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RESEARCH ARTICLE

Gastrointestinal Symbionts of Chimpanzees in Cantanhez National Park, Guinea-Bissau With Respect to Habitat Fragmentation

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One of the major factors threatening chimpanzees (*Pan troglodytes verus*) in Guinea-Bissau is habitat fragmentation. Such fragmentation may cause changes in symbiont dynamics resulting in increased susceptibility to infection, changes in host specificity and virulence. We monitored gastrointestinal symbiotic fauna of three chimpanzee subpopulations living within Cantanhez National Park (CNP) in Guinea Bissau in the areas with different levels of anthropogenic fragmentation. Using standard coproscopical methods (merthiolate-iodine formalin concentration and Sheather´s flotation) we examined 102 fecal samples and identified at least 13 different symbiotic genera (*Troglodytella abrassarti*, *Troglocorys cava*, *Blastocystis* spp., *Entamoeba* spp., *Iodamoeba butschlii*, *Giardia intestinalis*, *Chilomastix mesnili*, *Bertiella* sp., *Probstmayria gombensis*, unidentified strongylids, *Strongyloides stercoralis*, *Strongyloides fuelleborni*, and *Trichuris* sp.). The symbiotic fauna of the CNP chimpanzees is comparable to that reported for other wild chimpanzee populations, although CNP chimpanzees have a higher prevalence of *Trichuris* sp. Symbiont richness was higher in chimpanzee subpopulations living in fragmented forests compared to the community inhabiting continuous forest area. We reported significantly higher prevalence of *G. intestinalis* in chimpanzees from fragmented areas, which could be attributed to increased contact with humans and livestock. Am. J. Primatol. 75:1032–1041, 2013.

Key words: Cantanhez National Park; fragmentation; *Pan troglodytes verus*; parasites; symbionts; *Trichuris* sp.

INTRODUCTION

The gastrointestinal tract of primates is colonized by broad range of organisms with a variety of relationships with their host. Although most of them are traditionally referred to as parasites, term "symbionts" is more appropriate to describe the community in its complexity [Combes, 2001; Douglas, 2010]. Then, symbionts can be further defined as (i) mutualists (in reciprocally positive interactions); (ii) commensals (neither benefit nor harm their facilitators); and (iii) parasites (occur in a win-lose relation when one species benefits while the other species is harmed) [Bronstein, 2009].

Some parasites can constitute a risk for nonhuman primate conservation by affecting health, behavior and survival of their hosts, especially in cases when they are already threatened by other factors [Daszak et al., 2000; Goldberg et al., 2005; McCallum & Dobson, 2002]. Most primate populations nowadays live in more or less disturbed landscapes [e.g., Cowlishaw & Dunbar, 2000;

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Marsh, 2003; Gillespie et al., 2005; Hopkins & Nunn, 2007]. Anthropogenic disruptions such as habitat loss and fragmentation, overexploitation and climate change are regularly listed as extinction drivers at global and local scales [Caldecott & Miles, 2005; Coop & Holmes, 1996; Smith et al., 2009]. These factors may modify symbiont host ranges, vector dynamics, parasite virulence and transmission rates and consequently may lead to changes in infection risks and clinical outcomes of the infections, finally leading to host population decline [Gillespie et al., 2005; Pedersen et al., 2007].

Habitat loss reduces not only species movement and dispersal but also resource availability and as a consequence animals suffer the effects of overcrowding [Gillespie & Chapman, 2008]. As the contact and conflict among individuals increases, their stress levels rise and immunological competence starts to weaken and therefore their infection resistance can decrease, eventually promoting the spread of diseases and symbiont transmission [Ashford et al., 1996; Coe, 1993; Eley et al., 1989; Nunn & Altizer, 2006; Scott, 1988; Sleeman et al., 2000]. Several studies on primate symbiont ecology reported higher prevalence and richness of gastrointestinal symbionts in non-human primates living in forest fragments assuming positive correlation between pathogen prevalence and richness and host density [Gillespie & Chapman, 2006, 2008; Kowalewski et al., 2011; Mbora et al., 2009] while other studies recorded the opposite or no effect [Cristóbal-Azkarate et al., 2010; Lane et al., 2011].

Endangered species, such as chimpanzees, have usually limited geographic ranges and irregular distributions within their ranges [Chapman et al., 2005; Fahrig, 2003]. Many studies have reported the gastrointestinal symbionts of several populations of the common chimpanzee (*Pan troglodytes*) in different types of habitats [e.g., Ashford et al., 2000; Howells et al., 2010; Huffman et al., 1997; Muehlenbein, 2005; Petrášová et al., 2010]. However, there is a paucity of information about the symbionts of chimpanzees in Guinea-Bissau, West Africa, which represents the most western limit of the species distribution where its survival is considered very precarious [Sousa et al., 2005; Torres et al., 2010]. Major threats to their survival include the pet trade, hunting for animistic/traditional medicine practices and importantly also habitat fragmentation caused by logging and agriculture [Casanova & Sousa, 2007; Sá et al., 2009].

We present the results of the parasitological survey of chimpanzee population inhabiting Cantanhez National Park (CNP), in the south of Guinea-Bissau. We compared three chimpanzee subpopulations living within the Park in the areas with different levels of anthropogenic fragmentation.

METHODS

Study Site

CNP (Fig. 1) is located in Tombali Region, in southern Guinea-Bissau and comprises a total area of 1,068 km^2. The Cacine and Cumbidjã Rivers act as natural boundaries and form the Cubucaré Peninsula. The park was formally established in 2008 but since the mid-1980s was considered a forest hunting reserve [IBAP, 2008]. The climate is tropical humid with two annual seasons: the rainy season from June to October and the dry season from November to May

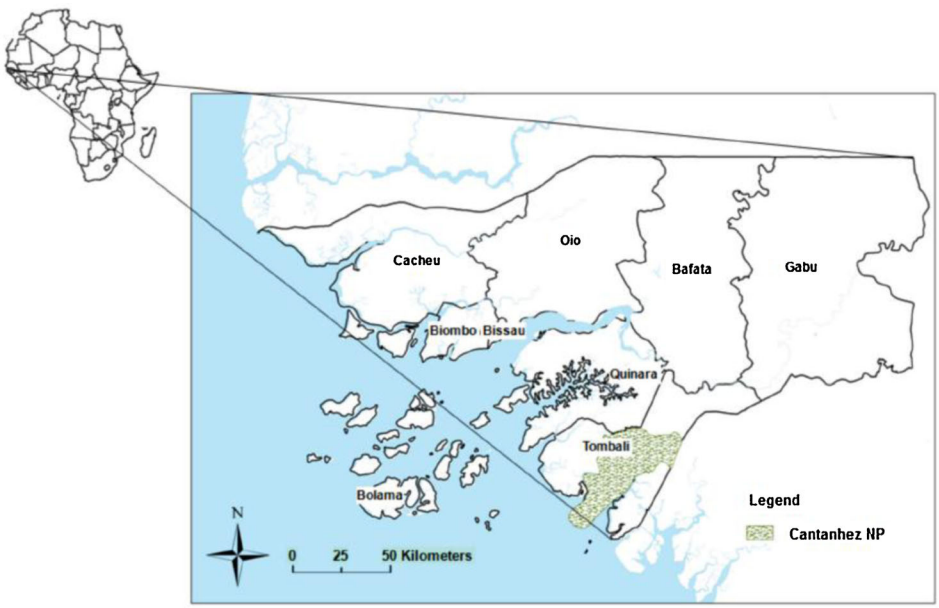

Fig. 1. Location of Cantanhez National Park, Republic of Guinea-Bissau, West Africa [after Hockings & Sousa, 2013].

with little or no rainfall. Mean annual rainfall is 2,000 mm (SD ± 500) and the temperature varies between 28 and 31°C [Simão, 1997].

CNP is approximately 70 m above sea level and consists of a patchy environment of small rivers; mangroves, arborous and grassland savannahs; agriculture fields, human settlements and sub-humid forests characterize the landscape. Forest fragments consist of a mixture of evergreen and semi-deciduous vegetation cover [Catarino, 2004]. Native fauna include seven species of non-human primates: the lesser bush baby (*Galago senegalensis*), the western red colobus (*Procolobus badius temmincki*), the king colobus (*Colobus polykomus*), the vervet monkey (*Chlorocebus aethiops sabaeus*), the Campbell's monkey (*Cercopithecus campbelli*), the Guinean baboon (*Papio papio*), and the western chimpanzee (*P. troglodytes verus*) [Casanova & Sousa, 2007; Gippoliti & Dell'Omo, 2003].

The World Wide Fund for Nature (WWF) has recognized the Cantanhez forests as one of the 200 most important ecoregions in the world, and ones of the last vestigial segments of humid forest in West Africa. However, through satellite images Oom et al. [2009] identified a trend of forest loss with a conversion from closed humid forests to savanna-woodlands. This loss has been caused by "slash and burn" agriculture. The amount of land for crops is continually expanding due to increasing numbers of people [Hockings & Sousa, 2011]. Consequently, the encounters of humans and domestic animals with wildlife occur with increased frequency [Hockings & Sousa, 2011].

Permission to carry out research in the CNP was conceded by the Instituto da Biodiversidade e das Áreas Protegidas as well as by the consent of the traditional leaders.

Study Population

Formerly, chimpanzees were erroneously considered extinct in Guinea-Bissau [Lee et al., 1988]. However, a survey in 1994 reconfirmed chimpanzee presence in the study area and a preliminary evaluation of their conservation status was carried out [Gippoliti & Dell'Omo, 1995, 1996]. According to the most recent national estimate there are 600–1,000 chimpanzees in Guinea-Bissau with approximately 400 individuals occurring in CNP [Gippoliti & Dell'Omo, 2003; Sousa et al., 2005]. More recently, Torres et al. [2010] have demonstrated that suitable forest habitat for chimpanzees in the park declined by approximately 11% (270 km^2) from 1986 to 2003, resulted in a decrease of chimpanzee population. However, the exact number of chimpanzee communities remains unclear.

Within CNP, chimpanzees live in three principal areas (i.e., North, Central, and South) (Table I, Fig. 2). Recent phylogeographic studies have shown that there are three chimpanzee genetic subpopulations in CNP corresponding to the areas. The three subpopulations are significantly genetically different from each other. It was shown that 39.18% of the genetic variation occurs between subpopulations and the largest fraction of the variation (56.24%) is partitioned among individuals within populations [R. Sá, unpublished data].

The Northern area has more available forested habitat (3.55%) than in the Central (1.24%) or South (1.84%) and can be perceived as a more continuous forest block. The central area is under a high anthropogenic pressure where chimpanzees are encroached at a very high density of 3 individuals/km^2 [Hockings & Sousa, 2011]. The southern and central areas possess the higher number of forest fragments in comparison to the northern one (Table I) and with continuing habitat degradation (Fig. 2).

Sampling Strategy

The current field study was conducted from September to November 2008, during the rainy season (mean annual rainfall ca. 2,000 mm). Fresh fecal samples were collected opportunistically during the day, near the nests or on the trails in all three areas (North, Central, and South). In total, 14 fragmented forest patches were surveyed from north, central, and south CNP areas (Table I). The samples could not be attributed to specific individuals and to avoid sampling the same individual only one sample was collected from the same nest. On the following days we moved to a different forest fragment where the connectivity with the previous nest site was limited or absent. However, we cannot exclude the possibility that the same individual was sampled more than once. Only fresh samples were collected (from their inner part to avoid soil contamination), any potentially rain- "washed" or old (>12 hr) samples were discarded. Approximately 5 g of each sample was immediately fixed in a 13 ml single vial tube of PROTOfix™ CLR (Alpha-tech-Systems, Inc., Vancouver, WA) according with the manufacturer's instructions [Jensen et al., 2000] and stored at room temperature until they were shipped under international permits to the Department of Pathology and Parasitology of the Veterinary and Pharmaceutical University, Brno, Czech Republic.

All samples were collected non-invasively in conformity with the ASP-Principles for the ethical treatment of non-human primates. Presented research adheres to the legal requirements of Guinea Bissau, approved by the Institute of Biodiversity and Protected Areas (IBAP), and by the animal care committee of the Veterinary and Pharmaceutical Sciences University (UVPS). Sampling procedures also adhere to the *American Journal of Primatology* principles for the ethical treatment of primates.

TABLE I. Characteristics of Chimpanzee Communities Sampled in Cantanhez National Park, Republic of Guinea-Bissau, West Africa

Areas	No. of fragments	Size of forested area (km^2)	Forest cover (%)	Distance to nearest village (m)	No. of samples collected
North	1	37.93	3.55	3,465	45
Central	5	13.20	1.24	67	25
South	8	19.67	1.84	650	32

Parasitological Screening

About half of each sample was stored in the original vial for possible further examination. The remainder was homogenized with water and filtered thought a standard sieve (~100 μm) for macroscopic examination. This filtered material was processed using combined a modified Sheather's solution flotation (e.g., 1.33) [Sheater, 1923] and a Merthiolate-Iodine-Formaldehyde Concentration (MIFC) sedimentation technique [Blagg et al., 1955]. A drop of Lugol's iodine was added to stain the preparations. Several drops were examined for each technique (Sheather's flotation and MIFC) from each sample in a compound microscope at 200×, 400×, and 1,000× magnification. Symbionts were identified on the basis of the morphology (i.e., size, wall structure, internal structures, and shape), of their stages (e.g., eggs, cysts, trophozoites, or larvae) using identification keys [Ash & Orihel, 2007; Hasegawa et al., 2009; Jessee et al., 1970]. Measurements were made to the nearest 0.1 μm, using a calibrated ocular micrometer. Symbionts were microphotographed using Nomarski interference contrast on an Olympus AX70.

Data Analyses

The terminology were defined according to Stuart and Strier [1995], Bush et al., [1997], and Gillespie [2006]; therefore, prevalence refers to the percentage of samples with a given symbiont taxa and sample richness is the number of unique symbiont taxa recovered from a sample. Chi square or Fisher's exact tests with subsequent Bonferroni correction were

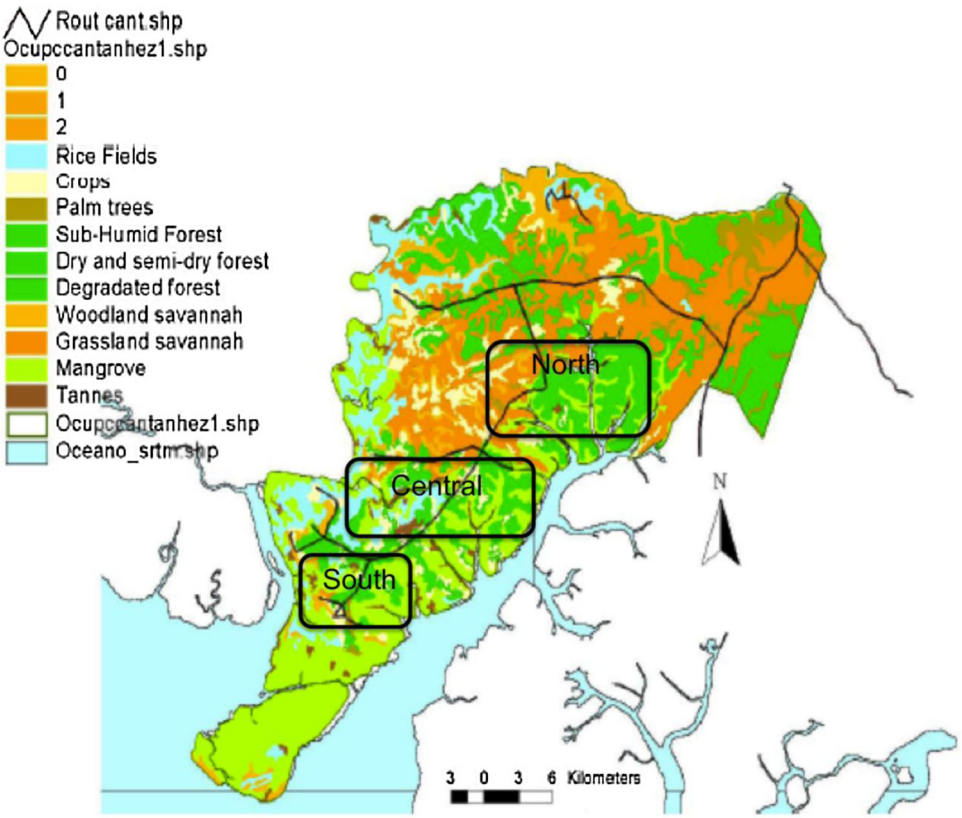

Fig. 2. Chimpanzee distribution in three principal areas across Cantanhez National Park, Republic of Guinea - Bissau, West Africa.

TABLE II. Symbiont Prevalence (%) of Western Chimpanzees (*Pan troglodytes verus*) at Cantanhez National Park, Republic of Guinea-Bissau, West Africa

Symbiont taxa	North (n = 45)	Central (n = 25)	South (n = 32)	Total (n = 102)
Protozoa				
Entamoeba spp.	2	20	34	18
Iodamoeba butschlii	4	4	3	4
Giardia intestinalis	0	16	6	6
Chilomastix mesnili	4	16	3	7
Troglodytella abrassarti	42	80	69	62
Troglocorys cava	22	36	19	25
Blastocystis sp.	29	64	56	49
Cestoda				
Bertiella sp.	0	4	13	5
Nematoda				
Undetermined strongylid eggs	27	48	16	38
Strongyloides fuelleborni	27	16	16	22
Strongyloides stercoralis	4	8	6	6
Probstmayria gombensis	7	4	0	4
Trichuris sp.	22	0	6	15
Overall %	87	100	91	91

performed in order to compare sample prevalence in chimpanzees inhabiting North, Central, and South CNP areas for each symbiont taxa separately. Differences in symbiont richness among areas were investigated using Kruskal–Wallis ANOVA, with LSD post hoc tests used for pairwise comparisons. The value of $\rho < 0.05$ was set as significant. SPSS, version 17 [SPSS, Inc., Chicago, IL] and SISA [http://www.quantitativeskills.com/sisa/] were used for all statistical analyses.

RESULTS

A total of 13 symbiont taxa were identified including three symbionts specific for chimpanzees [entodinomorphid ciliates *Troglodytella abrassarti* and *Troglocorys cava* and nematode *Probstmayria gombensis*]. Further, we found ten symbionts with wider range of hosts and with more or less prominent zoonotic potential [*Blastocystis* spp., amoebas *Entamoeba* spp. and *Iodamoeba butschlii*, flagellates *Giardia intestinalis* and *Chilomastix mesnili*; anoplocephalid tapeworm *Bertiella* sp., and several nematodes: unidentified strongylids, *Strongyloides stercoralis*, *Strongyloides fuelleborni*, and *Trichuris* sp.] (Table II). No flukes were observed. Neither tapeworm proglottids nor nematodes were macroscopically observed in fecal samples.

The median sample richness was three (range = 0–7, mean ± SD = 2.6 ± 1.6). Differences in prevalence among subpopulations were only detected for *G. intestinalis* (North, n = 0; Central, n = 4; South, n = 2; Fisher exact test, $P = 0.012$), *Trichuris* sp. (North, n = 13, Central, n = 0, South, n = 2; Fisher exact test, $P = 0.001$), and *Bertiella* sp. (North, n = 0, Central, n = 1, South, n = 4; Fisher exact test, $P = 0.025$; Table II). There was a significant difference in sample richness among the three subpopulations (Kruskal–Wallis ANOVA, $H = 6.636$, $P = 0.036$) with LSD post hoc tests revealing that the north community has significantly lower sample richness than the central community ($P = 0.013$) but the differences were not significant between north and south ($P = 0.131$) and central and south ($P = 0.301$) communities.

DISCUSSION

To the best of our knowledge, this is the first study assessing the gastrointestinal symbionts of chimpanzees in Guinea-Bissau. Based on our results we can conclude that the symbiont fauna of chimpanzees inhabiting CNP is similar to that of other wild chimpanzee populations living in primary and secondary forest habitats, for example Lopé, Gabon [Landsoud-Soukate et al., 1995]; Dzanga-Ndoki, Central African Republic [Lilly et al., 2002]; Mahale, Uganda [Huffman et al., 1997, 2009]; Gombe, Tanzania [Bakuza & Nkwengulila, 2009; File et al., 1976; Gillespie et al., 2010; Murray et al., 2000]; Kibale, Tanzania [Ashford et al., 2000; Krief et al., 2010]. We detected significant changes in symbiont fauna due to anthropogenic fragmentation. We demonstrate that fragmentation can have different impact on individual symbiont taxa and that both host ecology and symbiont characteristics must be taken in consideration to interpret the results.

Entodiniomorphid ciliate *T. abrassarti* was the most common symbiont species reaching the prevalence of 62%; the other detected ciliate was *T. cava* found in 24.5% of samples. Both ciliates are currently

considered chimpanzee specific commensals [Pomajbíková et al., 2010, 2012; Profousová et al., 2011; Tokiwa et al., 2010]. It was shown that at least *T. abrassarti* can actively participate in ape hindgut digestion, however its contribution to overall hydrolytic activities is low [Profousová et al., 2011]. Although reported prevalence of both ciliates greatly varies among the studied populations, they are probably present in all individuals in wild chimpanzee populations [Pomajbíková et al., 2010, 2012].

Groups of detected commensals further include the amoebas *Entamoeba* spp. and *I. butschlii* and the flagellate *C. mesnili*. All three species were determined based on the cyst morphology, which is consistent with those described in humans [Ash & Orihel, 2007]. Molecular-phylogenetic analyses are necessary for precise identification and clarification of possible transmissions between humans and primates [Levecke, 2010]. Observed prevalence of both amoebas is similar to that reported in Gombe chimpanzees in Tanzania [Murray et al., 2000], but published data tend to vary significantly across study sites [Krief et al., 2005; Muehlenbein, 2005]. Prevalence of *C. mesnili* (7%) is comparable to that reported by Landsoud-Soukate et al. [1995] in chimpanzee population inhabiting Lope, Gabon.

The *Giardia* cysts were recovered only from samples originating from central and southern chimpanzee subpopulations inhabiting more fragmented habitats. This finding is in accordance with previous studies relating *Giardia* infections in wild primates to increased contact with humans and livestock [Graczyk et al., 2002; Johnston et al., 2010; Kowalewski et al., 2011; Lane et al., 2011; Nizeyi et al., 2002; Salzer et al., 2007; Wolfe et al., 1998]. *G. intestinalis* is typical of cross-species transmissions, including zoonotic transmissions and determination of particular assemblages by molecular techniques clarified this aspect of *G. intestinalis* ecology [Hunter & Thompson, 2005; Johnston et al., 2010; Sprong et al., 2009; Thompson, 2004]. Undoubtedly, chimpanzees living in fragmented CNP areas are exposed to high contact with local inhabitants and livestock. Humans create trails and enter frequently in the forest fragments along with livestock like pigs, goats and cows. Chimpanzees also leave the fragments to crop raid in villages. Thus, humans and livestock share water sources with chimpanzees, shedding the *Giardia* cysts into water and increasing the chance for chimpanzees to get infected. Future studies should focus on determination of *Giardia* assemblages using molecular tools in order to detect the exact reservoir of infection for chimpanzees, and to determine if cross-species transmission is occurring.

Cysts of *Blastocystis* spp. were detected in 49% of samples; such high prevalence was recorded only in introduced chimpanzees of Rubondo Island, Tanzania [Petrášová et al., 2010]. However, cysts of *Blastocystis* can be easily overlooked due to their small size and we assume that this protist is rather common in also in populations of wild great apes as reported in captive ones [Stensvold et al., 2007].

Both the strongylids and *Strongyloides* infections are common in free-ranging great apes with strongylids being reported as the most prevalent parasites in several populations of wild chimpanzees reaching prevalence between 70% and 100% [e.g., Gombe, Tanzania: File et al., 1976; Mahale, Tanzania: Huffman et al., 1997; Kibale, Uganda: Gillespie et al., 2010; Muehlenbein, 2005]. Therefore, the prevalence of strongylid nematodes in CNP chimpanzees (38%) is lower in comparison with most studied sites, with exception of Lope Reserve in Gabon, where the prevalence reached only 21% [Landsoud-Soukate et al., 1995]. Absence or very low prevalence of strongylid nematodes was recorded also in savanna chimpanzees [Howells et al., 2010; McGrew et al., 1989] and introduced chimpanzees of Rubondo Island, Tanzania [Petrželková et al., 2010]. No impact of fragmentation/increased human contact on these nematodes was recorded in CNP chimpanzees. Without developing larvae using coprocultures, strongylid eggs cannot be reliably determined even to genera [Greiner & McIntosh, 2009].

Both *S. fuelleborni* and *S. stercoralis* were found in CNP chimpanzees. Despite that *S. fuelleborni* is known to predominantly infect chimpanzees whilst *S. stercoralis* is common in humans, mixed infections have been reported in both humans and chimpanzees [Hasegawa et al., 2010; Petrželková et al., 2010]. Future studies are warranted to clarify zoonotic potential of strongylids and *Strongyloides* occurring in chimpanzees and humans within CNP.

Probstmayria gombensis, an enigmatic non-pathogenic nematode originally described from chimpanzee [File, 1976] was easily recognized by its characteristic larvae. It has been found in several, but not all chimpanzee populations in similar or lower prevalence in comparison to CNP chimpanzees [e.g., Gombe NP, Tanzania: McGrew et al., 1989; Kibale NP, Uganda: Ashford et al., 2000; Muehlenbein, 2005].

Bertiella sp. (usually tentatively referred to as *Bertiella studeri*) is so far the only tapeworm reported to occur in free-ranging chimpanzees, usually at low prevalence comparable to our study [Howells et al., 2010; Krief et al., 2005] or even lower [Ashford et al., 2000; Kawabata & Nishida, 1991]. Transmission occurs when an intermediate host, usually an oribatid mite, containing the cystercercoid is accidentally ingested by the primate. Surprisingly, prevalence of *Bertiella* sp. was higher in fragmented habitats. We speculate that fragmentation might have an effect on the intermediate hosts, oribatid mites; however, very little is known about life cycle and factors which affect this cestode and further research is warranted.

Probably the most striking difference in comparison to other free-ranging chimpanzee populations is a relatively high prevalence of *Trichuris* spp. (15%) in CNP chimpanzees with most cases recorded in the northern community. Whipworms are regularly found in many primate species, including humans [Ashford et al., 2000; McGrew et al., 1989; Mbora & Munene, 2006; Murray et al., 2000]. Most of the studies reported absence or low prevalence of *Trichuris* (less than 10%) in wild chimpanzees [e.g., Gillespie et al., 2010; Krief et al., 2005] with exception of the chimpanzee community in Mahale, Tanzania where prevalence of *Trichuris* sp. reached up to 46% in certain periods [Huffman et al., 2009]. Whipworms found in non-human primates are usually considered as *Trichuris trichiura* [Liu et al., 2012; Ooi et al., 1993; Reichard et al., 2008] and several authors implied the zoonotic cross-transmission between non-human primates and humans [e.g., Chapman et al., 2007; Munene et al., 1998]. However, direct evidence for transmission between wild great apes and humans is lacking and unusually broad host range of *T. trichiura* rather implies underestimated diversity of *Trichuris* in non-human primates. Also morphometric variation observed in eggs suggests that species found in chimpanzees is probably divergent from human *T. trichura*; obviously, only molecular assessments can shed light on this uncertainty [Petrášová et al., 2010]. Significantly higher prevalence of *Trichuris* sp. in northern community in comparison to very low prevalence/total absence of *Trichuris* sp. in the central communities living in more fragmented habitats seems puzzling. Contrary to previous studies, habitat fragmentation does not result in higher prevalence of this nematode in CNP chimpanzees as it was shown in red colobus (*Procolobus rufomitratus* ssp. *tephrosceles*) and black-and-white colobus (*Colobus guereza*) in Kibale, Uganda [Gillespie & Chapman, 2006, 2008]. High prevalence of *Trichuris* sp. has been associated with increased host density in the fragments [Gillespie & Chapman, 2006, 2008]. To our knowledge there are no data on the effect of fragmentation on chimpanzee behavior and ecology. Based on personal observations [R. Sá, personal observation] it seems that chimpanzees in fragmented areas tend to increase their travel distances by moving among the fragments probably in order to search for food. Thus the host density and range use intensity decreases leading to lower prevalence of *Trichuris* in fragmented biotopes in comparison to northern area with continuous forest. Additionally, we assume that crop raiding performed only by chimpanzees from fragmented habitats [R. Sá, personal observation] could improve their nutritional situation facilitating more effective immune response to parasites [Holmes, 1995] as suggested by Chapman et al. [2006], who reported less severe parasite infections in crop raiding black and white colobus in comparison to red colobus which did not crop raid. A similar situation was observed also in baboons [Eley et al., 1989; Hahn et al., 2003].

The symbiont richness observed in this study shows a classic host-symbiont over-dispersed distribution when most samples harbor few symbiont species while few others contain the largest proportion of multi-symbiont infections [Anderson & May, 1978; Morand & Poulin, 1998; Shaw & Dobson, 1995; Shaw et al., 1998]. The symbiont richness pattern is an important variable to understand the population dynamics of the host-symbiont relationship; it is assumed that the over dispersal pattern acts to increase density-dependent regulation of abundance in both hosts and symbionts, and to reduce the level of interspecific competition among symbionts [Tompkins et al., 2011]. Moreover, even individually benign infections can have a cumulative pathogenic effect [McCallum, 1994; McCallum and Dobson, 2005]. Compared to 7.83 symbiont species per individual in Gombe [Gillespie et al., 2010], the CNP chimpanzees have a reduced incidence of co-infections, however the data are in agreement with the ranges reported for chimpanzees at Rubondo Island, Tanzania [Petrášová et al., 2010] and in Kibale NP, Uganda [Muehlenbein, 2005], giving the average richness of 2.0 and 4.75 symbiotic species per individual, respectively.

Symbiont richness was higher in chimpanzee subpopulations living in fragmented forests compared to the north community, which live in a more continuous forest area; however, pairwise comparisons revealed that only central community had significantly higher symbiont richness in comparison to northern one. Epidemiological theory predicts that symbiont species richness should positively correlate with host population density [e.g., Nunn et al., 2003] expecting higher host densities in fragmented biotopes. Gillespie and Chapman [2008] recorded that the number of symbiont species infecting red colobus (*P. rufomitratus*) in Kibale, Uganda was greater in forest fragments when compared to red colobus living in continuous forests, demonstrating a greater infection risk for those populations, which live at higher densities in fragmented landscapes. Similarly, increased host density due to forest fragmentation and loss mediates increases in symbiont richness in Tana River red colobus (*P. rufomitratus*) and mangabeys (*Cercocebus galeritus*) [Mbora et al., 2009]. The observed symbiont richness of this study is in agreement with the epidemiological theory suggesting that the forest fragmentation in the Central area is indicative of human disturbance, which is promoting a higher co-infection of symbionts in that chimpanzee subpopulation.

Oates [2006] argues that marginal populations are more prone to habitat destruction and vulnerable to demographic changes. Associated with these anthropogenic alterations, disease derived by parasite

disturbance can enhance the extinction risk of wild primates [Pedersen et al., 2007]. Under this complex scenario gastrointestinal symbiotic surveillance cannot be neglected for conservation purposes [Whiteman & Parker, 2005]. Currently, there are no apparent parasite illness problems on CNP chimpanzees, nonetheless, further monitoring and epidemiological surveys not only on chimpanzees but also, on other primate sympatric species in the area are necessary. The results of this study should be considered in the conservation and management of this endangered ape especially when there are ecotourist development plans for the park [AD, 2010; Hockings & Sousa, 2013; IBAP, 2010].

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