies suggested the presence of two different species in captive chimpanzees: *A. lumbricoides*, primarily a human parasite, and *A. suum*, a pig parasite likely to be transmitted to humans (da Silva et al., 2003; Nejsun et al., 2010; Zhou et al., 2012). However, recent molecular evidences suggests that these two taxa may be a single species (Leles et al., 2012). Whatever the taxonomy, *Ascaris* spp. seems to be very common among captive chimpanzees, but rare in the wild (Mbaya and Udendeye, 2011; Mul et al., 2007). This could be due to the mode of contamination: ingestion of mature eggs present in soil, and water or food contaminated with human or animal feces (faecoral contamination).

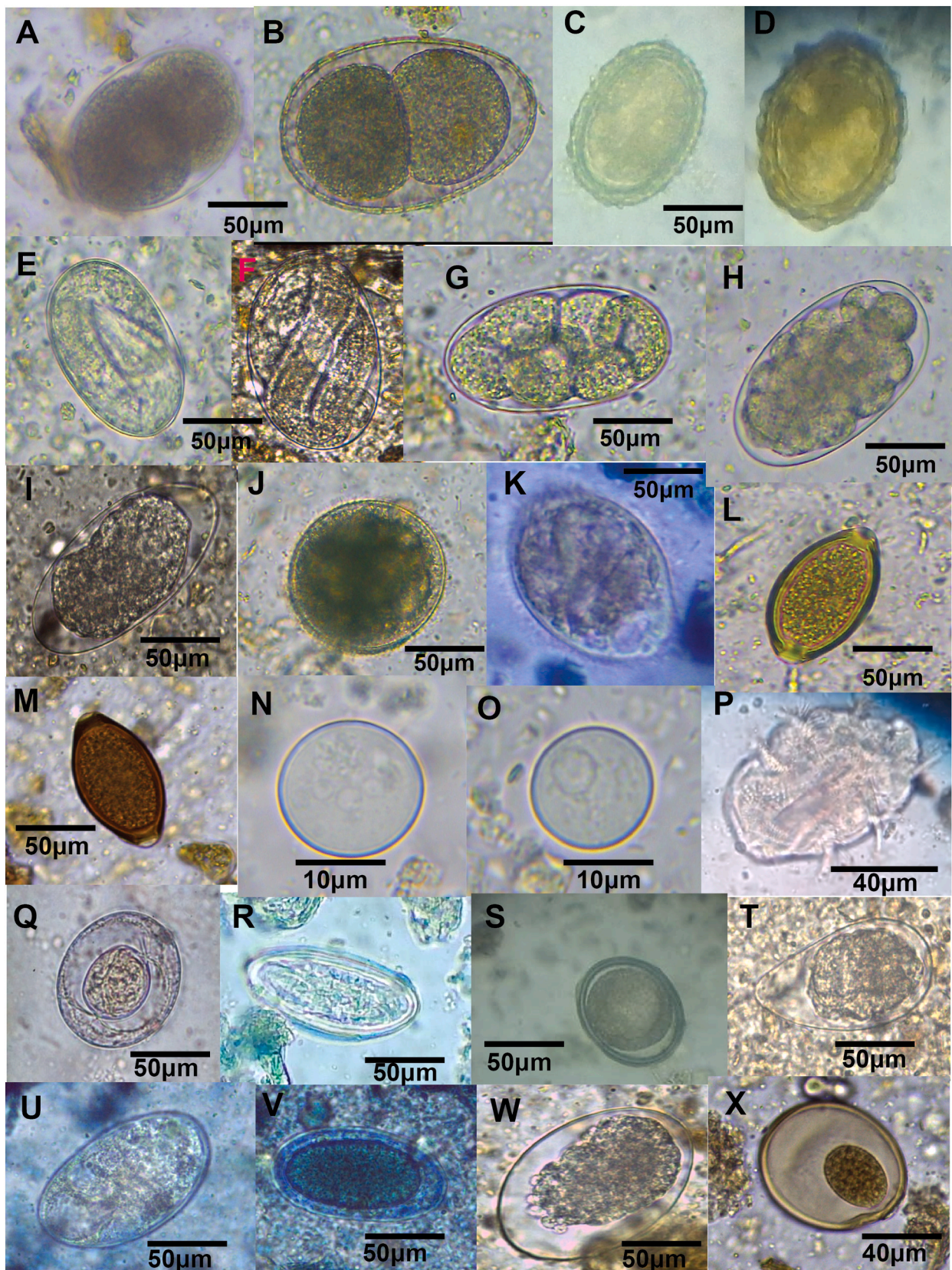
##### 4.1.3. *Trichuris* spp.

*Trichuris* spp. have been reported in captive and wild chimpanzees (Drakulovski et al., 2014; Mbaya and Udendeye, 2011; Petrášová et al., 2010) and are the third most prevalent parasite in our study. For this parasite our results suggest a higher infection rate in captive (23.6%) than wild chimpanzees (between 0 and 5% in Drakulovski et al., 2014; Petrášová et al., 2010). This may be due to higher proximity to humans in captive animals and support the zoonotic potential of this parasite. In all cases in the literature, the parasite was identified as *T. trichiura* (Ghai et al., 2014; Gillespie et al., 2010), which is known to be a common parasite of humans and non-human primates (Barriga, 1982) and sometimes implicated in the death of chimpanzees (Hennessy et al., 1994; Toft, 1982).

##### 4.1.4. *Enterobius* spp.

*Enterobius* spp. have previously been identified in African primates (Ebbert et al., 2015; Gillespie et al., 2010) and infect chimpanzees in captivity (Hasegawa and Udono, 2007; Hugot et al., 1996; Hugot, 1993). The specific parasite species found in wild or captive chimpanzees is *Enterobius anthropopithecii* (Hasegawa and Udono, 2007; Hugot, 1993). However, recent studies reported the presence of *E. vermicularis*, the





**Fig. 2.** Intestinal parasites genus found in captive chimpanzees. *Mammomonogamus* spp. (A, B); *Ascaris* spp. (C, D); *Strongyloides* spp. (E, F); strongylid eggs (G, H, I); *Balantioides* spp. (J, K); *Trichuris* spp. (L, M); *Entamoeba* spp. (N, O); *Troglodytella* spp. (P); *Hymenolepis* spp. (Q); *Enterobius* spp. (R) and unidentified parasites (T, U, W, X).

**Table 1**

Prevalence of gastrointestinal parasites taxa identified during the period of study following the site of collection.

Parasites taxa	Global Prevalence	Chimpanzees				Comparison test					
		CDP		LEK		$\chi^2$	df	p-value	S	CDP	LEK
		N/94 (%)	P	N/46	P (%)						
<b>Helminths</b>											
<i>Ascaris</i> spp	43.57	51	54.26	10	21.74	4.94	1	0.026	+	+	
Strongylid eggs	57.14	34	36.17	46	100	7.62	1	0.000620	+	-	+
<i>Strongyloides</i> spp	67.14	64	68.08	30	91.30	1 <sup>2</sup> .4	1	0.99	-	-	+
<i>Enterobius</i> spp.	7.14	10	10.64	0		3.31	1	0.0684	+	+	-
<i>Trichuris</i> spp.	23.57	13	13.83	20	43.47	7.58	1	0.0059	+	-	+
<i>Hymenolepis</i> spp	1.43	0		2	4.34	0.050	1	0.8219	-	-	+
<i>Mammomonogamus</i>	12.86	7	7.44	11	23.91	4.36	1	0.0367	+	-	+
Unidentified eggs	3.57	5	5.31	0	0		1	0.2424	-	-	+
<b>Protozoas</b>											
<i>Balantioides</i> spp	65.71	53	56.38	39	84.78	1.78	1	0.1818	-	-	+
<i>Entamoeba</i> spp	47.86	36	38.30	31	67.39	2.94	1	0.0865	-	-	+
<i>Troglodytella</i> spp	7.14	0	0	10	21.73	15.2	1	9.522 <sup>e-05</sup>	+	-	+

Comparison of the prevalence between two sites computed using the chi-square test.

**Table 2**

Distribution of infection by parasite taxa according seasonal pattern.

Parasites taxa	Rainy season		Dry season		Comparison test						
	N/47	P (%)	N/47	P(%)	$\chi^2$	df	p-value	S	Rs	Ds	
<b>Primate center</b>											
<i>Ascaris</i> spp	36	76.59	15	31.91	4.916	1	0.0266	+	+		
Strongylid eggs	24	51.01	10	21.28	3.492	1	0.0617	-	+		
<i>Strongyloides</i> spp	45	95.74	19	40.42	5.65	1	0.0175	+	+		
<i>Enterobius</i> spp	10	21.28	0		7.21	1	0.00722	+	+		
<i>Balantioides</i> spp	37	78.72	16	34.04	4.653	1	0.031	+	+		
<i>Entamoeba</i> spp	24	51.06	12	25.53	2.284	1	0.130	-	+		
<i>Trichuris</i> spp	8	17.02	5	10.63	0.234	1	0.628	-	+		
<i>Mammomonogamus</i> spp	7	14.86	0	0	4.69	1	0.030	+	+		
Unidentified parasites	2	4.25	0	0	0.46	1	0.4934	+	+		
<b>Lékédi Park</b>											
<i>Ascaris</i> spp	10	43.47	0	0	6.56	1	0.0105	+	+		
Strongylid eggs	23	100	21	91.30	0.138	1	0.7099	-	+		
<i>Strongyloides</i> spp	23	100	7	30.43	4.35	1	0.037	+	+		
<i>Balantioides</i> spp	23	100	16	69.56	0.371	1	0.54	-	+		
<i>Entamoeba</i> spp	23	100	8	34.78	3.6	1	0.059	+	+		
<i>Trichuris</i> spp	19	82.60	1	4.34	10.33	1	0.0013	+	+		
<i>Troglodytella</i> spp	4	17.39	6	26.08	0.0504	1	0.822	-	-	+	
<i>Mammomonogamus</i> spp	10	43.47	1	4.34	4.5	1	0.033	+	+		
<i>Hymenolepis</i> spp	2	8.69	0	0	0.4392	1	0.508	-	+		

(N = number of positive specimens; P = prevalence; S = +, test significant; + higher prevalence in Rainy season (Rs) or Dry season (Ds).

human pinworm, in captive chimpanzees with a prevalence similar to that observed in our study (Mbaya and Udendeye, 2011). Moreover, infection by *E. vermicularis* in captivity can persist for more than 20 years (Hasegawa and Udono, 2007). Our results show that *Enterobius* spp. was present only at the CDP, where apes are most exposed to humans. Further studies are needed to determine which species are present in our samples.

#### 4.1.5. *Hymenolepis* spp.

*Hymenolepis* spp. occurred in chimpanzees at Lékédi only (1%). The very low prevalence reflects a previous study reporting that it was relatively rare in semi-captive chimpanzees (Mbaya and Udendeye, 2011). Because this parasite is common in humans (Shahnazi et al., 2019), the possibility of host-switching between apes and human must be considered, but needs to be confirmed by further investigations, including molecular studies.

#### 4.1.6. *Mammomonogamus* spp.

*Mammomonogamus* spp. had a prevalence of 13%. This result was unexpected because this parasite is uncommon in chimpanzees and had never been reported before in wild or captive chimpanzees (Mul et al., 2007). Thus, as suggested by Freeman et al., 2004, it is probable that chimpanzees acquire this parasite through ecological interactions with other mammals. Cases of primates infected with *Mammomonogamus* have been observed (Mul et al., 2007; Setchell et al., 2007; Valenta et al., 2017), as well as exchange of this species between gorillas and elephants (Červená et al., 2017).

#### 4.2. Protozoa parasites

Three genera were identified: *Balantioides* spp., *Entamoeba* spp. and *Troglodytella* spp.

##### 4.2.1. *Balantioides* spp.

This parasite is the most prevalent protozoan (66%). and infects a



**Table 3**

Distribution and prevalence of parasite species reported to the gender of chimpanzees collected during the period of study.

Primatology center										
Parasites taxa	Males		Females		Comparison test					
	N/46	P (%)	N/48	P(%)	$\chi^2$	df	p-value	S	M +	F+
<i>Ascaris</i> spp	33	71.73	18	37.5	2.71	1	0.09972	-	+	
<i>Strongylid</i> eggs	29	63.04	10	20.83	6.2475	1	0.01244	+	+	
<i>Strongyloides</i> spp	45	67.40	18	18.75	6.9358	1	0.0085	+	+	
<i>Enterobius</i> spp	2	4.34	8	16.66	1.9921	1	0.1581	-	+	
<i>Balantoides</i> spp	39	84.8	13	27.08	8.3092	1	0.00394	+	+	
<i>Entamoeba</i> spp	22	47.82	14	29.16	1.0972	1	0.2949	-	+	
<i>Trichuris</i> spp	9	19.56	4	8.33	1.158	1	0.2818	-	+	
<i>Mammomonogus</i> spp	7	15.21	0	0	4.918	1	0.027	+	+	
unidentified parasites	3	6.52	0	0	1.334	1	0.248	+	+	

Lékédi Park										F+
Parasites taxa	N/24		P (%)		Comparison test					
	N/24	P (%)	N/22	P(%)	$\chi^2$	df	p-value	S	M +	F+
<i>Ascaris</i> spp	7	29.17	3	13.64	0.458	1	0.498	-	+	
<i>Strongylid</i> eggs	24	100	18	68.18	0.0641	1	0.8001	-	+	
<i>Strongyloides</i> spp	20	83.33	10	45.45	1.02	1	0.311	-	+	
<i>Balantoides</i> spp	19	79.16	20	90.90	0.01	1	0.9223	-	+	+
<i>Entamoeba</i> spp	16	66.67	15	68.18	0	1	1	-	+	+
<i>Trichuris</i> spp	13	54.16	7	31.81	0.4831	1	0.48	-	+	
<i>Troglodytella</i> spp	5	20.83	5	22.72	0	1	1	-	+	
<i>Mammomonogus</i> spp	6	25	5	22.72	0	1	1	-	+	
<i>Hymenolepis</i> spp	2	8.33	0	0	0.365	1	0.5458	-	+	

(N = number of positive specimens; P = prevalence; S = +, test significant; + higher prevalence in males (M) or females (F).

**Table 4**

Distribution of the prevalence of parasites taxa reported to the age of chimpanzees collected during the period of the study.

Lékédi Park											Y
Parasites taxa	Adults (>12 years)		Young (<12 years)		Comparison test						
	N/26	P (%)	N/20	P (%)	$\chi^2$	df	p-value	S	A	Y	
											<i>Ascaris</i> spp
<i>Strongylid</i> eggs	23	73.07	20	100	0.0055	1	0.9408	-	+	+	
<i>Strongyloides</i> spp	24	92.31	8	40	2.055	1	0.151	-	+		
<i>Balantoides</i> spp	24	92.31	15	75	0.0611	1	0.8048	-	+		
<i>Entamoeba</i> spp	11	42.30	20	100	2.45	1	0.1142	-	+	+	
<i>Trichuris</i> spp	18	69.23	2	10	5.6046	1	0.018	+	+		
<i>Troglodytella</i> spp	9	34.61	1	5	2.62	1	0.1049	-	+		
<i>Hymenolepis</i> spp	2	7.69	0	0	0.239	1	0.625	-	+		
<i>Mammomonogus</i> spp.	11	42.30	0	0	5.5825	1	0.0181	+	+		

(N = number of positive specimens; P = prevalence; S = +, test significant; + higher prevalence in adults (A) or young (Y).

variety of hosts (Barbosa et al., 2018; da Silva Barbosa et al., 2017), including captive primates (Mbaya and Udendeye, 2011; Pomajbikova et al., 2013). The prevalence observed here matches the results of a study by Pomajbiková et al. (2010) but is higher than in another study in Nigeria which reported an infection rate of 8.7% (Mbaya and Udendeye, 2011). Because this parasite is unknown in wild chimpanzees (Pomajbiková et al., 2010), the difference could be related to the captive conditions. Finally since our method does not allow identification at the specific level, we cannot exclude the possibility that our observation corresponds to another parasite in this group: *Neobalantidium coli*, recently identified in captive primates, including chimpanzees (Pomajbiková et al., 2010).

#### 4.2.2. *Entamoeba* spp.

With 48% prevalence this parasite is the second most prevalent protozoan in our samples. Parasites of this group have been observed in captive chimpanzees in Nigeria and in Japan (Mbaya and Udendeye, 2011; Mul et al., 2007; Tachibana et al., 2000). In both cases, however, prevalence was much lower than observed in our study, although an outbreak was associated with severe mortality in chimpanzees (Mbaya and Nwosu, 2005). Recent studies have reported the presence of at least three species of *Entamoeba* (*Entamoeba histolytica*, *E. hartmanni* and

*E. coli*) infecting chimpanzees living in captivity or in the wild (Jirku-Pomajbikova et al., 2016). This suggests that the parasites identified here may belong to different species, and molecular approaches are needed to identify these protists. Because humans are considered the main reservoir for this pathogen, our observations suggest exchanges of parasites between humans and apes.

#### 4.2.3. *Troglodytella* spp.

With a prevalence of 7%, *Troglodytella* spp. have the lowest rate among the protozoa. Two species of Entodiniomorphida have been recorded in captive and wild apes: *Troglodytella abrossarti* and *Troglodytella cava* (McLennan et al., 2017; Modry et al., 2009; Mul et al., 2007; Petzelkova et al., 2012; Ruzicova et al., 2014). In captive apes, infection by *T. cava* tends to gradually disappear (Modry et al., 2009), which may explain why only *T. abrossarti* was observed in our work (Fig. 2). This hypothesis is reinforced by a study showing that chimpanzees at Lope Park (Gabon) had a prevalence of *Troglodytella* spp. around 4 times higher than we observed in our study (Landsoud-Soukate et al., 1995).

## 5. Conclusion

Our work reveals very similar parasite diversity in two groups of

captive chimpanzees in Gabon. Factors as habitat, season, sex and host age may affect parasite prevalence and diversity. The lower prevalence observed at the CDP could be due to the fact that animals living there are treated with antiparasitic medication more often, while the animals at Lékédi live in almost natural conditions. Our study shows that the rainy season seems to have a significant influence on parasite prevalence. This result is consistent with previous studies (Altizer et al., 2006; Huffman et al., 1997), showing higher parasite prevalence in monkeys during the rainy season or parasite lowest egg abundance and prevalence during the dry season (Setchell et al., 2007). Four parasite genera (*Strongyloides*, *Balantioides*, *Mammomonogamus* and an unidentified strongyloid), have a significantly higher infection rate in males than in females; dissimilarities that are probably related to differences in behavior or physiology between the sexes (Poulin, 1996). For two parasites (*Trichuris* spp. and *Mammomonogamus* spp) a higher occurrence rate was observed in adults than in young animals. This observation suggests an age effect for these parasites, as proposed by MacIntosh et al. (2010) and Mbaya and Udendeye (2011).

All parasite taxa identified in our study were previously found in other primate hosts including captive or wild apes, and/or humans. This suggests that some parasites found here could be zoonotic; to confirm this hypothesis we need a precise identification of the parasites at the species level, which is not feasible using coprological analyses based on morphological examination. Determination of the parasites could be improved through the use of molecular analysis but these methods were not accessible in the context of the present study. This study must therefore be considered preliminary and additional observations are needed to confirm our conclusions. This study also suggests the interest that there might be to periodically monitor the intestinal parasites of staff and other animals working and/or living close together.

## Conflicts of interest

The authors declare no conflict of interest.

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## Authorship contribution statement

**LB:** Conceptualization; Data curation; Writing - original draft

**NB:** Resources; Supervision; Writing - review & editing

**NM:** Data curation, Investigation; Writing - review & editing

**SD:** Methodology, Investigation

**CM:** Formal analysis, Validation

**JPH:** Writing - review & editing

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## References

- Altizer, S., Dobson, A., Hosseini, P., Hudson, P., Pascual, M., Rohani, P., 2006. Seasonality and the dynamics of infectious diseases. *Ecol. Lett.* 9, 467–484.
- Anderson, R.C., 2000. *Nematode Parasites of Vertebrates: their Development and Transmission*, 10016. Cabi Publishing, New York, NY.
- Ashford, R., Crewe, W., 2003. *Parasites of Homo sapiens: An Annotated Checklist of the Protozoa, Helminths and Arthropods for which we are Home*. CRC Press.
- Barbosa, A.D.S., Barbosa, H.S., Souza, S.M.O., Dib, L.V., Uchoa, C.M.A., Bastos, O.M.P., Amendoeira, M.R.R., 2018. *Balantioides coli*: morphological and ultrastructural characteristics of pig and non-human primate isolates. *Acta Parasitol.* 63, 287–298.

- Barriga, O., 1982. Trichuriasis. In: Section C: Parasitic Zoonoses. CRC Handbook Series in Zoonoses, 2, pp. 339–345.
- Beck, B., Rodrigues, M., Travis, D., Unwin, S., 2007. Best Practice Guidelines for the Re-Introduction of Great Apes. IUCN.
- Boundenga, L., Moussadjji, C., Mombo, I.M., Ngoubangoye, B., Lekana-Douki, J.B., Hugot, J.-P., 2018. Diversity and prevalence of gastrointestinal parasites in two wild Galago species in Gabon. *Infect. Genet. Evol.* 68, 249–256. <https://doi.org/10.1016/j.meegid.2018.04.035>.
- Červená, B., Vallo, P., Pafčo, B., Jirků, K., Jirků, M., Petrželková, K.J., Todd, A., Turkalo, A.K., Modrý, D., 2017. Host specificity and basic ecology of *Mammomonogamus* (Nematoda, Syngamidae) from lowland gorillas and forest elephants in Central African Republic. *Parasitology* 144, 1016–1025.
- Chitwood, B.G., Chitwood, M.B., 1950. *An Introduction to Nematology* Section 1: Anatomy.
- Clough, D., Heistermann, M., Kappeler, P.M., 2010. Host intrinsic determinants and potential consequences of parasite infection in free-ranging red-fronted lemur (*Eulemur fulvus rufus*). *Am. J. Phys. Anthropol.* 142, 441–452.
- Combes, C., 1996. Parasites, biodiversity and ecosystem stability. *Biodivers. Conserv.* 5, 953–962.
- da Silva Barbosa, A., Ponce-Gordo, F., Dib, L.V., Antunes Uchoa, C.M., Bastos, O.M.P., Pissinatti, A., Amendoeira, M.R.R., 2017. First molecular characterization of *Balantioides coli* (Malmsten, 1857) isolates maintained in vitro culture and from feces of captive animals, Rio de Janeiro, Brazil. *Vet. Parasitol. Reg. Stud. Rep.* 10, 102–113.
- da Silva, N.R., Brooker, S., Hotez, P.J., Montresor, A., Engels, D., Savioli, L., 2003. Soil-transmitted helminth infections: updating the global picture. *Trends Parasitol.* 19, 547–551.
- Drakulovski, P., Bertout, S., Locatelli, S., Butel, C., Pion, S., Mpoudi-Ngole, E., Delaporte, E., Peeters, M., Mallié, M., 2014. Assessment of gastrointestinal parasites in wild chimpanzees (pan troglodytes troglodytes) in Southeast Cameroon. *Parasitol. Res.* 113, 2541–2550.
- Ebbert, M., McGrew, W., Marchant, L., 2015. Differences between chimpanzee and baboon gastrointestinal parasite communities. *Parasitology* 142, 958–967.
- Estrada, A., Garber, P.A., Rylands, A.B., Roos, C., Fernandez-Duque, E., Di Fiore, A., Nekaris, K.A.-I., Nijman, V., Heymann, E.W., Lambert, J.E., 2017. Impending extinction crisis of the world's primates: why primates matter. *Sci. Adv.* 3, e1600946.
- Etiendem, D.N., Tagg, N., Hens, L., Pereboom, Z., 2013. Impact of human activities on Cross River gorilla *Gorilla gorilla diehli* habitats in the Mawambi Hills, Southwest Cameroon. *Endanger. Species Res.* 20, 167–179.
- Freeman, A.S., Kinsella, J.M., Cipolletta, C., Deem, S.L., Karesh, W.B., 2004. Endoparasites of western lowland gorillas (*Gorilla gorilla gorilla*) at Bai Hokou, Central African Republic. *J. Wildl. Dis.* 40, 775–781.
- Ghai, R.R., Simons, N.D., Chapman, C.A., Omeja, P.A., Davies, T.J., Ting, N., Goldberg, T. L., 2014. Hidden population structure and cross-species transmission of whipworms (*Trichuris* sp.) in humans and non-human primates in Uganda. *PLoS Negl. Trop. Dis.* 8 (e3256).
- Gillespie, T.R., 2006. Noninvasive assessment of gastrointestinal parasite infections in free-ranging primates. *Int. J. Primatol.* 27, 1129.
- Gillespie, T.R., Lonsdorf, E.V., Canfield, E.P., Meyer, D.J., Nadler, Y., Raphael, J., Pusey, A.E., Pond, J., Pauley, J., Mlengeya, T., 2010. Demographic and ecological effects on patterns of parasitism in eastern chimpanzees (pan troglodytes schweinfurthii) in Gombe National Park, Tanzania. *Am. J. Phys. Anthropol.* 143, 534–544.
- Golvan, Y.J., 1990. *Atlas de Parasitologie: Schémas Explicatifs D'épidémiologie (Le Léopard d'or)*.
- Guynup, S., 2017. African Great Ape Bushmeat Crisis Intensifies; Few Solutions in Sight. Mongabay, July 7.
- Harrison, R.M., Nystrom, P., Mehu, M., Dunbar, R.I., Waters, S.S., Picone, B., Dumas, F., Stanyon, R., Lannino, A., Bigoni, F., 2008. Iberian primatology: present and future challenges. *Folia Primatol.* 79, 283–304.
- Hasegawa, H., Udono, T., 2007. Chimpanzee pinworm, *Enterobius anthropopitheci* (Nematoda: Oxyuridae), maintained for more than twenty years in captive chimpanzees in Japan. *J. Parasitol.* 93, 850–853.
- Hasegawa, H., Kalousova, B., McLennan, M.R., Modry, D., Profousova-Psenkova, I., Shutt-Phillips, K.A., Todd, A., Huffman, M.A., Petrzelkova, K.J., 2016. Strongyloides infections of humans and great apes in Dzanga-Sangha protected areas, Central African Republic and in degraded forest fragments in Bulindi, Uganda. *Parasitol. Int.* 65, 367–370.
- Hennessy, A., Phippard, A., Harewood, W., Horam, C., Horvath, J., 1994. Helminthic infestation complicated by intussusception in baboons (*Papio hamadryas*). *Lab. Anim.* 28, 270–273.
- Hosey, G.R., 2005. How does the zoo environment affect the behaviour of captive primates? *Appl. Anim. Behav. Sci.* 90, 107–129.
- Howells, M.E., Pruetz, J., Gillespie, T.R., 2011. Patterns of gastro-intestinal parasites and commensals as an index of population and ecosystem health: the case of sympatric Western chimpanzees (pan troglodytes verus) and Guinea baboons (*Papio hamadryas papio*) at Fongoli, Senegal. *Am. J. Primatol.* 73, 173–179.
- Huffman, M.A., Gotoh, S., Turner, L.A., Hamai, M., Yoshida, K., 1997. Seasonal trends in intestinal nematode infection and medicinal plant use among chimpanzees in the Mahale Mountains, Tanzania. *Primates* 38, 111–125.
- Hugot, J., 1993. Redescription of *Enterobius anthropopitheci* (Gedoelst, 1916) (Nematoda, Oxyurida), a parasite of chimpanzees. *Syst. Parasitol.* 26, 201–207.
- Hugot, J.-P., Gardner, S.L., Morand, S., 1996. The Enterobiinae subfam. nov. (Nematoda, Oxyurida) pinworm parasites of primates and rodents. *Int. J. Parasitol.* 26, 147–159.



- Jirku-Pomajbíková, K., Cepicka, I., Kalousova, B., Jirku, M., Stewart, F., Levecke, B., Modry, D., Piel, A.K., Petrzalkova, K.J., 2016. Molecular identification of *Entamoeba* species in savanna woodland chimpanzees (*pan troglodytes schweinfurthii*). *Parasitology* 143, 741–748.
- Kalousova, B., Piel, A.K., Pomajbíková, K., Modrý, D., Stewart, F.A., Petrzalková, K.J., 2014. Gastrointestinal parasites of savanna chimpanzees (*pan troglodytes schweinfurthii*) in Ugalla, Tanzania. *Int. J. Primatol.* 35, 463–475.
- Krief, S., Huffman, M.A., Sévenet, T., Guillot, J., Bories, C., Hladik, C.M., Wrangham, R. W., 2005. Noninvasive monitoring of the health of *pan troglodytes schweinfurthii* in the Kibale National Park, Uganda. *Int. J. Primatol.* 26, 467–490.
- Landsoud-Soukate, J., Tutin, C., Fernandez, M., 1995. Intestinal parasites of sympatric gorillas and chimpanzees in the lope reserve, Gabon. *Ann. Trop. Med. Parasitol.* 89, 73–79.
- Leles, D., Gardner, S.L., Reinhard, K., Iñiguez, A., Araujo, A., 2012. Are *Ascaris lumbricoides* and *Ascaris suum* a single species? *Parasit. Vectors* 5, 42.
- Macfie, E.J., Williamson, E.A., 2010. Best Practice Guidelines for Great Ape Tourism. IUCN.
- MacIntosh, A.J., Hernandez, A.D., Huffman, M.A., 2010. Host age, sex, and reproductive seasonality affect nematode parasitism in wild Japanese macaques. *Primates* 51, 353–364.
- Mafuyai, H., Barshep, Y., Audu, B., Kumbak, D., Ojobe, T., 2013. Baboons as potential reservoirs of zoonotic gastrointestinal parasite infections at Yankari National Park, Nigeria. *Afr. Health Sci.* 13, 252–254.
- Mbaya, A., Nwosu, C., 2005. Outbreak of clinical amoebiasis among captive chimpanzees (*pan troglodytes*) at the Sanda Kyarima park, Maiduguri, Nigeria. *Niger. Vet. J.* 27, 68–73.
- Mbaya, A., Udendeye, U., 2011. Gastrointestinal parasites of captive and free-roaming primates at the Afi Mountain Primate Conservation area in Calabar, Nigeria and their zoonotic implications. *Pak. J. Biol. Sci.* 14, 709.
- McLennan, M.R., Hasegawa, H., Bardi, M., Huffman, M.A., 2017. Gastrointestinal parasite infections and self-medication in wild chimpanzees surviving in degraded forest fragments within an agricultural landscape mosaic in Uganda. *PLoS One* 12, e0180431.
- McPherson, F., 2013. Normal blood parameters, common diseases and parasites affecting captive non-human primates. *J. Primatol.* 2, e112.
- Modry, D., Petrzalkova, K.J., Pomajbíková, K., Tokiwa, T., KRÍZEK, J., Imai, S., Vallo, P., Profousova, I., SLAPETA, J., 2009. The occurrence and ape-to-ape transmission of the entodiniomorphid ciliate *Troglodytella abressarti* in captive gorillas. *J. Eukaryot. Microbiol.* 56, 83–87.
- Mul, I.F., Paembonan, W., Singleton, I., Wich, S.A., van Bolhuis, H.G., 2007. Intestinal parasites of free-ranging, semicaptive, and captive *Pongo abelii* in Sumatra, Indonesia. *Int. J. Primatol.* 28, 407–420.
- Nejsum, P., Bertelsen, M.F., Betson, M., Stothard, J.R., Murrell, K.D., 2010. Molecular evidence for sustained transmission of zoonotic *Ascaris suum* among zoo chimpanzees (*pan troglodytes*). *Vet. Parasitol.* 171, 273–276.
- Nellemann, C., Redmond, L., Refisch, J., 2010. The Last Stand of the Gorilla: Environmental Crime and Conflict in the Congo Basin (UNEP/Earthprint).
- Nunn, C.L., Hare, B., 2012. Pathogen flow: what we need to know. *Am. J. Primatol.* 74, 1084–1087.
- Pafčo, B., Kreisinger, J., Čížková, D., Pšenková-Profousova, I., Shutt-Phillips, K., Todd, A., Modrý, D., 2019. Genetic diversity of primate strongylid nematodes: do sympatric nonhuman primates and humans share their strongylid worms? *Mol. Ecol.* 28 (21), 4786–4797.
- Petrášová, J., Modrý, D., Huffman, M.A., Mapua, M.I., Bobáková, L., Mazoch, V., Singh, J., Kaur, T., Petrzalková, K.J., 2010. Gastrointestinal parasites of indigenous and introduced primate species of Rubondo Island National Park, Tanzania. *Int. J. Primatol.* 31, 920–936.
- Petrzalkova, K.J., Schovancova, K., Profousova, I., Kisidayova, S., Varadyova, Z., Pekar, S., Kamler, J., Modry, D., 2012. The effect of low- and high-fiber diets on the population of entodiniomorphid ciliates *Troglodytella abressarti* in captive chimpanzees (*Pan troglodytes*). *Am. J. Primatol.* 74, 669–675.
- Pomajbíková, K., Petrzalková, K.J., Profousova, I., Petrášová, J., Modrý, D., 2010. Discrepancies in the occurrence of *Balantidium coli* between wild and captive African great apes. *J. Parasitol.* 96, 1139–1144.
- Pomajbíková, K., Obornik, M., Horak, A., Petrzalkova, K.J., Grim, J.N., Levecke, B., Todd, A., Mulama, M., Kiyang, J., Modry, D., 2013. Novel insights into the genetic diversity of *Balantidium* and *Balantidium*-like cyst-forming ciliates. *PLoS Negl. Trop. Dis.* 7, e2140.
- Poulin, R., 1996. Sexual inequalities in helminth infections: a cost of being a male? *Am. Nat.* 147, 287–295.
- Robins, J.G., Husson, S., Fahroni, A., Singleton, L., Nowak, M.G., Fluch, G., Llano Sanchez, K., Widya, A., Pratje, P., Ancrenaz, M., 2019. Implanted radio telemetry in orangutan reintroduction & post-release monitoring and its application in other ape species. *Front. Vet. Sci.* 6, 111.
- Ruzicova, M., Petrzalkova, K.J., Kalousova, B., Modry, D., Pomajbíková, K., 2014. Validation of FLOTAC for the detection and quantification of *Troglodytella abressarti* and *Neobalantidium coli* in chimpanzees and pigs. *J. Parasitol.* 100, 662–670.
- Setchell, J.M., Bedjabaga, I.-B., Goossens, B., Reed, P., Wickings, E.J., Knapp, L.A., 2007. Parasite prevalence, abundance, and diversity in a semi-free-ranging colony of *Mandrillus sphinx*. *Int. J. Primatol.* 28, 1345–1362.
- Shahnazi, M., Mehrizi, M.Z., Alizadeh, S.A., Heydarian, P., Saraei, M., Alipour, M., Hajjalilo, E., 2019. Molecular characterization of *Hymenolepis nana* based on nuclear rDNA ITS2 gene marker. *Afr. Health Sci.* 19, 1346–1352.
- Soulsby, E., 1982. Helminths. In: *Arthropods and Protozoa of Domesticated Animals*, p. 291.
- Tachibana, H., Cheng, X.J., Kobayashi, S., Fujita, Y., Udono, T., 2000. *Entamoeba dispar*, but not *E. histolytica*, detected in a colony of chimpanzees in Japan. *Parasitol. Res.* 86, 537–541.
- Tangtrongsup, S., Sripakdee, D., Malaivijitnond, S., Angkuratipakorn, R., Lappin, M., 2019. Intestinal parasites and the occurrence of zoonotic *Giardia duodenalis* genotype in captive gibbons at Krabokkoo wildlife breeding center, Thailand. *Front. Vet. Sci.* 6, 110.
- Toft, J., 1982. The pathoparasitology of the alimentary tract and pancreas of nonhuman primates: a review. *Vet. Pathol.* 19, 44–92.
- Valenta, K., Twinomugisha, D., Godfrey, K., Liu, C., Schoof, V.A., Goldberg, T.L., Chapman, C.A., 2017. Comparison of gastrointestinal parasite communities in vervet monkeys. *Integr. Zool.* 12, 512–520.
- Wolfe, N.D., Escalante, A.A., Karesh, W.B., Kilbourn, A., Spielman, A., Lal, A.A., 1998. Wild primate populations in emerging infectious disease research: the missing link? *Emerg. Infect. Dis.* 4, 149.
- Zhou, C., Li, M., Yuan, K., Deng, S., Peng, W., 2012. Pig *Ascaris*: an important source of human ascariasis in China. *Infect. Genet. Evol.* 12, 1172–1177.