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Epidemiological Significance of Parasitic Infections in Olive Baboons (*Papio anubis*) at Gombe National Park, Tanzania

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Abstract

Several parasites of significant health importance have been observed in baboons at Gombe National Park in western Tanzania. However, little is known on impacts these infections have on baboon health. Baboon stools were examined for parasites using formol-ethyl technique and their health and troop membership associated with parasitic infections. Observed nematode parasites were; *Streptopharagus* sp., *Physaloptera* sp., unidentified nematodes, hookworms and *Trichuris* sp. Trematode parasites included *Schistosoma mansoni* and unidentified trematode, with the latter's intensity being highest in DB troop baboons. Parasite egg counts (epg) for nematodes ranged from 9 to 12, and that of trematodes from 4 to 40 epg. *Trichuris* sp. was most prevalent while *Streptopharagus* sp. was least common. Female baboons in crab-feeding C troop had significantly lower body weight than others ($p < 0.05$). The present observation of schistosomiasis in Gombe baboons suggests the disease may have been maintained among the animals since its introduction in the park in the 1980s. Baboons in C and DB troops in Gombe are most likely infected with food-borne unidentified trematodes. For years, the baboons have remained constant in size and are emaciated and weak-looking suggesting that there is probably a link between the parasites and the animals' poor health.

Keywords: Parasitic infections, baboon health, trematodes, Gombe.

Introduction

Free-ranging primate species harbour a number of parasites, some of which can have significant influence on their populations and health (McGrew et al. 1989, Müller-Graf et al. 1997, Wallis and Lee 1999, Murray et al. 2000). Previous parasitological studies in baboons (*Papio anubis*) at Gombe National Park, Tanzania, have for instance reported various intestinal helminths from the animals, including some such as *Trichuris* sp., *Strongyloides* sp. and hookworms that also infect humans (McGrew et al. 1989, Müller-Graf et al. 1997, Murray et al. 2000). In this area, non-human primates such as baboons interact regularly with humans, including sharing resources such as stream water and forests (Wallis and Lee 1999). The park is comparatively small in size and is surrounded and threatened by human settlements and activities to all its borders (Inskipp 2005, Pusey et al. 2007). The shrinking of wildlife habitats in many parts of the world has brought people and wild animals closer while raising the risks for sharing diseases and parasites among them. For instance, the observation of unusually high prevalence of *S. mansoni* in baboons with regular humans contacts at Gombe National Park in the 1990s (Müller-Graf et al. 1997, Wallis and Lee 1999), was a good illustration of this point. Thus, proper identification and monitoring of parasitic infections in such areas is important for improving animal health and for controlling possible spill over of animal diseases into nearby human populations.

Other parasitic infections that have been detected in the Gombe baboons include notably the unidentified trematodes, which were tentatively recognized as *Paragonimus* species (Müller-Graf et al. 1997).

Little is known about the epidemiology and possible association of parasitic infections with baboon health at Gombe, particularly for trematode species such as *S. mansoni* and putative *Paragonimus* despite their demonstrated high egg burden and variability among the animals (Müller-Graf et al. 1997, Bakuza 2012). The present study examined the possible link between parasitic infections and baboon health at Gombe National Park, Tanzania. The study specific objectives were to identify current intestinal parasites in baboons at Gombe National Park and determine the prevalence and intensity of the infections in the park. The study also intended to examine the identity and health implications of the presence of *Paragonimus*-like parasites in the Gombe baboon populations by comparing the body conditions and reproductive rates of the different baboon troops with their levels of infections for the parasite.

Materials and Methods

Humane care guidelines

The permission to conduct this study was granted by the Tanzania Wildlife Research Institute (Permit Ref. No. TNP/HQ/E.20/08B). Samples were obtained from baboons in accordance with accepted animal welfare guidelines for working with wildlife subjects for research purposes (Bakuza 2012) and without immobilising or touching them.

Study area

The study was carried between April 2010-November 2011 and June – December 2018 in Gombe National Park. The park is located in western Tanzania about 16 km north of Kigoma town (4.6908° S, 29.6272° E) on the eastern side of Lake Tanganyika (Figure 1).

The studied baboon community

The studied baboon populations at Gombe have been under daily observations of their behaviour and feeding ecology since 1967 (Ransom 1981). They are thus habituated to humans and can therefore be approached when studying or observing them. They can also be distinguished and identified individually by the researchers. The baboons live mainly in the forest area, although the home ranges for most baboon troops, which largely overlap each other, extend to the beaches of Lake Tanganyika and into the research station in the centre of Gombe National Park (Figure 1).

Wild baboon populations are organized in permanent and complex units called troops (Nash 1976), although the word group with which it is sometimes used interchangeably, describes a more loose and temporary baboon social organization. Baboon troops at Gombe have been splitting to form new ones. At the time of this study, six recognized troops included AC, which was originally the A-troop, BA and BB that split from the B-or Beach group, and DA, DB and DC troops, which were originally the D-troop (Ransom 1981). The home ranges of the troops such as DA, DC and AC overlap with each other as well as with the restricted human residential areas at Gombe (Figure 1). The spatial distribution of the baboon troops in Gombe are described in Bakuza (2012), while detailed descriptions are found in Müller-Graf (1994).

Study design, sample size and sampling strategy

Sampling strategy was performed as detailed elsewhere (Bakuza 2012). In general, 30 individuals were sampled per troop from larger baboon troops, i.e., BA, DA and DC troops, whose populations each exceeded 30 individuals (Bakuza 2012). Randomization for sampling in these troops was achieved by putting names of known individual baboons into a container and randomly selecting those to sample. In the small baboon troops such as AC, BB and DB whose size were below 30 individuals (Domb and Pagel 2001, Bakuza 2012), all members of the group were targeted. Age groups in the baboons were classified according to other workers (Pereira 1989, Müller-Graf 1994); with juveniles being aged 3-5 years, adolescents 5-8 years and adults over 8 years.

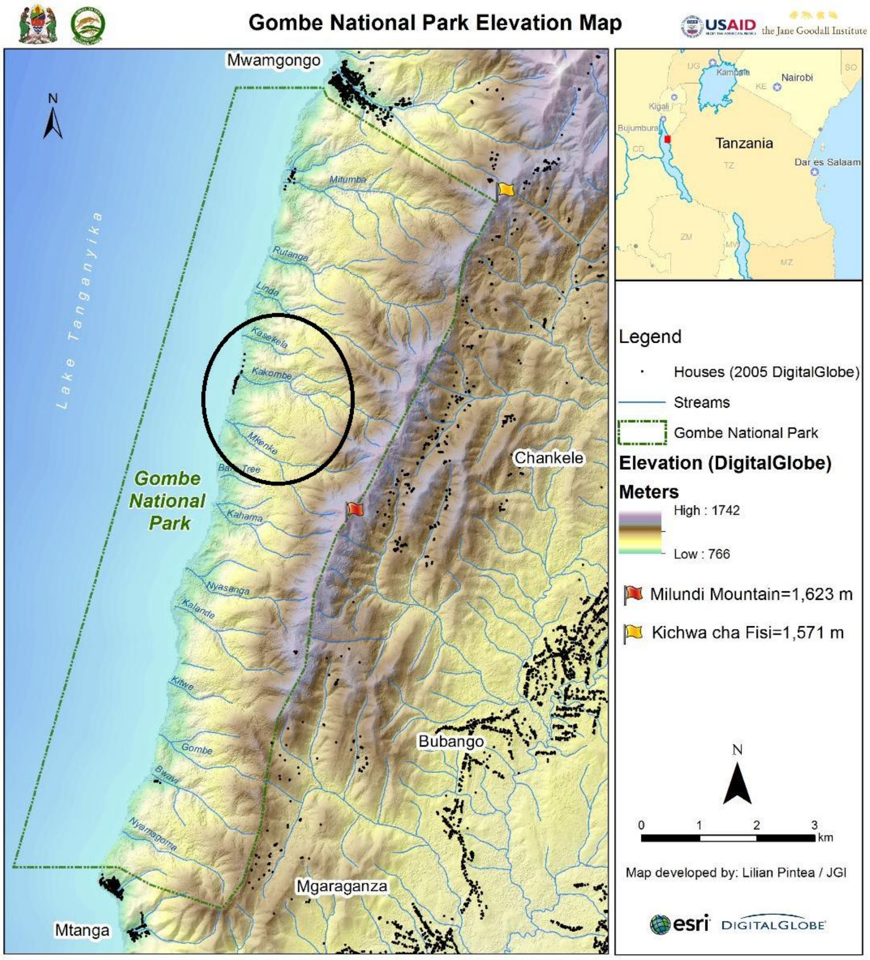


Figure 1: Gombe National Park located in western Tanzania (insert map: top right corner) showing the park's boundaries and other key features. The location of baboon troops sampled at Kasekela in the centre of the park is indicated by a circle. Map source: Courtesy of Lilian Pintea of the Jane Goodall Institute.

Collection and preservation of stool samples

Faecal samples from baboons were collected by field assistants from the Gombe Stream Research Centre who could identify all individual animals in the study-troops. Baboons were watched as they fed in the forest and approximately 5 g of stool sample picked up immediately after defaecation and preserved in 20 ml vials containing buffered 10% formalin. At least two stool samples were targeted from each individual baboon in the habituated troops, with one sample collected in the wet season (January-April) and another in the dry season (July-September) in 2010. Seasons were defined as previously described, with the wet season running from October to May, and the dry season from June to September (Goodall 1986, Collins and McGrew 1988, Müller-Graf 1994).

Laboratory examination and identification of parasites

Formalin-preserved faecal samples were examined for parasite eggs in the Zoology Laboratory at the University of Dar es Salaam, Tanzania using the formol-ethyl concentration technique as described in literature (Allen and Ridley 1970, WHO 1991, Cheesbrough 1998). Observed parasite eggs were identified based on morphology, size and other recommended guidelines, keys and photographs (WHO 1991, Müller-Graf 1994, Cheesbrough 1998).

Inspection of long-term research data at Gombe to assess the health status and reproductive rates in baboons

In addition to the visual assessment of baboon's overall health, determination of their body conditions, death rates, emigration and reproductive rates was also made by analysing the long-term project-data archived at Gombe from 2010 to 2018. The assessment results were then compared with the levels of parasite infections for each individual baboon.

Data analysis

Infection intensity, as indicated by parasite egg counts, was expressed as the number of eggs in 1 g of stool (eggs per gram or epg) for each infected individual host (WHO 1991, Montresor et al. 1998). Infection prevalence was calculated as the percentage of infected individuals out of all examined individuals (Bush et al. 1997). Prevalence for each parasite taxon was coded as one (1) when a parasite species was present and zero (0) if it was not detected followed by analysis with Generalized Linear Models (GLMs) under a binomial distribution, as previously used (Bakuza 2012) and suggested by Zuur et al. (2009). Zero-inflated negative binomial models (ZINB) were used to analyze variations in parasite egg counts while accommodating the overdispersion and excess zero parts of the data (Zuur et al. 2009). The significance of weight variations between DC troop baboons and other troops was analyzed using Mann-Whiney test.

Results

Parasite distribution and infection patterns

Faecal samples were collected from all six of the habituated baboon troops at Gombe (Table 1). In total, 121 and 62 stool samples were collected from baboons in the wet season and dry season, respectively. The identities and characteristic features of the parasite species detected from baboons at Gombe are described in Figure 2. Among the parasites observed, *Trichuris* sp. was the most prevalent occurring in 35% of samples, followed by hookworms and unidentified nematode larvae at 27% and 25% prevalence, respectively (Figure 3A). However, as shown in Table 2, the differences were not statistically significant ($p > 0.05$). The least common nematode species was *Streptopharagus* sp. occurring at less than 5% prevalence (Figure 3A).

The prevalence of trematode parasites identified as *S. mansoni* and unknown operculate trematodes were 10% and 14%, respectively (Figure 3A). Except for *Streptopharagus* sp. and *Physaloptera* sp., other nematodes (hookworms and *Trichuris* sp.) had egg counts (mean intensity) below 10 epg (Figure 3B). The lowest mean intensity of infection was exhibited by *S. mansoni* (4 ± 1.06 epg) while unidentified trematode had the highest mean intensity at 47 ± 21.69 epg (Figure 3B). There was a disproportionate high prevalence (Figure 4A) and direct egg counts of unidentified trematode in DB troop compared to others (Figure 4B), and as detailed in Table 3, the variations were statistically significant for BB (Pr (>|z|) = 0.0266) and DB troop baboons (Pr (>|z|) =

0.0163). Furthermore, there were major differences in body weights between female baboons from C troop and others (Table 4), and a statistical analysis indicated that the variations were significant (Mann-Whitney U test, $U = 151$, $n^1 = 12$, $n^2 = 17$, $p < 0.05$).

Table 1: Studied babons at Gombe and the numbers of samples obtained from each troop in wet and dry seasons

Category	Baboon troop						
	DC	DB	DA	BB	BA	AC	Total
Sample size (wet season)	22	21	22	10	28	18	121
Sample size (dry season)	0	12	16	6	18	10	62
Estimated troop size	60	22	40	18	36	29	205

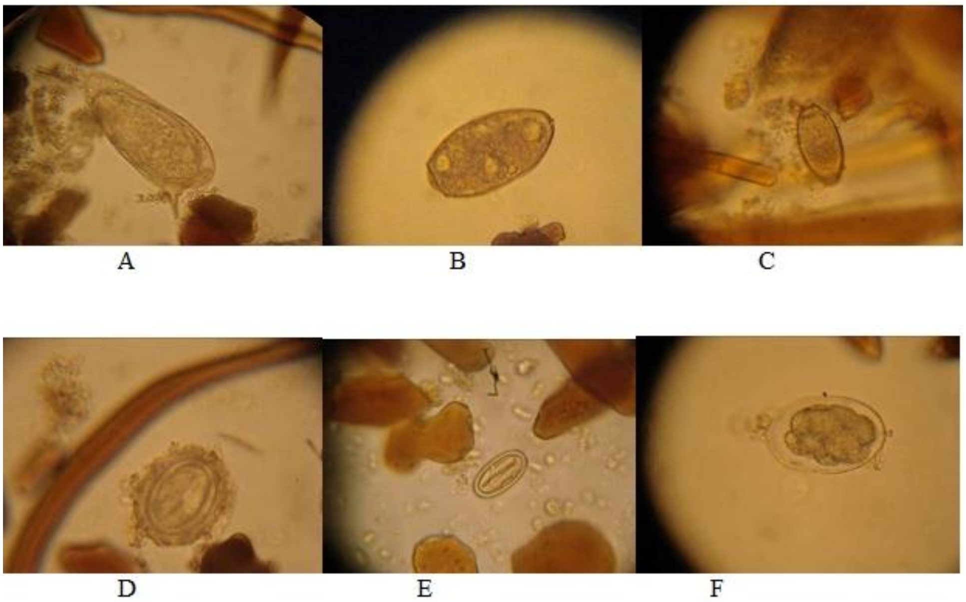


Figure 2: Parasite eggs from baboons at Gombe National Park. From left to right: *S. mansoni* with a lateral spine (A); unidentified trematode characterized by golden brown-colour, prominent operculum and a thickened abopercular pole (B); *Trichuris* sp. with flattened top and bottom and curving sides (C). Other eggs belonged to *Physaloptera* sp. based on their roundish shapes and an outer layer with protuberances (mammillated) surrounding a coiled larva (D); *Streptopharagus* sp. due to their ovoid, pointed shapes and a smooth double shell surrounding an undeveloped larva (E) and hookworms due to ovoid shapes with thin and smooth walls (F). Unidentified nematode eggs and larvae have been omitted due to the poor quality of their images.

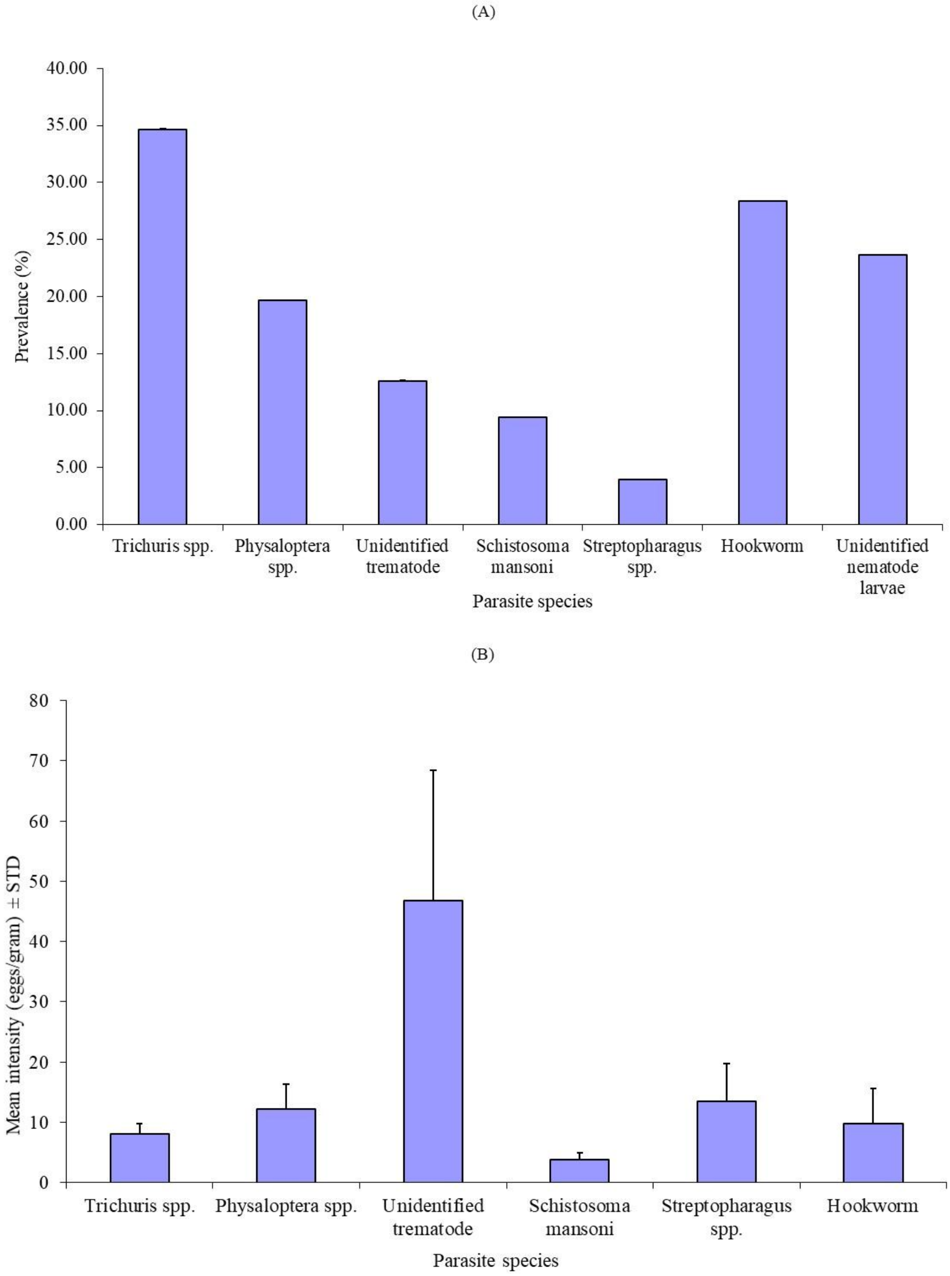


Figure 3: Overall prevalence (%) (A) and intensity of infection (epg) (B) for observed parasites in baboons at Gombe National Park (N = 26). Bars on top of each histogram in (B) are standard deviations.

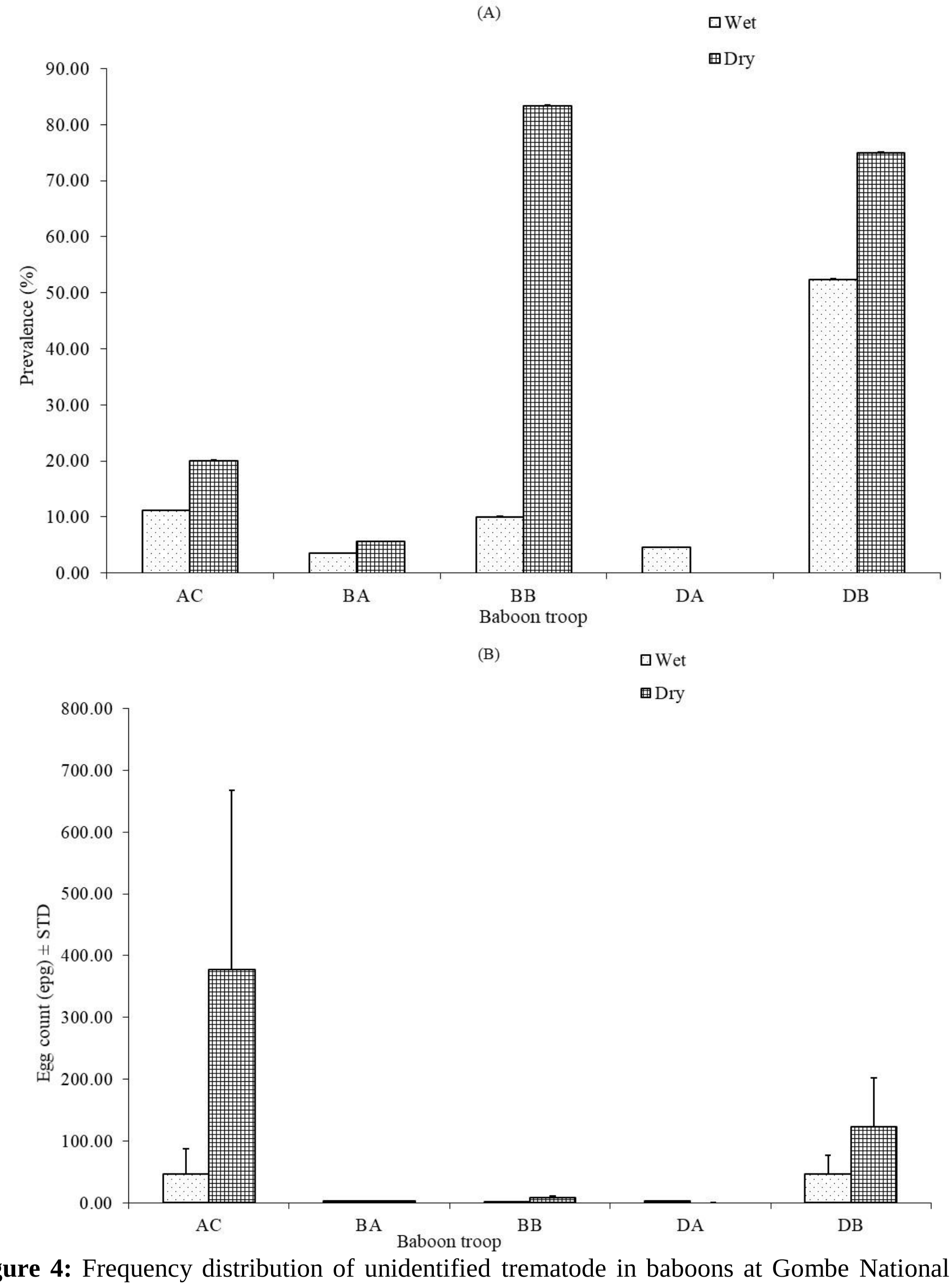


Figure 4: Frequency distribution of unidentified trematode in baboons at Gombe National Park showing parasite's highest prevalence (A) and egg counts (B) in BB and DB troops. High standard deviation values indicate intensities were more spread out among members of the troop (B).

Table 2: GLM analysis results indicating non-significant impact of wet season and baboon troop on the prevalence of *Trichuris* sp in baboons at Gombe. Due to missing samples for some baboon individuals in the dry season, only wet season data have been analysed.

Variable	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.857e+01	2.063e+03	0.009	0.993
Wet season	–1.902e+01	2.063e+03	–0.009	0.993
DA troop	–1.761e+01	2.063e+03	–0.009	0.993
BB troop	–1.857e+01	2.063e+03	–0.009	0.993
DA troop	–1.778e+01	2.063e+03	–0.009	0.993
DB troop	1.916e-10	2.793e+03	0.000	1.000
Wet season: BA troop	1.627e+01	2.063e+03	0.008	0.994
Wet season: BB troop	1.817e+01	2.063e+03	0.009	0.993
Wet season: DA troop	1.673e+01	2.063e+03	0.008	0.994
Wet season: DB troop	–2.412e-01	2.793e+03	0.000	1.000

Table 3: Results of GLM binomial analysis indicating that baboon troop membership was a significant predictor of *Paragonimus* prevalence. Due to seasonal discrepancy resulting from fewer samples collected in the dry season, only wet season samples have been considered here.

Variable	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	–1.3863	0.7906	–1.754	0.0795.
Season: Wet	0.6931	1.0897	–0.636	0.5247
BA troop	–1.4469	1.2976	–1.115	0.2648
BB troop	2.9957	1.3509	2.218	0.0266*
DA troop	–17.1798	1630.6598	–0.011	0.9916
DB troop	2.4849	1.0341	2.403	0.0163*
Wet season: BA troop	0.2305	1.8120	0.127	0.8988
Wet season: BB troop	–3.1135	1.8705	–1.665	0.0960
Wet season: DA troop	16.2147	1630.6603	0.010	0.9921
Wet season: DB troop	–0.3102	1.3501	0.230	0.8183

Table 4: Comparison of body weight among baboon troops at Gombe in December 1989 indicating low mean weight for most baboons in C troop

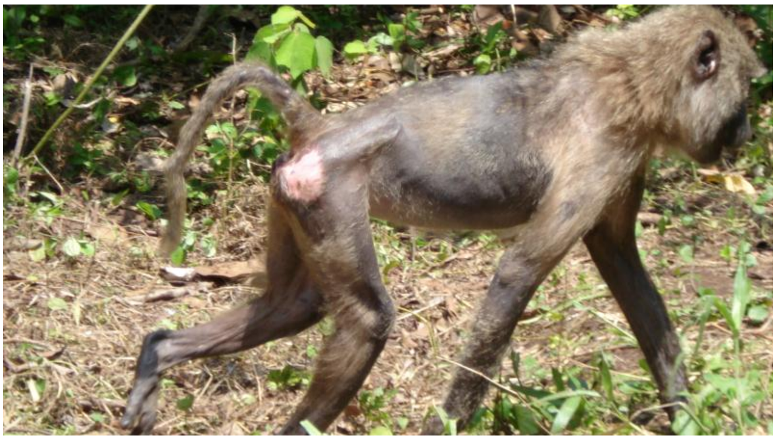
Troop	Number of individuals sampled	Median (kg)	Minimum weight (kg)	Maximum weight (kg)
A	11	14.9	9.4	18.9
C*	12	11.85	9.1	13.35
D	6	14.0	12.1	19.35

*The differences between the weights of the females of C troop compared with the females in the other troops were statistically significant (Mann-Whitney U test, $p < 0.05$).

Baboon health

Most baboons from DB troop were seen actively searching for freshwater crabs from underneath rocks in Kakombe stream (Figure 5A). Some of these baboons were apparently very weak and emaciated (Figure 5B). Of the baboons infected with unidentified trematode, it was possible to follow-up their health from the routine monthly observations of each troop over the continuous seven years extracted from Gombe research archived data from 2010 to 2018 (Table 5).

A



B

Figure 5: Baboons at Gombe National Park actively searching for freshwater crabs from underneath rocks in Kakombe stream (A). Some of these baboons (from DB troop) were apparently very weak and emaciated (B) possibly due to an infection believed to be caused by unidentified trematode parasites acquired through feeding on freshwater crabs.

Table 5: Unidentified trematode intensity (epg) and its possible impact on baboon health conditions at Gombe National Park

Baboon's name	Troop	Age when tested positive (Years, Months)	Sex	Intensity (epg)	Signs of ill-health (before and up to time of death)
Baselan	BB	Adult	Male	16	None until emigration after one year.
Ambrosia	DB	12 yrs, 1 month	Female	5	Cough, weight and hair loss; died after six years aged 18 years and 4 months. Both of her infants died.
Asali	DB	19 yrs, 8 months	Female	118	For 3 years repetitive coughing, hair loss, bore one infant which died.
Advil	DB	18 yrs, 11 months	Female	101	Periodic severe coughing, vomiting, weakness, hair loss, bore no infant, died six months later aged 19 years and 5 months.
Makoto	DB	Adult	Male	737	Intense coughing, very weak, died after two years.
Mzee	AC	Adult	Male	86	None until emigration after six months.
Akarura	BA	13 yrs, 6 months	Female	3	None over 7 years, but bore 3 infants who all died.
Aggie	DB	6 yrs	Male	64	None, until emigration at normal age of 9 years 6 months.
Araceae	BB	17 yrs, 1 month	Female	11	Bore 1 infant, which survived, then after years she developed severe coughing.
Akaze	BB	12 yrs, 6 months	Female	2	None, bore 2 infants (1survived), then no reproductive output four years except 1 miscarriage.
Azanza	BB	18 yrs, 8 months	Female	7	None but died 8 months after sampling aged 19 years 4 months.
Adila	DB	9 yrs, 3 months	Female	1	Had 2 infants (1 survived) and one miscarriage, coughing and weight loss.
Harungana	DB	18 yrs, 1 month	Female	46	None. Bore 1 infant, which died.
Aresiti	DB	6 yrs	Male	28	Severe coughing, vomiting, diarrhoea, weight loss, weakness. Emigration delayed past normal age.

Discussion

Spatial and temporal patterns of parasitic infections in baboons

All parasite taxa presently observed in the Gombe baboons have been described in the animals before (McGrew et al. 1989,Müller-Graf et al. 1997, Murray et al. 2000). In some previous studies (e.g Müller-Graf 1994), at least one parasite was recorded in all individual baboons sampled while the present study has found only 17% of them infected, with significant temporal variations in prevalence of infections among parasite taxa. For instance, in the 1960s, the prevalence range of *Trichuris* sp. and *Streptopharagus* sp. was 68-80%, higher than the 35-42% of the 1970s (McGrew et al. 1989) and 48-66% for the 1980s recorded for the two parasite species (Murray et al. 2000). The most comparable prevalence range for the two parasites was 67-81% in the 1990s (Müller-Graf 1994) compared to for instance 35% recorded for *Trichuris* sp. in the present study. There is an overall temporal decline in levels of parasitic infections among the Gombe baboons if recent records are considered. The highest prevalence of *S. mansoni* had been found in baboon troops that had regular interactions with humans in the area (Müller-Graf et al. 1997). In the present study, the parasite was recorded only in baboon troops with low human contact such as BA and BB troops, which were originally B-group (Müller-Graf 1994), and DA troop originally D-group (Müller-Graf 1994).

No schistosomes were found in DC troop baboons whose home ranges include the camp village at Kakombe where research and national park staff live. Baboons in BA and BB troops are genealogically related as they were both split from the former B-group (Nash 1976), and it is possible that they were infected before the separation. It is also likely that these baboons are being exposed to infectious sites within their habitat range, especially in areas where their troops intersect. However, only a thorough and comprehensive analysis of the habitats of infected baboon troops in their home range would be able to identify the sources of schistosomiasis transmission in the area. Other parasites observed in the baboons were unidentified trematodes, which were the most locally abundant in terms of egg intensity although not the most common (less prevalent). The trematodes were found largely in resident baboons in DB troop and in a few individuals in BA, BB and DA troops with 68.75% of infected baboons belonging to DB troop (Figure 4).

The observed dynamics and variations over time in infection levels of parasites among baboons at Gombe may have resulted from varying climatic and ecological factors in the area as suggested for other primate species in the park (Bakuza and Nkwengulila 2009). The present infection levels also corroborate findings from other baboon sites. For instance, high prevalence of *Trichuris* sp. has been reported in baboons at Amboseli National Park and Mpala Wildlife Research Centre in Kenya (Muriuki et al. 1998). The occurrence of similar parasite species in baboons across their range is possibly due to their common feeding habits (Hamilton et al. 1978) that expose them to several parasites and disease vectors. Like humans, baboons have regular contacts with potentially infectious materials such as water and human domestic waste from which they can acquire disease-causing organisms or pathogens (Huffman et al. 1997, Appleton and Henzi 1993). However, comparison of parasites and their infection rates between different baboon populations is hampered by factors such as variation in ecological settings and the sampling techniques used.

Implications of schistosome and unidentified trematode infections in baboons

Most baboons presently diagnosed with schistosomiasis in Gombe were born after Müller-Graf's study in 1992 (Müller-Graf 1994), which also detected the disease in the same populations, although not the same individuals. The current observations suggest that there is a continuity of transmission of schistosomiasis in the area. These findings also support the suggestion that wild baboons might be able to maintain the transmission of intestinal schistosomiasis in nature. Some field studies have indicated that free-ranging baboons are capable of maintaining schistosome infections on their own for a long time even in the absence of humans (Ouma and Fenwick, 1991, Bakuza 2012). Other researchers have described baboons as being susceptible to *S. mansoni* infection but it is not known whether they can act as primary hosts for the parasites (Nunn and Altizer 2006). Future studies should continue to assess and monitor the dynamics of *S. mansoni* in wild baboon populations. This would serve to establish the extent to which baboons can maintain *S. mansoni* transmission in absence of humans and whether or not they can serve as reservoirs for human infections in shared habitats.

For years, the C troop baboons at Gombe that actively feed on freshwater crabs had remained almost constant in size (30-40 individuals) from 1969 until 2006 while its neighbouring troop that did not have access to the crabs multiplied and divided repeatedly from an initial group of 53 individuals to eight separate troops totalling 260 individuals (Müller-Graf et al. 1996, Packer et al. 1995, Bakuza 2012). There have also been persistent differences in reproductive outputs and growth rates with the annual growth rate in these crab-feeding (C troop) averaging 1.71% between 1970 and 1996 compared to for instance 9.04% of non-crab-feeding D troop between 1978 and 1996 (Packer et al. 1995, 2000). The C troop individuals have been emaciated and weak-looking all the years through, and the female baboons were substantially lighter in weight (Packer et al. 2000) (Table 4). Although some baboons such as Advil and Asali had heavy unidentified trematode infections alongside intense cough and poor reproductive output (Table 5), some such as Ambrose and Adila deviated from this trend as they had poor health condition despite their low intensity of unidentified trematode. While there is a plausible link between the unidentified trematode infection and poor baboon health at Gombe, further investigations on the pathophysiology of the parasite and its impact to the host's health are necessary in order to make conclusive interpretation.

In more recent years, another troop of baboons at Gombe, the DB troop, took over the C Troop area, and its members switched to feed on freshwater crabs (*Potamonautes emini*) after the closure of fishing camps on the Gombe beach along Lake Tanganyika (Bakuza 2012). Baboons from the troop, in which most individuals had high egg-output of unidentified trematode during the present study (Figure 4B; Table 5), have had similar demographic characteristics and health conditions as those of C troop baboons, being largely emaciated with poor growth rates and lower reproductive outputs compared to other baboons in the park which did not feed on freshwater crabs (Bakuza 2012, Table 5). Since baboons have a broad and opportunistic diet (Hamilton et al. 1978), the present findings provide a chance to examine the costs incurred by the animals' exploitation of unusual foods. There is increasing evidence on the possible existence of unidentified trematodes in the Gombe baboon populations that are having substantial pathological impacts on the health of these animals. In humans, related parasites such as *Paragonimus* species and most other trematodes except schistosomes are transmitted via diet (Moyou-Somo et al. 2003) Thus, the unidentified trematode parasites detected in baboons may not be of eminent public health problem in the study area because the local people there do not eat uncooked freshwater crabs. Future studies should investigate whether the Gombe baboons might be harbouring certain strains of *Paragonimus* parasites with major public health implications, although in reality no cases of human paragonimiasis are known in Africa east of the Congo basin (Aka et al. 2008).

Conclusion

There was a declining trend in the prevalence of parasitic infections in Gombe that can be attributed to recent ecological and demographic changes in the park such as restrictions of human activities and residence in the park. The C troop originally occupied the habitat range-area near the Kakombe waterfall (Dell site) known to harbour *P. emini* freshwater crabs, and active feeding on the crustaceans by baboons has been observed. Apart from slow maturation, baboons in C troop had poor health with many emaciated individuals as those in DB troop. It is as though DB troop inherited the place and the illness which, most likely was caused by unidentified trematode parasites. Comprehensive future studies should explore further the identity and pathological importance of this trematode on population dynamics of baboons at Gombe.

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Conflict of interest statement

The author declares that there is no potential conflict of interests whatsoever related to the publication of this article.

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