

Endoparasites of the eastern rock sengi (*Elephantulus myurus*) from South Africa

¹Heike Lutermann, ¹Katarina Medger, and Kerstin Junker*

¹Mammal Research Institute, Department of Zoology and Entomology, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa. *ARC-Onderstepoort Veterinary Institute, Private Bag X05, Onderstepoort, 0110, South Africa. Correspondence should be sent to: hlutermann@zoology.up.ac.za

BSTRACT: The endoparasite fauna of the eastern rock sengi (*Elephantulus myurus* Thomas and Schwann) was studied for the first time for any sengi species from September 2007 until August 2008 in the Limpopo Province of South Africa. From the 121 sengis examined, we recovered 11 endoparasite taxa including 9 nematodes, 1 cestode family (Hymenolepididae) and 1 pentastomid species [*Armillifer armillatus* (Wyman, 1834)]. The overall endoparasites prevalence was high at 100% and largely attributable to the nematode *Maupasina weissi* Seurat, 1913, with only a single individual being parasite free. Despite the high diversity, species richness was low (1.58 ± 0.06) and only *M. weissi* and spiruroid larvae occurred at a prevalence exceeding 8%. The abundance of *M. weissi* varied significantly between seasons and was lowest in summer and autumn. In contrast, the abundance of spiruroid larvae remained relatively constant across seasons in males but was significantly higher in spring and summer compared to winter in females. These patterns may be generated by an accumulation of *M. weissi* with age as well as sex-specific seasonal shifts in diet. An updated list on the hosts and geographic range of parasites of sengis is provided.

Sengis (Macroscelidea) are small insectivorous mammals endemic to Africa comprising 4 genera (*Rhynchocyon* Peters, *Macroscelides* A. Smith, *Petrodromus* Peters and *Elephantulus* Thomas and Schwann) and 19 extant species of which 11 are from the genus *Elephantulus* (Rathbun, 2009; Dumbacher et al., 2014). They have a wide distribution across Africa which includes the entire continent apart from western Africa and the Sahara desert. Members of *Rhynchocyon* and the monotypic genus *Petrodromus* inhabit mesic woodlands and tropical rainforests while the other 2 genera exploit more arid savannah and desert habitats (Rathbun, 2009). Despite their wide geographic distribution sengis have received comparatively limited attention when it comes to their endoparasite fauna and the available records are restricted to incidental observations of a taxonomic nature mainly from *Elephantulus rozeti* (Duvernoy) in Tunisia (Seurat, 1913, 1914; Quentin, 1978; Quentin and Seureau, 1978) and *Petrodromus tetradactylus* Peters from central and east Africa (Bayliss, 1934; van den Berghe and Vuylsteke, 1938). In contrast, the center of biodiversity of sengis lies in southern Africa with 3 genera and 7 species occurring in South Africa, and *E. rozeti* being the only species found north of the Sahara (Rathbun,

2009). Conversely, only a single nematode record is available from South Africa for *Macroscelides proboscideus* Shaw (Ortlepp, 1937). However, either the indicated geographic location (former Western Transvaal, corresponding to the northeastern part of today's Northwest Province) or the host species was misidentified, since this locality lies outside the distributional range of *M. proboscideus* (Dumbacher et al., 2014). The vast majority of endoparasites reported for sengis parasitize the gastrointestinal tract (GIT) with the exception of *Thelazia lewisi* Ogden, 1968 retrieved from the eyelid of *Rhynchocyon cirnei* Peters in Uganda and the pentastomid *Armillifer armillatus* Wyman, 1845 from an unspecified sengi species (Zumpt, 1961; Ogden, 1968). In the current study we examined the GITs of eastern rock sengis (*Elephantulus myurus* Thomas and Schwann) for endoparasites and evaluated the contributions of season and host sex to their species richness, prevalence and abundance. *Elephantulus myurus* has a wide geographic distribution, including parts of Zambia, Mozambique, Zimbabwe, Botswana and South Africa (Skinner and Chimimba, 2005). The current study constitutes the first long-term assessment of the endoparasite fauna in the order Macroscelidea.

MATERIALS AND METHODS

Sengis were captured between September 2007 and August 2008 in a private game reserve (22°58'S, 29°25'E) in the Limpopo Province of South Africa using Sherman live traps baited with a mixture of oats, peanut butter and sardines (permit number: CPM-333-00002) as part of a study on their reproductive biology (Medger et al., 2012). Additional captures were made during October 2008 and April 2009. A maximum of 5 individuals of each sex were caught on a monthly basis. All animals included in the current study (n = 121, 58 males, 63 females) had a body mass exceeding 36g suggesting that they were sub-adults or adults (Medger et al., 2012). Once captured, animals were maintained in standard rodent cages with wood shavings as bedding and fed a diet of commercial dog food (Promeal Ltd, Atlantis, South Africa), Pro Nutro (high protein cereal; Pioneer Foods Ltd, Epping, South Africa), mealworms and grated carrots and apple with water available ad libitum. They were killed with an overdose of halothane within a maximum of 8 days after capture. The body cavity was opened, the GIT removed in its entirety and stored in 70% ethanol. Endoparasites encountered in the body cavity during this procedure were removed and also stored in 70% ethanol but no systematic search for endoparasites in the body cavity was conducted. The GIT was later separated into stomach, small intestine, cecum and colon. Each of these sections was examined separately by flushing out the contents and any parasites encountered were stored in 70% ethanol. All helminths were cleared in lactophenol while pentastomids were cleared in Hoyer's medium before being examined under a compound light microscope for identification. Voucher specimens were deposited in the National Collection of Animal Helminths, Agricultural Research Council-Onderstepoort Veterinary Institute, Onderstepoort, South Africa (accession numbers S/2015/5-14).

We recorded the presence/absence as well as the number of individuals for each parasite taxon encountered and calculated the species richness, prevalence and mean abundance following Bush et al., (1997). Since the number of individuals of each sex per month

was low, we pooled data across seasons (spring: September-November, summer: December-February, autumn: March-May and winter: June-August) for analyses. To assess possible effects of season and host sex on the species richness, prevalence and abundance, we employed generalized linear models (GLMs) with a Poisson, a binomial (prevalence) and negative binomial (abundance) data distribution and a log-link function, respectively. Season and sex as well as the interaction between sex and season were included as independent variables in the model. Host body mass was added as covariate. Only 2 parasite taxa occurred at sufficiently high prevalence to allow a meaningful statistical analysis and hence these analyses were only carried out for these parasites. However, since one of these was encountered in all but 1 individual, only the abundance was considered for this parasite species. For significant terms least significant differences (LSD) post-hoc tests were carried out. All analyses were conducted using SPSS v.21 and results are reported as means \pm SE.

RESULTS

Eleven endoparasite taxa were recovered from the 121 host specimens dissected. Parasites were determined as: 1 unidentified cestode from the family Hymenolepididae, *A. armillatus* (Pentastomida, Porocephalidae), and the nematodes *Syphacia minuta* Greenberg, 1969 (Oxyuridae), *Moaciria* sp. and *Spinicauda* sp. (Heterakidae), *Maupasina weissi* Seurat, 1913 (Subuluroidea, Maupasiniidae), *Abbreviata* spp. and *Physaloptera* spp. (Physalopteridae), *Trichuris* spp. (Trichuridae), adult specimens belonging to Physalopterinae which could not be further identified, as well as unidentified larvae of Spiruroidea (Table I). Despite this fairly large species diversity the species richness was low (1.58 ± 0.06 , CI: 1.47-1.69) and ranged from 1-3. It was neither significantly affected by season ($\chi^2 = 1.841$, df = 3, p = 0.606), sex ($\chi^2 = 0.001$, df = 1, p = 0.974), the interaction between season and sex ($\chi^2 = 0.605$, df = 3, p = 0.895) nor the body mass of the host ($\chi^2 = 0.006$, df = 1, p = 0.941). Although most endoparasite taxa retrieved occurred only at low prevalence, the overall endoparasite prevalence was high (100%). This was largely attributable to the high prevalence of

M. weissi (Table I) with only 1 individual not being infected. The abundance of *M. weissi* differed significantly between seasons ($\chi^2 = 13.533$, $df = 3$, $p = 0.004$, Fig. 1A). It was significantly lower in summer compared to spring and winter ($p \leq 0.044$, Fig. 1A). In addition, it was significantly greater in winter compared to autumn (LSD: $p = 0.026$), while none of the remaining pairwise comparisons was significant ($p \geq 0.190$). Neither sex ($\chi^2 = 2.799$, $df = 1$, $p = 0.094$) nor the interaction between season and sex was significant ($\chi^2 = 0.694$, $df = 3$, $p = 0.875$). However, the abundance of *M. weissi* increased significantly with body mass (estimate \pm SE: 0.051 ± 0.021 , $\chi^2 = 6.192$, $df = 1$, $p = 0.013$).

Unidentified spiruroid larvae were the only other endoparasites exceeding a prevalence of 8% (Table I). However, the prevalence of spiruroid larvae was not significantly affected by either season ($\chi^2 = 4.865$, $df = 3$, $p = 0.182$), sex ($\chi^2 = 1.648$, $df = 1$, $p = 0.199$) or body mass ($\chi^2 = 0.124$, $df = 1$, $p = 0.725$). Similarly, the interaction between season and sex was not significant ($\chi^2 = 1.119$, $df = 3$, $p = 0.772$). In contrast, the abundance of spiruroid larvae differed significantly between seasons ($\chi^2 = 14.169$, $df = 3$, $p = 0.003$). It was significantly higher in summer (1.19 ± 0.22 , CI: 0.84-1.71) compared to autumn (0.48 ± 0.12 , CI: 0.30-0.78) and winter (0.37 ± 0.14 , CI: 0.17-0.76, $p \leq 0.004$). In addition, it was significantly greater in spring (1.00 ± 0.22 , CI: 0.64-1.55) compared to autumn and winter ($p \leq 0.041$). None of the remaining pairwise comparisons was significant ($p \geq 0.528$). The abundance of spiruroid larvae was significantly lower in females (0.52 ± 0.12 , CI: 0.34-0.80) compared to males (0.89 ± 0.13 , CI: 0.67-1.19, $\chi^2 = 4.028$, $df = 1$, $p = 0.045$). However, it was not significantly affected by body mass ($\chi^2 = 0.255$, $df = 1$, $p = 0.614$). Furthermore, the interaction between season and sex was significant ($\chi^2 = 18.617$, $df = 3$, $p < 0.0001$, Fig. 1B). Among female sengis the abundance of spiruroid larvae was significantly greater in summer than in all other seasons ($p \leq 0.015$, Fig. 1B). Furthermore, it was significantly greater in spring compared to autumn and winter for females ($p \leq 0.042$). In addition, spiruroid larvae abundance was significantly higher for males compared to females in winter (LSD: $p =$

0.002) while the opposite was true in summer (LSD: $p = 0.003$, Fig. 1B). None of the remaining pairwise comparisons was significant ($p \geq 0.281$).

DISCUSSION

Prior to the present study, 15 species of helminths had been reported as parasite of the Macroscelidea, belonging to nematodes (11), cestodes (3), and pentastomids (1) (Seurat, 1915; Baer, 1926, 1933; Gedoelst, 1916; Sandground, 1933, Baylis, 1934; Zumpt, 1961; Ogden, 1968; Bain and Quentin, 1977, Quentin, 1978; Quentin and Seureau, 1978; Hugot and Cuisance, 1990) (Table II). The species richness of endoparasites retrieved from the current study nearly equals the species richness previously known for the entire order. In addition, Baylis (1934) mentioned specimens resembling members of the genus *Nycteridostrongylus* Baylis, 1930 and small oxyurids recovered from *P. tetradactylus* (syn. *P. nigriseta* Neumann) in Tanzania. No systematic assessment of the endoparasite fauna of any other sengi species is currently available for comparison but the species richness recorded in the present study is substantially larger than that reported for sympatric African spiny mice (*Acomys spinosissimus* Peters) (Lutermann et al., 2014). Although this may be due to the smaller body size of *A. spinosissimus* (ca. 20 g), it is also likely to be a result of the differences in diet between the 2 species. The insectivorous diet of sengis in contrast to the omnivorous diet of *A. spinosissimus* is likely to have contributed to the large number of endoparasite taxa that use arthropods as intermediate hosts found in the GIT of *E. myurus* (Skinner and Chimimba, 2005). At the same time, the current study is the first to report the presence of the directly transmitted oxyurid nematode *S. minuta* in a species other than a member of the genus *Acomys* I. Geoffroy (Lutermann et al., 2014). It is noteworthy that species of *Syphacia* Seurat, 1916 are typically considered parasites of rodents (Petter and Quentin, 1976), whereas members of the spinicaudine genera *Spinicauda* Travassos, 1920 and *Moaciria* Freitas, 1956 are typically parasites of reptiles (Chabaud, 1978). *Syphacia minuta* was recovered from 2 host individuals only, and *Spinicauda* sp. and *Moaciria* sp. were registered in only 1 of the

sengis; thus, their presence should currently be considered an accidental infection rather than an expansion of their host range.

Species of the pentastomid genus *Armillifer* Sambon, 1922 are parasites of the respiratory tract of snakes, especially pythons, and larval stages have been reported from a vast range of mammalian intermediate hosts such as antelopes, suids, primates, including humans, small and large carnivores, as well as small mammals, such as *Potamogale* sp., *Steatomys* sp., *Cricetomys* spp. and *A. spinosissimus* (Fain, 1961; Greve and Russell, 1974; Ogunsusi and Mohammed, 1978; Riley and Self, 1981; Lutermann et al., 2014). The presence of *Armillifer* larvae in *A. spinosissimus* and *E. myurus* in Limpopo Province constitute the first records of this genus from small mammals in South Africa and the first indication of the presence of this genus in South African snakes. Earlier reports recorded the presence of *Raillietiella* Sambon, in Vaney and Sambon, 1910 (Raillietiellidae) in *Bitis* spp. and *Psammophis* spp. (Hering-Hagenbeck, 2001; Lutermann et al., 2014) only.

The endoparasite assemblage of *E. myurus* was dominated by *M. weissi*, a nematode species also found in *E. rozeti* in Tunisia, *R. cirnei* in the DRC as well as an incorrectly identified *Elephantulus* sp. in South Africa (Table II). That the same parasite species is found across such divergent host subfamilies as Macroscleridae (*Elephantulus*) and Rhynchoconinae (*Rhynchocyon*) that differ substantially in size and habitat preferences but share life-history traits (Rathbun, 2009) as well as the large geographical distribution, is suggestive of a long co-evolutionary history of this parasite and the Macroscleridae.

Spiruroid larvae were the only other endoparasites found in substantial numbers in *E. myurus*. Their resemblance to descriptions of larval stages of *Streptopharagus* Blanc, 1912 (Chabaud, 1954) and *Mastophorus* Diesing, 1853 (Quentin, 1969; 1970) suggests the presence of several genera, but in the absence of adults of these genera identifications could not be confirmed. In combination with the other spiruroids, such as *Physolaptera* sp. and *Abbreviata* sp., it suggests that *E. myurus* is host to a diversity of Spiruroida. This corresponds

with the diversity of spiruroids across the order Macroscleridae (Bayliss, 1934; Quentin, 1978; Quentin and Seureau, 1978) and suggests that the spiruroid larvae found in the current study may represent several species.

The abundance of both of the most prevalent nematode taxa varied seasonally; however, their patterns were vastly different with a nadir in summer and peaks in spring and winter for *M. weissi* while the abundance of spiruroid larvae was lowest in winter and highest in spring and summer. Two mechanisms may explain this difference. Firstly, if *M. weissi* accumulates over time, the recruitment of subadults in the sengi population as the breeding season progresses (Medger et al., 2012) may account for the lower abundance of this species in summer and autumn. This hypothesis is further supported by the positive correlation between sengi body mass and *M. weissi* abundance. However, since sengis achieve adult weight within a few weeks after birth (K. Medger, unpubl. data), we could not unequivocally identify juveniles based on their body mass and can thus not further evaluate this hypothesis. Although juvenile recruitment may have contributed to the pattern observed for *M. weissi*, it cannot explain the variation in the abundance of spiruroid larvae. Nevertheless, if both of these nematode taxa use different intermediate hosts, seasonal shifts in the arthropods consumed may explain the seasonal patterns. Although under laboratory conditions *M. weissi* has been successfully propagated in *Locusta migratoria* (L.) (Acrididae) and *Ornithodoros erraticus* Lucas (Argasidae) (Bain and Quentin, 1977; Quentin and Verdier, 1979), the myrmecophagous habit of sengis suggests that ants and/or termites are likely to be the intermediate host for this nematode in the study area (Rathbun, 2009). These are presumably the staple in the diet of *E. myurus* throughout the year, but during spring and summer the available insects may increase in abundance and diversity. If this is reflected in the diet of *E. myurus*, it could account for the observed variation in nematode abundance. At the same time, the dominance of ants and termites in the diet of the study species could account for the low endoparasite species richness observed in the current study.

While the abundance of spiruroid larvae was relatively constant among males it varied dramatically among females. If the hypothesis proposed above proves to be correct this would suggest that males include a relatively fixed proportion of non-myrmecophagous prey in their diet while females greatly increase their intake of such insects during spring and summer but only consume low numbers during winter. Given that ants and termites are small and of low nutritional value (Redford and Dorea, 1984), the high energetic demands of pregnancy and lactation (Speakman, 2008) compared to the low reproductive investment of the monogamous males, that does not extend beyond mating (Rathbun, 2009), makes such sex-specific strategies likely.

In summary, the endoparasite species diversity found for *E. myurus* was fairly high but dominated by 2 nematode taxa, *M. weissi* and spiruroid larvae. The former has previously been reported for other sengi species over a wide geographical range suggesting host specificity for the order Macroscelidea. We suggest that fluctuations in the abundance of 2 common parasites are linked to juvenile recruitment and/or seasonal and sex-specific differences in diet.

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Figure 1. Variation in the abundance of (A) *Maupasina weissi* with season and (B) spirurid larvae with season and sex in *Elephantulus myurus* from the Limpopo Province, South Africa.

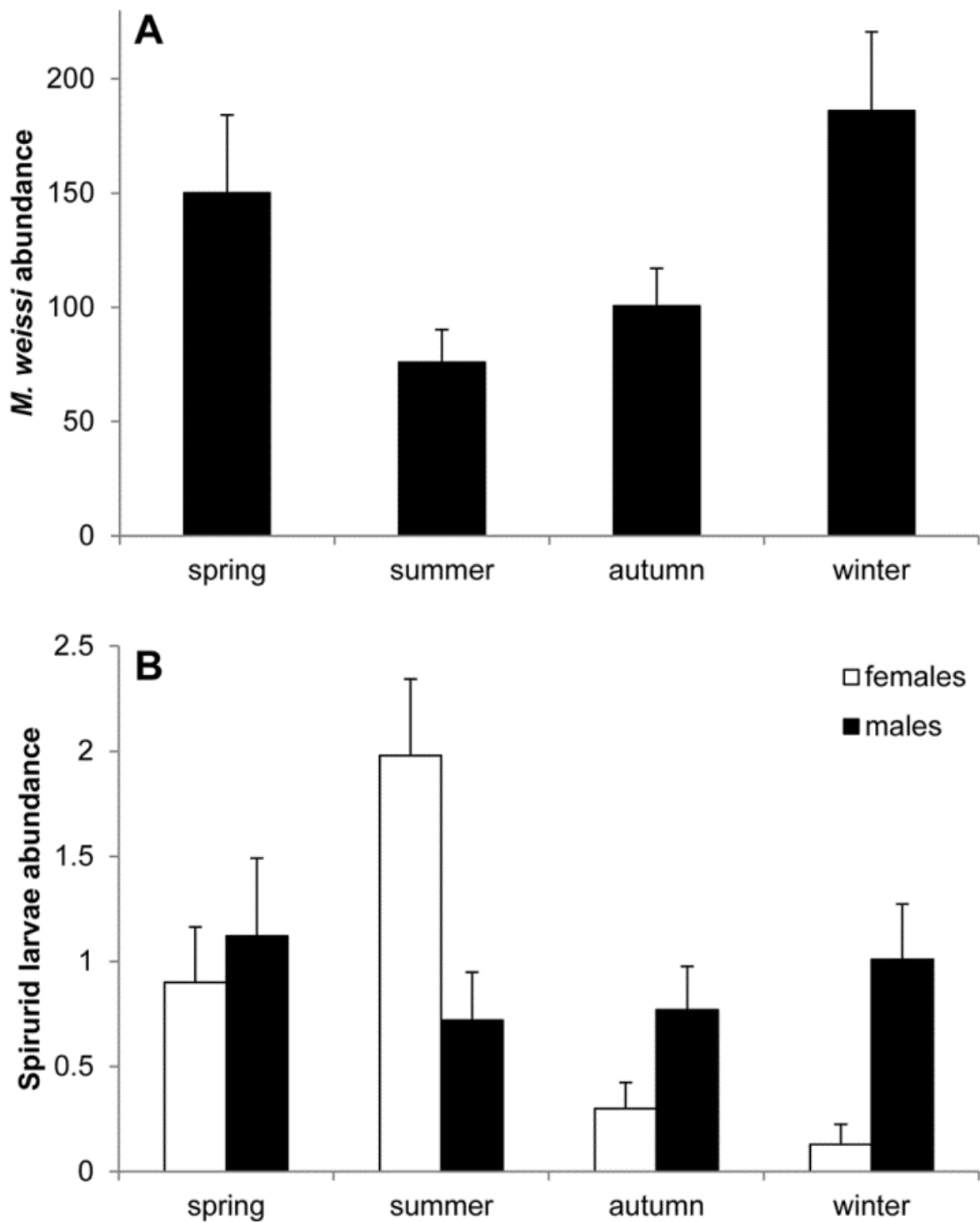


Table I. Endoparasites recovered from 121 *Elephantulus myurus* in the Limpopo Province, South Africa.

Taxon	Life cycle	Site in host	Total count	Prevalence (%)	Abundance (mean \pm SE)	Range
Nematoda						
<i>Syphacia minuta</i>	Direct	Cecum/colon	23	1.7	0.19 \pm 1.84	0 - 20
<i>Moaciria</i> spp.	Direct	Cecum/colon	4	0.8	0.03 \pm 0.36	0-4
<i>Spinicauda</i> spp.	Direct	Cecum/colon	4	0.8	0.03 \pm 0.36	0-4
<i>Maupasina weissii</i>	Indirect	Cecum/colon	15,367	99.2	127.00 \pm 84.87	0 - 476
<i>Abbreviata</i> spp.	Indirect	Stomach	14	5.0	0.12 \pm 0.66	0 - 5
<i>Physolapetra</i> spp.	Indirect	Stomach	26	7.4	0.21 \pm 1.08	0 - 10
Physalopterinae	Indirect	Stomach	5	1.7	0.01 \pm 0.09	0 - 1
Spiruriod larvae	Indirect	Stomach	111	24.0	0.92 \pm 0.207	0 -13
<i>Trichuris</i> spp.	Direct	Cecum/colon	5	1.7	0.04 \pm 0.33	0 -3
Cestoda						
Hymenolepididae*	Indirect	Small intestines	-	4.1	-	-
Pentastomida						
<i>Armillifer armillatus</i>	Indirect	Body cavity	21	6.6	0.17 \pm 0.88	0 - 8

*no scoleces were recovered and hence the number of cestodes could not be determined.

Table II. List of endoparasites recorded from Macroscelidae prior to this study

Taxon	Locality	Host species	Reference
Nematoda			
<i>Maupasina weissii</i>	Southern Tunisia ¹	<i>Elephantulus rozeti</i> ²	a
	Zimbabwe	<i>Elephantulus brachyrhynchus</i>	p
	Zaire	<i>R. cirnei</i>	p
	South Africa	<i>Elephantulus</i> sp.	i
<i>Parasubulura gerardi</i>	Zaire ¹	<i>Petrodromus tetradactylus</i> ²	j
	Zimbabwe	<i>Elephantulus brachyrhynchus</i>	p
<i>Parasubulura callosa</i> (syn. <i>Subuluara callosa</i>)	Zimbabwe ¹	<i>Petrodromus tetradactylus</i> ²	g; j
<i>Parasubulura petrodromi</i> (syn. <i>Numidica petrodromi</i>)	Tanzania ¹	<i>Petrodromus tetradactylus</i> ²	h; j; p
<i>Pterygodermatites (Neopaucipectines) zaiedi</i>	Southern Tunisia ¹	<i>Elephantulus rozeti</i> ²	n
<i>Thelazia lewisi</i>	Uganda ¹	<i>Rhynchocyon cirnei</i> ² (syn. <i>R. cirnei stuhlmanni</i>)	l
<i>Gongylonema brevispiculum</i>	Tunisia ¹	<i>Elephantulus rozeti</i> ²	o
<i>Spirurida rothschildi</i>	Algeria ¹	<i>Elephantulus rozeti</i> ² (syn. <i>Elephantulus deserti</i>)	c
<i>Cyathospirura chevreuxi</i> (syn. <i>Habronema chevreuxi</i>)	Tanzania ¹	<i>Petrodromus tetradactylus</i> (syn. <i>Petrodromus nigriseta</i>)	a; h
<i>Acanthocheilonema weissii</i> (syn. <i>Microfilaria matamatae</i>)	North Africa ¹ , Tunisia	<i>Elephantulus rozeti</i> ² (syn. <i>Elephantulus rozeti deserti</i>)	b; m
<i>Onchocercella katangensis</i> (syn. <i>Grammophora katagensis</i>)	DRC ¹	<i>Petrodromus tetradactylus</i>	d
Cestoda			
<i>Hymenolepis</i> s.l. <i>macroscelidarum</i>	South Africa ¹	<i>Elephantulus brachyrhynchus</i> ² (syn. <i>Macroscelides brachyrhynchus</i>)	e
<i>Hymenolepis</i> s.l. <i>petrodromi</i>	Zimbabwe ¹	<i>Petrodromus tetradactylus</i> ²	f
<i>Hymenolepis</i> sp.	Tanzania	<i>R. cirnei</i> (syn. <i>R. cirnei hendersoni</i>)	f*
Pentastomidae			
<i>Armillifer armillatus</i>	unspecified	unidentified	k

¹type locality; ²type host; ^aSeurat (1913); ^bSeurat (1914); ^cSeurat (1915); ^dGedoelst (1916); ^eBaer (1926); ^fBaer (1933); ^gSandground (1933); ^hBaylis (1934); ⁱOrtlepp (1937); ^jvan den Berghe and Vuylsteke (1938); ^kZumpt (1961); ^lOgden (1968); ^mBain and Quentin (1977); ⁿQuentin (1978); ^oQuentin and Seureau (1978); ^pHugot and Cuisance (1990); *no description provided, specimen in poor condition without scolex