First Report of Gastrointestinal Parasites from Ansell's Mole-Rat (*Fukomys anselli*) in Zambia

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ABSTRACT: The endoparasite fauna of Ansell's mole-rat, *Fukomys anselli* (Burda, Zima, Scharff, Macholán and Kawalika) (Rodentia, Bathyergidae) was studied for the first time near Lusaka, Zambia. We recovered 7 endoparasite taxa including 5 nematodes (*Hexametra* sp., *Protospirura numidica* Seurat, 1914; *Protospirura muricola* Gedoelst, 1916; *Protospirura* sp. and *Mammalakis zambiensis* Junker, Lutermann and Mutafchiev, 2017); and 2 cestodes (*Inermicapsifer* sp. and *Rodentolepis* cf. *microstoma* (Dujardin, 1845)) from 272 individuals sampled between February 2009 and February 2010. Species richness (0-2), prevalence (14.7%), and abundance (0.44 ± 0.10) were low, probably as a result of the subterranean lifestyle of the study species. Although effect of host sex on helminth burden was largely absent, helminth burden varied with season and breeding status of the host. This may be a result of seasonal variation in burrow size in response to rainfall, but also the division of labor present in the study species.

Parasites are rarely evenly distributed throughout a host population with the majority of animals only sustaining few parasites while a small proportion of individuals are parasitized by the majority of parasites and this is likely to be a result of differences in host exposure and/or susceptibility (Wilson et al., 2002). Such differences can be caused by variation in behavior and physiology among host individuals. For example, the frequently observed male-bias in parasite burden in mammals has been alternatively attributed to a larger body size, greater home ranges or reduced immune function of males (Moore and Wilson, 2002; Scantlebury et al., 2010). However, reproductive investment of female mammals may also increase their susceptibility resulting in female-biased parasitism (Christe et al., 2000). Alternatively, climatic conditions may affect the survival of infective stages in the environment resulting in temporal or spatial heterogeneities in exposure to parasites such as helminths (Wilson et al., 2002).

Among small mammals, rodents host the largest diversity of helminth taxa, often sustaining great helminth burdens (Morand et al., 2006). Notable exceptions are subterranean species including many members of the Ctenomyidae and Bathyergidae. They only sustain a small number of helminth species which is generally attributed to the limited host exposure in burrow systems (Rossin et al., 2010; Lutermann and Bennett, 2012). However, studies of the helminth fauna of subterranean rodents are scant and hence our knowledge of their helminth fauna might be biased.

Members of the genus *Fukomys* Kock, Ingram, Frabotta, Honeycutt and Burda, 2006, 1 of 6 genera in the subterranean African mole-rat (Bathyergidae) family that is endemic to sub-Saharan Africa, comprise one of the most speciose rodent genera (Van Daele et al., 2007). Despite this diversity, only a single study of the helminths parasitizing *Fukomys* spp. has been conducted to date. Based on the examination of 18 and 14 individuals of *Fukomys kafuensis* Burda, Zima, Scharff, Macholán and Kawalika and *Fukomys mechowi* Burda, Zima, Scharff, Macholán and Kawalika, respectively, Scharff et al., (1997) report only generalist rodent helminths including 1 nematode (*Protospirura muricola* Gedoelst, 1916) and 1 cestode (*Inermicapsifer madagascariensis* Davaine, 1870) as well as unidentified cestodes from each host species. In addition, *F. mechowi* was parasitized by *Raillientina* sp. and eggs from *Capillaria* sp. were recovered from the feces of 1 individual (Scharff et al., 1997). Ansell's mole-rat (*Fukomys anselli* Burda, Zima, Scharff, Macholán and Kawalika) is

another member of this genus with a marked sexual dimorphism in body size (Sichilima et al., 2011). They are herbivorous and endemic to the grasslands and Miombo woodlands of the Lusaka Province, Zambia, and their limited geographic distribution in combination with their intense prosecution by humans has garnered them a near threatened status (Sichilima et al., 2011, Junker et al., 2017). Despite their seasonal habitat, *F. anselli* breed throughout the year. However, breeding is limited to 1-2 females and 1 to few males within a group of up to 16 individuals (Sichilima et al., 2011). The aim of the current study was to describe the helminth community of *F. anselli* and to investigate the contributions of season, host sex and breeding status on helminth burden. We hypothesized that (i) helminth species richness would be low. As previous studies from other bathyergids suggested increased burdens during the dry season (Archer et al., 2017; Viljoen et al., 2011; Lutermann et al., 2013), we predicted that (ii) helminth burden (i.e., prevalence and/or abundance) would be greater during the dry compared to the wet season. In addition, (iii) we expected males and (iv) breeders to sustain higher burdens than females and non-breeding animals.

Mole-rats were captured between February 2009 and February 2010 about 15 km west of Lusaka, Zambia, on Mukulaikwa Farm Block (14°65'S, 27°48'E) by digging up entire burrow systems located under mole-hills in areas of natural vegetation that were intermittently disturbed by agricultural practices (for details see Sichilima et al., 2011). Situated ca. 1,600 m above sea level, this area receives 800 ± 134 mm of rain annually with most of it falling during the rainy season from mid-November to mid-April (Sichilima et al., 2011). Temperatures peak in October (31.6 C) and are lowest in July (10.1 C, Sichilima et al., 2011). Animals were killed using an overdose of chloroform, weighed to the nearest 0.01 g and sexed. Breeders were identified based on their larger body mass as well as the presence of elongated teats and perforated vagina for females and stains around their mouth due to glandular secretions for males (Sichilima et al., 2011). The body cavity was opened and the gastrointestinal tract (GIT) removed and stored in 70% ethanol. For processing, we separated the GIT into the

stomach, small intestine, cecum, and colon and inspected them separately. The GIT content was flushed out and any helminths encountered were stored in 70% ethanol for later identification. Similarly, any helminths observed in the tissue and/or fat attached to the GIT were collected and stored in 70% ethanol. Nematodes were cleared in lactophenol and identified under a compound microscope. Cestodes were checked for the presence and armature of the rostellum in Berlese's medium. Hook number and morphology aided in taxon identification. Because cestodes were not relaxed prior to fixation, the anatomy of the mature proglottids could not be properly examined. However, gravid proglottids were checked for the presence of egg capsules. All helminth identifications were based on relevant keys and descriptions of various authors. Voucher specimens were deposited in the National Collection of Animal Helminths (NCAH), Agricultural Research Council-Onderstepoort Veterinary Institute, Onderstepoort, South Africa (accession numbers NCAH.4.1-13, S/2016/35-37).

We calculated the species richness as well as the prevalence and mean abundance for each parasite taxon following Bush et al. (1997). We defined samples collected between November and April as from the wet season while those collected between May and October were from the dry season. To evaluate the possible contributions of season (wet/dry), host sex and status (breeding/non-breeding) on the species richness, prevalence and abundance of helminths we used generalized linear models (GLMs) assuming a Poisson (species richness, abundance) or a binomial (prevalence) data distribution and a log-link function. All 2-way interaction terms were included in the model. In addition, we added body mass as a covariate to the model. Only helminth taxa with a prevalence exceeding 4.0% were considered. Consequently, we pooled data for *Protospirura* spp. for analyses. Also, since the condition of cestode specimens recovered was poor and scolices may have been lost, counts were not possible and only prevalence was analyzed for this group. The gut section of the GIT was damaged or missing for 12 animals. However, excluding these individuals from the analyses did result in

qualitatively identical results and hence only the former will be presented here. Results are reported as means ± SE.

We recovered 7 helminth taxa from a total of 272 mole-rats (154 females, 118 males; 120 dry, 154 wet season) sampled. Of these 5 were nematodes, namely *Hexametra* sp., *Protospirura numidica* Seurat, 1914, *P. muricola*, *Protospirura* sp. and *Mammalakis zambiensis* Junker, Lutermann and Mutafchiev, 2017, with *Hexametra* sp. being the most prevalent and abundant (Table I). In addition, we retrieved 2 cestodes, *Inermicapsifer* sp. and *Rodentolepis* cf. *microstoma* Dujardin, 1845, with *Inermicapsifer* sp. being the most prevalent helminth (Table I). A total of 127 nematodes were recovered and with the exception of *Hexametra* sp. (28 L3 and 6 adults), we only found adult nematodes. Species richness was low (0.24 ± 0.03) and ranged from 0 to 2. It was not affected by any of the parameters considered (P ≥ 0.084).

The overall prevalence and abundance of nematodes was 14.7% and 0.44 ± 0.10, respectively. None of the factors considered had a significant effect on the prevalence of *Hexametra* sp. (Table II). In contrast, *Hexametra* sp. abundance was significantly greater in the dry (0.10 ± 0.03) compared to the wet season (0.03 ± 0.02, Table II). At the same time, it did not differ significantly between the sexes (Table II). However, non-breeders (0.12 ± 0.03) had a significantly greater *Hexametra* sp. abundance than breeders (0.02 ± 0.02, Table II). The interaction between season and sex was significant (Table II, Fig. 1A) and males had a significantly lower abundance of *Hexametra* sp. than females during the wet season (LSD: P = 0.027, Fig. 1A). None of the remaining pairwise comparisons were significant (P ≥ 0.808). The interaction between season and breeding status was significant (Table II, Fig. 1B) with non-breeders having significantly higher abundances of *Hexametra* sp. compared to breeders during the wet season (LSD: P = 0.002, Fig. 1B). None of the other pairwise comparisons were significant (P ≥ 0.107). The interaction between sex and breeding status was significant (Table II; Fig. 2). The abundance of *Hexametra* sp. was significantly lower in male breeders compared to non-breeders (LSD: P < 0.0001, Fig. 2). None of the remaining

pairwise comparisons were significant (P ≥ 0.052). In addition, the abundance of *Hexametra* sp. increased weakly but significantly with body mass (coefficient: 0.032 ± 0.012, Table II).

Protospirura spp. achieved a prevalence of 7.4% and an abundance of 0.19 ± 0.07. The prevalence was significantly higher in the dry (10.8%) compared to the wet season (4.6%, Table II). None of the remaining factors had a significant effect on the prevalence of *Protospirura* spp. (Table II). The abundance of *Protospirura* spp. was significantly higher during the dry (0.18 ± 0.06) compared to the wet season (0.04 ± 0.02, Table II). Furthermore, it was significantly lower in males (0.04 ± 0.02) compared to females (0.19 ± 0.04, Table II). Also, breeders had significantly lower *Protospirura* spp. abundances (0.04 ± 0.02) than non-breeders (0.19 ± 0.04, Table II). None of the interaction terms were significant (Table II). In contrast, the abundance of *Protospirura* spp. increased weakly, but significantly with body mass (coefficient: 0.019 ± 0.010, Table II).

Statistical constraints did not allow the inclusion of these 2-way interactions for *M. zambiensis*. The prevalence of *M. zambiensis* was not significantly affected by any of the remaining factors (Table II). The *M. zambiensis* abundance was significantly lower during the dry (0.05 ± 0.02) compared to the wet season (0.20 ± 0.05, Table II). In contrast, neither sex nor breeding status affected the abundance of *M. zambiensis* significantly (Table II). None of the factors considered affected the prevalence of *Inermicapsifer* sp. significantly (Table II).

Similar to other subterranean rodents the observed helminth species richness for *F. anselli* was low supporting the hypothesis that the subterranean niche limits the exposure to parasites (Rossin et al., 2010; Lutermann and Bennett, 2012). At the same time, with 4 nematodes (as specimens identified as *Protospirura* sp. likely belong to *P. numidica* and *P. muricola*, however, their poor condition did not permit a reliable identification beyond genus level) and 2 cestode species the helminth community of *F. anselli* exhibits a greater species diversity than has previously been reported for the genus as well as for any other bathyergid species while prevalence and abundance of these species

is comparatively low (Scharff et al., 1997; Tenora et al., 2003; Viljoen et al., 2011; Lutermann and Bennett, 2012; Lutermann et al., 2013; Archer et al., 2017). Since sample sizes were relatively small for *F. kafuensis* and *F. mechowi* (Scharff et al., 1997), it remains unclear whether a similarly great species diversity is more common in the genus *Fukomys*. However, since the ectoparasite community of *Fukomys damarensis* Ogilby also showed low parasite abundance but high diversity, this might be a general pattern across members of the genus *Fukomys* (Lutermann et al., 2015). If ectoparasites, such as mites, would act as intermediate hosts for at least some of the recovered helminth taxa, this could also account for their low prevalence and abundance.

Hexametra spp. are frequently reported from reptile hosts, particularly snakes, while reports from wild rodent hosts are limited. However, larvae of the genus have previously been reported from *Heliophobius argenteocinereus* Peters from the Democratic Republic of Congo, a solitary bathyergid species also occurring in Zambia (Quentin, 1964). This nematode can have a direct as well as an indirect life cycle and its larvae exhibit extensive migration (Chabaud et al., 1962) which is evident in the study species by the large number of infection sites observed. The large proportion of *Hexametra* sp. larvae observed suggests that *F. anselli* acts mostly as intermediate host for this parasite. It is interesting to note that the plasticity of life cycles in the Ascaridoidea is pronounced, and some *Hexametra* spp. may complete their development in the intermediate or final host (Adamson, 1986), which might account for the adults collected from *F. anselli*. In the presence of a single male in poor condition, identification to species level was not possible. Since we only examined the GIT and attached tissue for the current study, the prevalence and abundance of *Hexametra* sp. may have been underestimated in the current study.

Protospirura spp., *Inermicapsifer* spp. and *Rodentolepis microstoma* are generalist parasites with an indirect life cycle. Hosts are mostly rodents including several species of bathyergids (de Graaff, 1964; Quentin, 1964; Scharff et al., 1997; Tenora et al., 2003; Viljoen et al., 2011). The current study constitutes the first

report of *P. numidica* from a bathyergid. The 4 members of the genus *Mammalakis* Inglis, 1991 are only known from subterranean mammals (Junker et al., 2017). Two of these have been found in bathyergids and while *M. zambiensis* was only recently described from *F. anselli*, *M. macrospiculum* (Ortlepp, 1939) parasitizes *Cryptomys hottentotus hottentotus* Lesson and *Bathyergus suillus* Schreber, which are sympatric in the Western Cape, South Africa (Archer et al., 2017; de Graaff, 1964; Lutermann and Bennett, 2012).

As expected, helminth burden differed between seasons for 3 of the 4 most common taxa, with *Hexametra* sp. and *Protospirura* spp. burdens being greater during the dry compared to the wet season while the opposite was true for *M. zambiensis*. In bathyergids of the genus *Cryptomys* Gray an increase of helminth burdens during the dry season has been attributed to a greater exposure to parasites as a result of the restrictions to digging activity in the absence of rain and/or the resulting food stress and could also account for the observed pattern in *F. anselli* (Viljoen et al., 2011; Lutermann et al., 2013; Archer et al., 2017). However, this cannot explain the inverse pattern observed for *M. zambiensis*, a pattern also observed for *Ortleppstrongylus bathyergi* (Ortlepp, 1939) (syn. *Longistriata bathyergi* Ortlepp, 1939) in solitary *B. suillus* (Lutermann and Bennett, 2012). These nematodes are host specific and their life cycle is currently unknown making it difficult to interpret the observed pattern.

Sex biases in helminth burden were largely absent in the study species. Similar observations have been made for other social bathyergids and it has been suggested that this is a result of the shared burrow system (Viljoen et al., 2011; Lutermann et al., 2013; Archer et al., 2017). However, this cannot account for the greater abundance of *Protospirura* spp. sustained by *F. anselli* females. Instead, the greater reproductive investment of breeding females compared to males could make them more susceptible and all of the breeding females sampled were pregnant and/or lactating (Sichilima et al., 2011). At the same time, in *F. anselli*, non-breeding females range the furthest from the nest compared to males and breeding

females (Šklíba et al., 2016) and this may increase their exposure to *Protospirura* spp.

Breeding status affected the abundance of *Hexametra* sp. and *Protospirura* spp. with non-breeders sustaining greater abundances than breeders which was more pronounced during the wet season and among males for *Hexametra* sp. This may be explained by the division of labor observed in social mole-rats were breeders participate to a lesser extent in energetically costly foraging activities, which are more extended in most soils, than non-breeders which may make them less susceptible (Viljoen et al., 2011). This hypothesis is supported by the observation that in the study area breeding males stay the closest to the nest (Šklíba et al., 2016). The weak increase in the abundance of *Hexametra* sp. and *Protospirura* spp. with body mass may be a result of an accumulation of parasites with age and has also been observed in other social bathyergids (Viljoen et al., 2011).

In summary, like other subterranean rodents *F. anselli* sustains low helminth diversity, prevalence, and abundance. We suggest that variation in helminth burden is linked to seasonal differences in ranging patterns, sex-specific reproductive investment and the division of labor in the study species.

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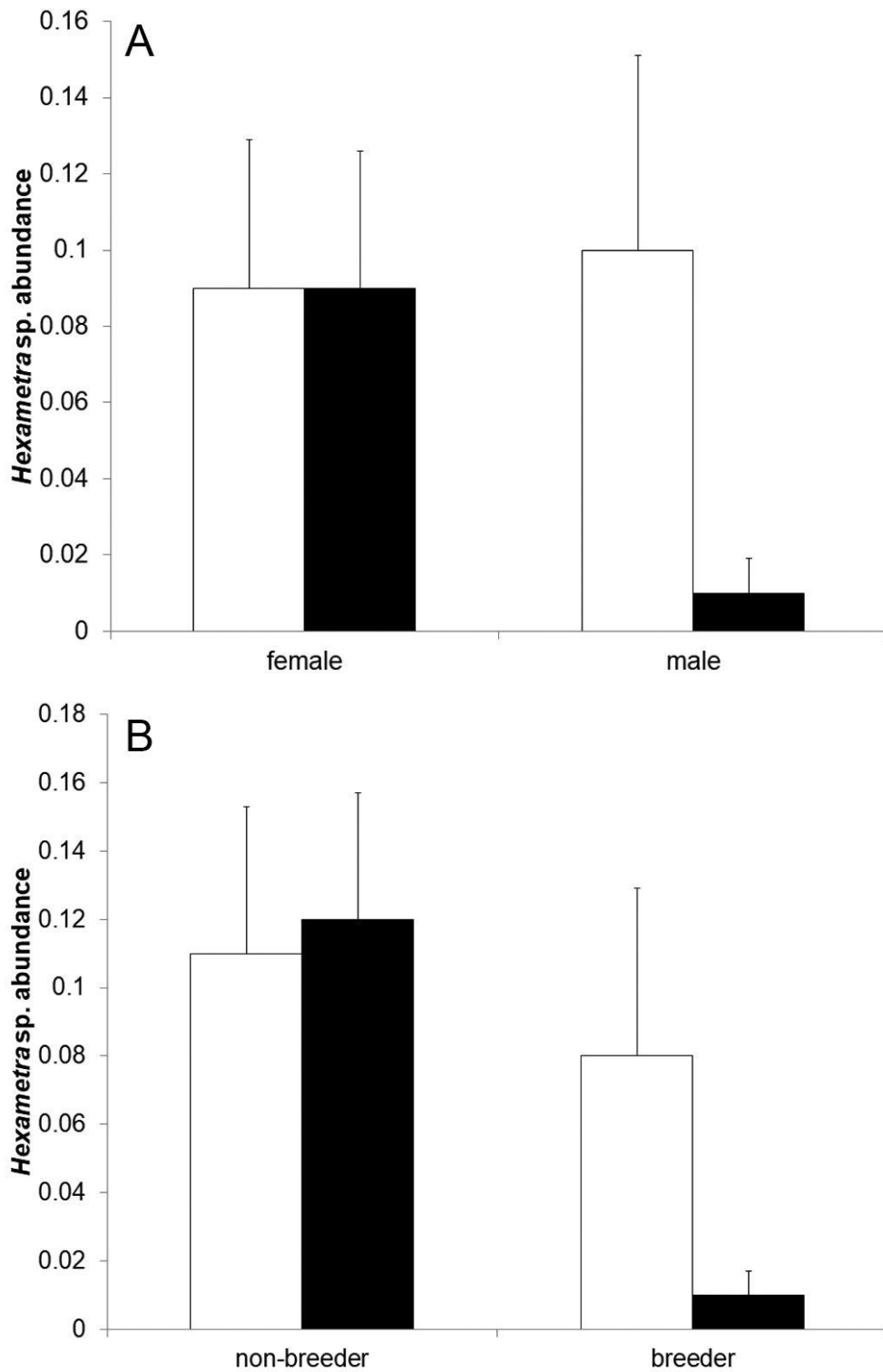
Figure 1. Effects of season and (A) host sex or (B) breeding status on the abundance of *Hexametra* sp. sustained by *Fukomys anselli*. Open bars indicate the dry season while solid bars indicate the wet season. Displayed are means ± SE.
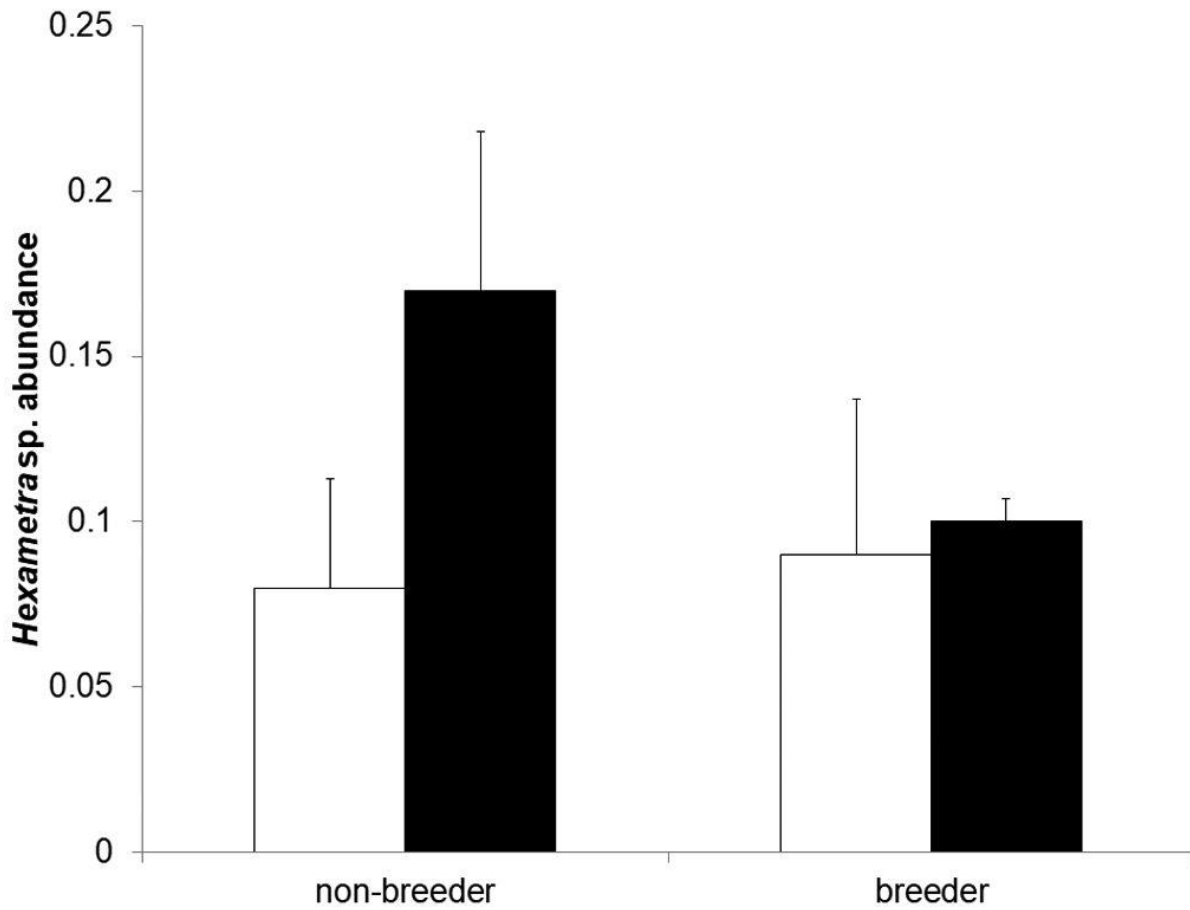
Figure 2. Effects of host sex and breeding status on the abundance of *Hexametra* sp. in *Fukomys anselli*. Females are indicated with open bars while males are indicated with solid bars. Displayed are means ± SE.

Table I. Summary of the parasite species and their infection characteristics in *Fukomys anselli* (n = 272) from Zambia

Parasite species	Site of infection	total	Prevalence (%)	Mean abundance	Range
Hexametra sp.	Large intestine, small intestine, stomach, GI fat	34	5.5	0.12 ± 0.04	0-6
Protospirura numidica	Stomach	42	3.7	0.13 ± 0.06	0-14
Protospirura muricola	Stomach	11	1.5	0.04 ± 0.02	0-6
Protospirura sp.	Stomach	4	2.2	0.02 ± 0.01	0-1
Mammalakis zambiensis	Large intestine, caecum	36	4.0	0.13 ± 0.05	0-11
Inermicapsifer sp.	Small intestine	-	6.6	-	-
Rodentolepis cf. *microstoma*	Small intestine	-	0.4	-	-

Table II. Results of the GLMs for the effects of season, host sex, breeding status and body mass on parasite prevalence and abundance in *Fukomys anselli*. Displayed are Wald χ^2 and p-values. Significant effects are highlighted in bold.

	Hexametra sp.		*Protospirura* spp.		*M. zambiensis*		*Inermicapsifer* sp.
	prevalence	abundance	prevalence	abundance	prevalence	abundance	prevalence
Season	0.323, p = 0.570	5.494, p = **0.019**	4.173, p = **0.041**	8.905, p = **0.003**	0.217, p = 0.642	8.975, p = **0.003**	0.380, p = 0.538
Sex	0.284, p = 0.594	3.251, p = 0.071	3.769, p = 0.052	6.361, p = **0.012**	1.340, p = 0.247	2.080, p = 0.149	0.422, p = 0.512
Status	0.306, p = 0.580	5.182, p = **0.023**	0.695, p = 0.404	5.673, p = **0.017**	0.043, p = 0.835	0.032, p = 0.859	0.514, p = 0.474
Season*sex	0.995, p = 0.318	5.511, p = **0.019**	1.678, p = 0.195	3.801, p = 0.051	-	-	0.466, p = 0.495
Season*status	0.920, p = 0.337	5.017, p = **0.025**	0.328, p = 0.567	0.010, p = 0.922	-	-	0.004, p = 0.953
Sex*status	1.009, p = 0.315	9.325, p = **0.002**	1.887, p = 0.169	3.022, p = 0.082	-	-	2.122, p = 0.145
Body mass	1.715, p = 0.190	6.722, p = **0.010**	1.189, p = 0.275	3.833, p = **0.050**	0.128, p = 0.721	0.638, p = 0.424	0.577, p = 0.447