

Research Article

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Gastrointestinal helminths from the common warthog, *Phacochoerus africanus* (Gmelin) (Suidae), in KwaZulu-Natal Province, South Africa, with comments on helminths of Suidae and Tayassuidae worldwide

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Abstract

Thirty warthogs, *Phacochoerus africanus*, were collected in the Pongola Game Reserve, South Africa and examined for helminths. Gastrointestinal helminth assemblages comprised *Gastrodiscus aegyptiacus*, the cestode genus *Moniezia* and seven species of nematodes. A single warthog harboured a metacystode of *Taenia hydatigena* in the mesenteries. No helminths were found in the heart, lungs or liver of the warthogs. *Probstmayria vivipara* and *Murshidia* spp. were the most prevalent as well as abundant helminth species, followed by *Physocephalus sexalatus*. The incidence of *Moniezia* did not differ between hosts of different sex or age. Numbers of *Murshidia* spp. were not affected by host sex, but were higher in adults than in juveniles. Conversely, burdens of *Trichostrongylus thomasi* were not affected by host age, but were higher in males than in females. While not highly significant, helminth assemblages in male warthogs were more species rich than in females. Helminth communities in the three genera of wild sub-Saharan suids are largely unique, but *Ph. africanus* and *Hylochoerus meinertzhageni* share more worm species with each other than with *Potamochoerus larvatus*, possibly because the former two are more closely related. Overlap between helminth communities of African wild suids and those of other suids and Tayassuidae worldwide is limited.

Introduction

The Suidae is a family within the Cetartiodactyla and comprises 17 species belonging to six genera. Originating in the Old World approximately 20 million years ago, they have successfully colonised the African and Eurasian continents (Frantz *et al.*, 2016). Their counterparts in the New World are the pig-like peccaries, Tayassuidae, who diverged from the common ancestry during the late Eocene/early Oligocene (Frantz *et al.*, 2016).

On the African continent, three genera of the Suidae are indigenous and listed on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species as of the least concern: *Phacochoerus* F. Cuvier, containing *Ph. africanus* (Gmelin) and *Ph. aethiopicus* (Pallas) (de Jong *et al.*, 2016a, 2016b), *Potamochoerus* Gray, comprising *Po. larvatus* (F. Cuvier) (Seydack, 2016) and *Po. porcus* (Linnaeus) (Reyna *et al.*, 2016), and *Hylochoerus* Thomas, represented by *H. meinertzhageni* Thomas (d'Huart and Reyna, 2016). Of these, only the geographic range of *Ph. africanus* and *Po. larvatus* extends into South Africa (Skinner and Chimimba, 2005; Seydack, 2016). For most of the 20th century, *Ph. africanus* was commonly considered a subspecies of *Ph. aethiopicus* and is usually recorded as such in studies pertaining to its ecology, habits and/or parasites. Nowadays, the validity of the two species of warthogs is again recognised. In South Africa, *Ph. a. aethiopicus* became extinct in the 1870s, and since then only *Ph. africanus* remains (Skinner and Chimimba, 2005; Wilson and Reeder, 2005; Grubb and d'Huart, 2010; de Jong *et al.*, 2016a, 2016b). However, the two species are sympatric in parts of north Somalia, as well as in parts of central, east, and southeast Kenya (de Jong *et al.*, 2016a, 2016b).

Of all the Suidae, *Sus* Linnaeus is the genus with an almost cosmopolitan distribution. This is not surprising, since the native range of *S. scrofa* Linnaeus covers vast areas of Eurasia and some North African countries, while humans have introduced the species in countries worldwide, including the Americas, Australia and Africa (Oliver and Leus, 2008; Frantz *et al.*, 2016). The remaining species of the genus *Sus* inhabit various parts of Asia, all being listed on the IUCN Red List of Threatened Species as near threatened to critically endangered (Frantz

et al., 2016). The second genus of the Suidae in Asia is monotypic, with *Porcula salvania* (Hodgson) considered extinct, except in a few areas in Assam (Narayan *et al.*, 2008; Frantz *et al.*, 2016), whereas representatives of the third genus, *Babyrousa* Perry, are categorised as vulnerable and their geographic range is limited to Indonesia (Macdonald *et al.*, 2008, 2016; Leus *et al.*, 2016).

In the Americas, the family Tayassuidae is represented by three extant species in three genera, *Pecari tajacu* (Linnaeus), listed as of the least concern on the IUCN Red List of Threatened Species, *Tayassu pecari* (Link), listed as vulnerable, and *Catagonus wagneri* (Rusconi), considered endangered (Gongora *et al.*, 2011a, 2011b; Keuroghlian *et al.*, 2013; Altrichter *et al.*, 2015).

Although the influence of parasites on host fitness as well as the population dynamics of their hosts is well documented (Hudson and Greenman, 1998; Torchin *et al.*, 2001; Hudson *et al.*, 2002), and the critical conservation status of many species of the Suidae and Tayassuidae is known, knowledge about their helminth parasites is scant.

Given that *Ph. africanus* is one of the most iconic suids on the African continent, surprisingly little work has been done on its helminth parasites, with most works focusing on taxonomy (Leroux, 1940; Ortlepp, 1964; Round, 1968; Troncy *et al.*, 1973; Boomker, 1990; Beveridge, 2014), and only a few studies describing the composition of helminth assemblages. The latter were conducted in mostly southern Africa and include surveys in Namibia as well as the Mpumalanga and Limpopo Provinces in South Africa (Horak *et al.*, 1983, 1988; Boomker *et al.*, 1991a; van Wyk and Boomker, 2011), while Ortlepp (1964) examined material obtained from *Ph. africanus* from Mozambique and South African game reserves in Zululand, now part of KwaZulu-Natal Province. Boomker *et al.* (1991a) provide a host parasite list for this host comprising 31 species of helminths: trematodes ($n = 2$), cestodes ($n = 6$) and nematodes ($n = 23$).

Even less is known about the helminth fauna of the remaining species of African wild suids, and, as for *Ph. africanus*, the majority of papers are taxonomic works or based on incidental findings (e.g. van den Berghe, 1943; Inglis, 1958; Ortlepp, 1964; Round, 1968; Troncy *et al.*, 1973; Iori and Lanfranchi, 1996).

Likely the best studied of the suids is *S. scrofa*, which may not be unexpected considering its wide geographic range and economic importance. Most of these studies were done on wild boars in Europe (see Jarvis *et al.*, 2007 and references cited therein), with fewer studies conducted in Africa, Asia, the Middle East and the Americas (e.g. Ajayi *et al.*, 1988; Pence *et al.*, 1988; McKenzie and Davidson, 1989; Esrony *et al.*, 1997; Solaymani-Mohammadi *et al.*, 2003; da Silva and Müller, 2013a, 2013b; Ahn *et al.*, 2015; Mansouri *et al.*, 2016; Chaisiri *et al.*, 2017).

The helminths of both barbitusas and peccaries are poorly studied (Schwartz and Alicata, 1933; Samuel and Low, 1970; Corn *et al.*, 1985; Munro *et al.*, 1990; Romero-Castañón *et al.*, 2008; Widjarsi, 2011).

The common warthog, *Ph. africanus*, is found in Grassland, Shrubland and Savanna habitats in sub-Saharan Africa. Warthogs are diurnal and spend much of the day grazing on short grass, preferring fresh and new shoots, sedges, herbs and wild fruits. Nights are spent holed up, typically in repossessed aardvark [*Orycteropus afer* (Pallas)] burrows that are changed frequently, possibly to avoid high parasite burdens (Somers *et al.*, 1994; Skinner and Chimimba, 2005). Socially, *Ph. africanus* is organised in the following categories: solitary males; bachelor groups containing 2–3 males more than one year old; matriarchal groups consisting of adult females with juveniles and/or yearlings; or yearling groups. Yearling groups comprising males and females break up as the females farrow and yearling males either move off

as solitary adult males or remain part of bachelor groups (Somers *et al.*, 1995; Skinner and Chimimba, 2005).

In this paper, we describe the helminth community of *Ph. africanus* in a game reserve in the KwaZulu-Natal Province, South Africa, a region for which currently only scant information on this particular host-parasite system is available, and assess the influence of host age and sex on the composition and abundance of these helminth assemblages. We expected males to carry higher helminth burdens than females as is the case with many mammal species (Folstad and Karter, 1992; Poulin, 1996; Arneberg, 2002; Moore and Wilson, 2002; Wirsing *et al.*, 2007). With regard to the effect of age, we proposed two alternative predictions, namely that yearlings will be (a) more heavily infected than adults because of their not yet fully-developed immune system (Reinecke, 1983; Anderson, 1987; MacIntosh *et al.*, 2010) or (b) less infected than adults due to the accumulation of helminth individuals and/or species in older animals (Behnke *et al.*, 1999).

We further compare our findings to earlier studies on the helminth parasites of warthogs in South Africa and compare similarities between helminth communities in warthogs and other species of the Suidae and Tayassuidae worldwide.

Materials and methods

Survey area

In March 2015, 31 free-roaming common warthogs were culled in the Pongola Game Reserve (PGR; 27° 22' 09.26" S, 31° 50' 42.16" E), KwaZulu-Natal Province, South Africa. The PGR is situated in the Savanna biome and forms part of the Zululand Lowveld. This bioregion is typically characterised by summer rainfall, although some rains might fall in winter, with mean annual precipitation ranging from 500–900 mm. Summers are warm to hot, and the mild winters remain frost-free (Mucina and Rutherford, 2006). The Pongola River, which flows through the reserve, is perennial and provides water throughout the year, together with the Pongolapoort Dam, which it enters within the boundaries of the reserve (<http://www.pongolagamereserve.co.za>). Altitude within the reserve varies from approximately 140–600 m above sea level (<http://en-za.topographic-map.com/places/Pongola-Nature-Reserve-9257351/>).

Survey animals and parasite collection

Warthogs were culled over a period of five days at different sites within the PGR, using single shot bolt action rifles during daylight (ethical clearance number: 11LV_HOF02) and within a radius of approximately 1 km from the water. The animals were shot as part of a project evaluating quality characteristics of warthog meat from different sex (males, females) and age classes [adults (>24 months), yearlings (12–24 months)] (see Rudman *et al.*, 2018 for further details on age classification and processing of animals). Except for the fact that specific sex and age classes were targeted, warthogs were shot randomly and belonged to different groups. Of the 31 warthogs that were culled, 30 (eight adult females, eight adult males, eight juvenile females and six juvenile males) could be examined for gastrointestinal helminths.

Carcasses were transported to the government accredited slaughter facility within the PGR, skinned and eviscerated. The gastrointestinal tract (GIT) was divided into stomach, small intestine and large intestine and these sections were placed into individual trays and cut open. Macroscopically visible parasites were removed and preserved in 70% ethanol. Aliquots of the ingesta from the different GIT sections were prepared and helminths collected from them as described by Boomker *et al.* (1991a). The heart was opened and examined macroscopically for parasites.

Longitudinal incisions, approximately 10 mm apart, were made in the lungs and liver and the exposed surfaces scanned macroscopically for parasites. All helminths collected were stored in 70% ethanol. Except for *Probstmayria vivipara* (Probstmayr, 1865) (see below), nematodes were identified and counted as temporary mounts in lactophenol under a compound light microscope. Cestodes and digeneans were cleared in Hoyer's medium for identification. Cestode counts reflect the number of scoleces present. We were not able to identify cestodes of the genus *Moniezia* Blanchard, 1891 to species level and list them here as *Moniezia* sp. However, Beveridge (2014) confirmed the presence of two species of *Moniezia* in warthogs. Identifications were based on descriptions and redescriptions of the various genera and species recovered; authorities of the species identified are listed in Table 1. Voucher material was deposited in the National Collection of Animal Helminths, Agricultural Research Council-Onderstepoort Veterinary Institute, South Africa (accession numbers S/2019/11-17).

Data analysis

Three of nine helminth species recorded in this study (*Ascaris phacochoeri*, *Impalaia tuberculata* and *Gastrodiscus aegyptiacus*) demonstrated very low prevalence (13.3–16.7%), whereas the numbers of *P. vivipara* could not be established due to the extremely high infection intensity of this parasite. For the analyses of the effects of host sex and age on the number of helminths of a given species they harboured, we, therefore, selected the five remaining species (*Moniezia* sp., *Murshidia hamata*, *M. pugnicaudata*, *Physocephalus sexalatus* and *Trichostrongylus thomasi*). Of these, *Moniezia* sp. was the least prevalent (43.3%), resulting in a large number of zeroes in the dataset for this species. In addition, the numbers of *Moniezia* sp. varied weakly among infected animals (on average, 1.96 ± 0.5 worms per animal). Consequently, we chose to analyse the effect of host sex and age on incidence (i.e. whether a parasite occurs in a host individual or not; Stanko *et al.*, 2015) rather than numbers of this species. The response variable for *Moniezia* sp. was thus dichotomous and took a value of either 1 or 0 if an individual was either infected with at least one helminth or not, respectively. We analysed the response variable using generalized linear models with the binomial error distribution and logit-link function. Categorical independent variables were host sex and host age as well as interaction between these factors, whereas we included host body mass as a continuous covariate. The effects of host sex and age and their interactions on the numbers of *M. hamata*, *M. pugnicaudata*, *P. sexalatus* and *T. thomasi* (separately) were analysed using generalized linear models with the gaussian error distribution and identity-link function. The values of the response variables were log+1-transformed prior to analyses. Host body mass was included in the model as a covariate. In addition, we calculated the number of helminth species recorded in each individual host and analysed the effect of host sex and age on this number in a similar way as we did for number of helminth individuals, except that we did not transform the values of the response variable. All analyses were done using R Statistical Environment (R Core Team, 2018). After the initial running of each model, we selected the best model based on the Akaike Information Criterion (AIC), using the function 'dredge' from the R package 'MuMIn' (Barton, 2018) implemented in R, and ran the best model again (in cases, when the best model was not the intercept-only model).

Results

Overall GIT helminth prevalence in common warthogs from the PGR was 100%. Cestodes and trematodes were represented by one

species each, whereas the majority of helminths were nematodes, represented by seven species belonging to six genera (Table 1). Except for *A. phacochoeri* and *I. tuberculata*, both of which had a low prevalence as well as abundance, all nematode species were highly prevalent. *Probstmayria vivipara* was the most abundant helminth in all hosts examined, followed by *M. hamata* which ranged from 2850–58110 individuals per host. *Murshidia pugnicaudata* was the third most abundant species, although it occurred in distinctly lower numbers (80–6070) than its congener. Mean species richness of GIT helminths was six, ranging from 4–7 species per individual host. In a single warthog, a metacystode of *Taenia hydatigena* Pallas, 1766 was collected from the mesenteries. No helminths were found in the heart, lungs and liver of the hosts examined.

No effect of either host sex or age or their interaction was found for the incidence of *Moniezia* sp. (z-values of coefficients varied from -0.12 for intercept to 0.70 for the sex \times age interaction; $P > 0.48$ for all). The best model for the incidence of *Moniezia* sp. was the intercept only model (log-likelihood = -20.53, AICcorrected = 43.2, Δ AIC = 0.00, AICweight = 0.37).

Numbers of *M. hamata* and *M. pugnicaudata* were similar in male and female warthogs, but were significantly higher in adults than in yearlings (Table 2, Fig. 1). No effect of either sex or age of a host on the numbers of *P. sexalatus* was found (Table 2). Numbers of *T. thomasi* were significantly higher in male than in female warthogs (Table 2, Fig. 2), but did not depend on host age (Table 2). Finally, male warthogs tended to harbour richer helminth assemblages than female warthogs, although this difference was only marginally significant (Table 2, Fig. 3).

Discussion

The prevalence of helminth infections in warthogs from the PGR was high and each animal that was examined harboured GIT helminths.

All nine species recovered had previously been recorded from *Ph. africanus* in South Africa and its neighbouring country Namibia (Ortlepp, 1964; Horak *et al.*, 1983, 1988; van Wyk and Boomker, 2011), and are considered typical parasites of this host. Interestingly, while the number of species recorded from the GIT of warthogs from the PGR and Namibia was similar (9 vs 11), warthogs in Namibia did not harbour any *Murshidia* spp., but were instead host to *Daubneyia* spp. (as *Oesophagostomum mpwapwae* Duthy, 1948, *O. mwanzae* Daubney, 1924 and *O. roubaudi* Daubney, 1926). In addition, the genus *Impalaia* Mönnig, 1923 was represented by *I. nudicollis* Mönnig, 1931, while *I. tuberculata* was not found (Horak *et al.*, 1983). Species richness of helminth assemblages in game and nature reserves in the Limpopo and Mpumalanga Provinces was usually higher than that in the PGR, and helminth assemblages in these two provinces contained both *Murshidia* spp. as well as *Daubneyia* spp. (as *O. mocambiquei* Ortlepp, 1964 and *O. mwanzae*) (Horak *et al.*, 1988; Boomker *et al.*, 1991a). It is noteworthy that Ortlepp (1964) reported a similar separation of these two oesophagostomine genera in warthogs from Mozambique and KwaZulu-Natal, with the former harbouring only *Daubneyia* spp. while the latter were parasitised by only *Murshidia* spp. Little is known about the life cycle of either genus, but oesophagostomines in general have a direct life cycle and eggs as well as first- to third-stage larvae occur free in the environment (Anderson, 2000). A possible explanation for the observed differences in the geographic distribution pattern of the two genera might be a difference in their tolerance towards environmental factors. A number of species of the Strongylida, including *Oesophagostomum* spp. and *Trichostrongylus* spp., have been shown to differ in the ability of their eggs to develop at different

Table 1. Prevalence and mean abundance (MA \pm s.e.) of gastrointestinal helminth parasites collected from 30 common warthogs in the Pongola Game Reserve, South Africa

Species	Site in host	Life cycle	Infected hosts (N)	Prevalence (%)	Total count	MA(\pm s.e.)	MA range
Trematodes							
<i>Gastrodiscus aegyptiacus</i> (Cobbold, 1876) Leuckart in Cobbold, 1877	Large intestine	Indirect	4	13.3	380	12.67 \pm 10.36	0–310
Cestodes							
<i>Moniezia</i> sp.	Small intestine	Indirect	13	43.3	59	1.97 \pm 0.55	0–13
Nematodes							
<i>Ascaris phacochoeri</i> Gedoelst, 1916	Stomach	Direct	5	16.7	6	0.20 \pm 0.09	0–2
<i>Impalaia tuberculata</i> Mönig, 1923	Small intestine	Direct	4	13.3	18	0.60 \pm 0.34	0–9
<i>Murshidia hamata</i> Daubney, 1923	Large intestine	Direct	30	100	458440	15281.33 \pm 2564.25	2850–58110
<i>Murshidia pugnicaudata</i> (Leiper, 1909) Yorke and Maplestone, 1926	Large intestine	Direct	30	100	41450	1381.67 \pm 273.97	80–6070
<i>Physocephalus sexalatus</i> (Molin, 1860) Diesing, 1861	Stomach	Indirect	27	90	1106	36.87 \pm 9.49	0–200
<i>Probstmayria vivipara</i> (Probstmayr, 1865) Ransom, 1907	Large intestine	Direct	30	100	Numerous ^a	ND	ND
<i>Trichostrongylus thomasi</i> Mönig, 1932	Stomach	Direct	23	76.7	784	26.13 \pm 7.98	0–167

ND, Not determined.

^aThis species was too abundant to obtain individual counts.

faecal moisture contents and their susceptibility to moisture and hot and cold temperatures (Rossanigo and Gruner, 1995; Anderson, 2000; O'Connor et al., 2006).

In areas where *Murshidia* spp. occur, both species have a more or less equally high prevalence (Horak et al., 1988; Boomker et al., 1991a; this paper), which somewhat contradicts speculation by Troncy et al. (1973) that *H. meinertzhageni* and not *Ph. africanus* is the true host of this parasite. However, we consistently found higher numbers of *M. hamata* than *M. pugnicaudata*. Similar results have been reported previously (Horak et al., 1988; Boomker et al., 1991a), and this might suggest certain variability in the suitability of warthogs as hosts for these two species.

Trichostrongylus thomasi had a high prevalence in the present study and, following *Murshidia* spp. and *P. sexalatus*, had the fourth highest mean abundance of all helminths found in warthogs in the PGR. It had a similarly high prevalence in warthogs in the Kruger National Park (KNP) (Horak et al., 1988) and the Hoedspruit Nature Reserve (HNR) (Boomker et al., 1991a), but was absent in warthogs examined in Limpopo Province by van Wyk and Boomker (2011), and by Horak et al. (1983) in Namibia, where *T. colubriformis* (Giles, 1892) was found instead, with low prevalence and abundance. Only a few *Trichostrongylus* spp. females were found in warthogs at a military base situated within the HNR, but separated from it by a number of fences (Boomker et al., 1991a). The latter authors pointed out that *T. thomasi* was typically a parasite of a number of antelope species and considered its presence in warthogs an accidental infection. Warthogs in the KNP, which supports a large diversity of antelopes, were parasitised by a number of *Trichostrongylus* spp. (Horak et al., 1988), and it is possible that the *Trichostrongylus* Looss, 1905 fauna of warthogs at a given

locality reflects the helminth fauna of co-occurring antelopes. The same might be true for species of *Impalaia*, which parasitise a vast number of antelope hosts (Boomker, 1977; Gibbons et al., 1977). Unfortunately, there are no data on the helminth assemblages of antelope species in the PGR to confirm these assumptions.

Compared to other nematode species with a direct life cycle, the prevalence of *A. phacochoeri* (*Ascaris* sp. in Namibia) in warthogs in southern Africa is relatively low (2.6–46%) (Horak et al., 1983, 1988; van Wyk and Boomker, 2011; this study), and the highest mean abundance, recorded in warthogs from HNR, was 4.07 (Boomker et al., 1991a). Contrary to *Impalaia* spp., *Murshidia* spp. and *Trichostrongylus* spp., in which developing larvae hatch from the eggs and the phototropic infective third-stage larvae climb to the top of grasses, larvae of *Ascaris* spp. remain in the egg during their development, and it is the embryonated egg on the ground that has to be ingested by the host (Anderson, 2000). The former might be a more effective mode of transmission in herbivorous warthogs.

Although typically a parasite of equines and highly abundant in zebra in southern Africa (Ransom, 1907; Scialdo-Krecek, 1983; Scialdo-Krecek et al., 1983), *P. vivipara* is clearly a most prominent nematode in helminth assemblages of warthogs, having a prevalence of 100% at all studied localities and an abundance either close to or in their millions (Horak et al., 1983, 1988; Boomker et al., 1991a; van Wyk and Boomker, 2011; this study). Their extraordinary abundance is likely the result of auto-infection, as females are viviparous and larvae develop to maturity in the large intestine; transmission from host to host is thought to occur when faeces containing larvae are ingested (Anderson, 2000). Allogrooming, including anal licking, has been reported

Table 2. Summary of best models of the effect of warthogs' age and sex and their interactions on the number of four helminths species and helminth species richness

Helminth	Factor	Coefficient			LL	AICc	ΔAIC	AICw
		Value±s.e.	t	P				
<i>Murshidia hamata</i>	Intercept	4.18 ± 0.09	48.44	>0.001	-9.65	26.20	0.00	0.30
	Age	-0.35 ± 0.12	-2.76	0.01				
<i>Murshidia pugnicaudata</i>	Intercept	3.06 ± 0.12	25.26	>0.001	-19.78	46.50	0.00	0.32
	Age	-0.37 ± 0.18	-2.08	0.047				
<i>Physocephalus sexalatus</i>	Intercept	-0.15 ± 1.05	-0.14	0.89	-31.27	67.00	0.00	0.43
<i>Trichostrongylus thomasi</i>	Intercept	0.63 ± 0.17	3.72	>0.001	-30.09	67.10	0.00	0.33
	Sex	0.57 ± 0.25	2.89	0.03				
Species richness	Intercept	0.51 ± 0.18	28.9	>0.001	-32.32	71.60	0.00	0.37
	Sex	0.54 ± 0.27	2.02	0.05				

LL, log-likelihood; AICc, Akaike Information Criterion corrected for sample size; ΔAIC, delta AIC; AICw, AIC weight. Body mass of a host individual was included in the full models as a covariate. Reference levels of explanatory variables were female for sex and adult for age.

in warthogs (Skinner and Chimimba, 2005) and might contribute towards the transmission of *P. vivipara* between hosts.

Of the species with an indirect life cycle, the nematode *P. sexalatus*, which uses a variety of dung beetles as intermediate hosts (Anderson, 2000; Schuster *et al.*, 2014), had the highest prevalence in this and other studies conducted in southern Africa (48–92%), with a moderate abundance, except for the warthogs in Namibia and the HNR, where mean abundance was as high as 341.92 and 371.47, respectively (Horak *et al.*, 1983, 1988; Boomker *et al.*, 1991a; van Wyk and Boomker, 2011). The cestode genus *Moniezia* is transmitted by oribatid mites that serve as intermediate hosts (Xiao and Herd, 1992; Denegri *et al.*, 1998; Schuster *et al.*, 2000). While its prevalence in this and previous studies was moderate to low, with few individuals collected from infected hosts (Horak *et al.*, 1983, 1988; Boomker *et al.*, 1991a; van Wyk and Boomker, 2011), the genus nevertheless has a wide geographic range. The occurrence of *P. sexalatus* and representatives of *Moniezia* in a large variety of geographic localities suggests that their intermediate hosts are wide-spread and readily ingested by the warthogs while feeding.

To the contrary, *G. aegyptiacus*, whose life cycle entails a freshwater snail and metacercariae that encyst on vegetation near waterbodies (Malek, 1971; Mukaratirwa *et al.*, 2004), was found only in the PGR and one locality within the KNP (Horak *et al.*, 1988). We believe that the presence of this digenean in the PGR is attributable to the Pongolapoort Dam, which forms part of the PGR and offers ample suitable habitat for freshwater snail intermediate hosts. The low prevalence of the parasite might be a result of warthogs being relatively independent of permanent sources of water (Skinner and Chimimba, 2005) and suggests that trematode infections play a minor role in this host.

Our finding of a metacestode of *T. hydatigena* in the mesenteries of one of the warthogs is not unexpected, and taeniids, including *Echinococcus* spp. and *Taenia* spp., have repeatedly been reported from warthogs (Horak *et al.*, 1983, 1988; Boomker *et al.*, 1991a; van Wyk and Boomker, 2011). They are some of the relatively few parasite species shared between warthogs and domesticated or feral pigs (Fabiyyi, 1979; Eslami and Farsad-Hamdi, 1992; Rajković-Janje *et al.*, 2002). Interestingly though, the *Taenia* spp. found in warthogs, are those using carnivores as definitive hosts, whereas *T. solium* Linnaeus, 1758, one of the main helminths of zoonotic concern in pigs (Sinha and Sharma, 2009), has not been reported from warthogs.

We found few effects of host sex or age on parasite assemblages in warthogs from the PGR. However, while the burdens of *Murshidia* spp. were similar in males and females, adults harboured significantly more worms than yearlings. While no comparative data exist for warthogs, studies on the influence of age on the composition of helminth assemblages in wild boar yielded mixed results. Some studies report a higher intensity of lung and stomach nematodes in younger animals (Humbert and Henry, 1989; Senlik *et al.*, 2011), whereas others record an increase of infection with age (Foata *et al.*, 2006). Yet others found no difference between intensity of infection and hosts of different ages (Magi *et al.*, 2002; Rajković-Janje *et al.*, 2002). The increase of intensity in *Murshidia* spp. in adults observed in the present study is likely attributable to the accumulative effect of repeated exposure to infective stages of this genus in older animals over time, as has been demonstrated for direct life cycle nematodes in other mammalian hosts (Behnke *et al.*, 1999).

A similarly varied picture emerges when looking at gender-bias in helminth infections in Suidae. Although not statistically significant, Rajković-Janje *et al.* (2002) found that female wild boars carried higher worm burdens than their male counterparts, whereas Senlik *et al.* (2011) found male wild boars infected with higher numbers of the digenean *Dicrocoelium dendriticum* (Rudolphi, 1819) when compared to females. In the present study, male warthogs supported larger numbers of *T. thomasi* as well as helminth assemblages that were more species rich than those seen in females, although the latter difference was only marginally significant. A number of factors pre-dispose males to parasite infections, e.g. immune-suppression based on male hormones, especially testosterone, larger body size, territoriality and movement patterns, dietary preferences and sociality, to name but a few (Folstad and Karter, 1992; Poulin, 1996; Arneberg, 2002; Moore and Wilson, 2002; Wirsing *et al.*, 2007). According to Somers *et al.* (1994), warthog males disperse more widely than females, following a dispersal pattern typical for mammals that are mostly polygamous. In addition, while Somers *et al.* (1994) found female home ranges to be slightly larger than those of males in a small reserve in South Africa, the opposite was true for warthogs in Kenya (Radke, 1990). An increased vagility in males will likely expose them to a higher number as well as larger diversity of infective stages of parasites in habitats frequented by co-occurring antelope and other possible reservoir species. Furthermore, males in the present study weighed

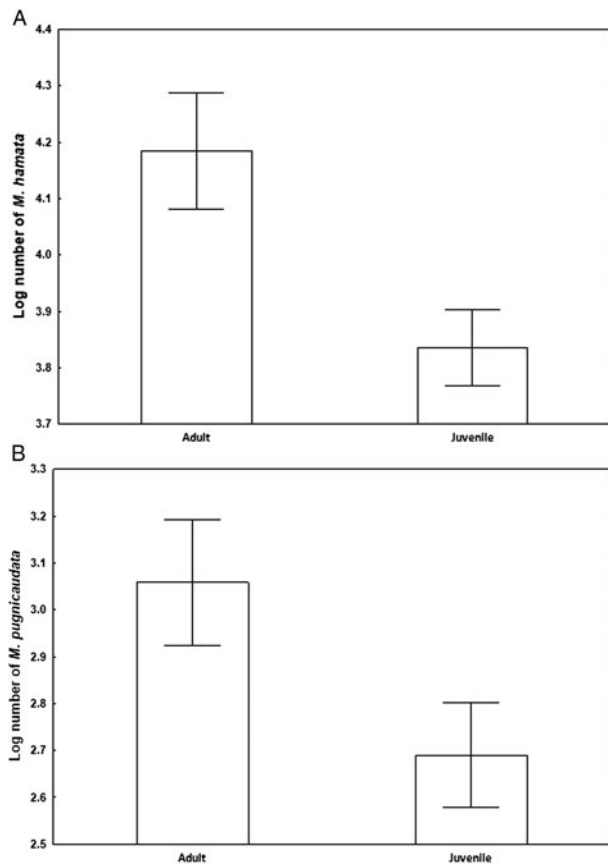


Fig. 1. Mean (\pm s.e.) numbers of *Murshidia hamata* (a) and *M. pugnicaudata* (b) in adult and juvenile warthogs.

significantly more than females (Rudman *et al.*, 2018). Increased food intake to maintain body mass would equally lead to increased exposure rates (Arneberg, 2002; George-Nascimento *et al.*, 2004).

We found no host-related differences in the incidence of *Moniezia* sp. in the present warthogs. Contrary to this, Boomker *et al.* (1991a) detected *Moniezia* sp. in young animals only, which is in accordance with *Moniezia* spp. in ruminants, where older animals develop immunity against infection (Reinecke, 1983). A possible explanation for the absence of an age effect in this study might be that yearlings at 12–24 months of age would likely have had previous exposure to the parasite, triggering their immune response to subsequent infections.

Bushpigs, *Po. larvatus*, are the only species of wild suids that are sympatric with warthogs in South Africa. Originally, bushpigs in the southern African subregion were referred to as *Po. porcus*, as reflected in the zoological and parasitological literature; they should, however, be referred to as *Po. larvatus* (Skinner and Chimimba, 2005). Few bushpigs have been examined for their parasites, possibly because of their nocturnal habits and relatively limited distribution in forested areas (van Wyk and Boomker, 2011). Nevertheless, the few data from localities in South Africa and Mozambique suggest that warthogs and bushpigs have fairly distinct helminth assemblages, with only *P. sexalatus* and *G. aegyptiacus* being shared between the two (Ortlepp, 1964; van Wyk and Boomker, 2011). On the other hand, *Morgascaridia sellsi* (Morgan, 1927), *O. aethiopicum* Duthy, 1948 and *Globocephalus versteri* Ortlepp, 1964 appear restricted to bushpigs and have also not been detected in *H. meinertzhageni*, the remaining species of wild pigs in sub-Saharan Africa. Although originally described from an East African ‘wart-hog’ (Duthy, 1948), Ortlepp (1964) believed the bushpig to be the

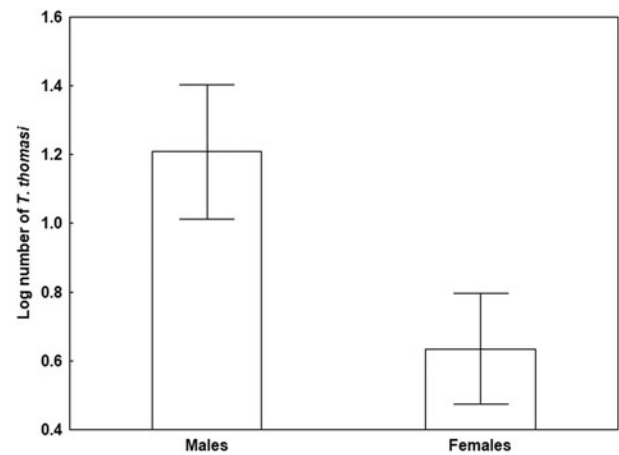


Fig. 2. Mean (\pm s.e.) numbers of *Trichostrongylus thomasi* in male and female warthogs.

normal host of *O. aethiopicum* and considered the warthog an accidental host. Moreover, it was Ortlepp’s (1964) contention that ‘as the habitats and the feeding habits of the two hosts are quite different, one would not expect them to harbour the same species of parasites’.

Interestingly, *Ascarops strongylina* (Rudolphi, 1819), a common parasite in *Sus* spp. worldwide, and also present in domesticated pigs in South Africa (Horak, 1978), appears absent in *Ph. africanus* as well as in *H. meinertzhageni*. The parasite was, however, collected from *Po. larvatus* (Ortlepp, 1964). Similarly, *Hyostromylus rubidus* (Hassall and Stiles, 1892), a common parasite of *S. scrofa* (Rajković-Janje *et al.*, 2002; Senlik *et al.*, 2011) and widespread in domesticated as well as feral pigs in Africa (Fabiyyi, 1979; Permin *et al.*, 1999; Nganga *et al.*, 2008; Nissen *et al.*, 2011), was found in *Po. larvatus* (Boomker *et al.*, 1991b), but not in *Ph. africanus* or *H. meinertzhageni*.

Furthermore, in areas in Central and East Africa, where the distribution ranges of *Phacochoerus* and *Hylochoerus* overlap, these two genera share a number of parasite species, which incidentally, are absent from *Potamochoerus*: *Bourgelatia hylochoeri* (van den Berghe, 1943), *B. pricei* (Schwartz, 1928), *D. farchai* Troncy, Graber and Thal, 1973, *D. goodeyi* (Daubney, 1926), *D. mwanzae* (Daubney, 1924), *D. yorkei* (Thornton, 1924), *M. hamata* and *M. pugnicaudata* (Troncy *et al.*, 1973; Iori and Lanfranchi, 1996). Frantz *et al.* (2016) present a phylogeny of extinct and extant Suidae in which *Hylochoerus* and *Phacochoerus* form a sistergroup to *Potamochoerus*. The above findings suggest that the closer relatedness of the former two genera is also reflected in their parasite communities. One should, however, not lose sight of the actual paucity of records (numerically as well as geographically) on the parasite communities of especially *Hylochoerus* and *Potamochoerus* in Africa. Hence, in some cases, the apparent absence of a given parasite, as for example that of the rather ubiquitous *P. sexalatus* in *H. meinertzhageni*, might simply be because of a lack of data.

In fact, *P. sexalatus* has the widest host range of helminths in suids and peccaries worldwide (Ortlepp, 1964; Corn *et al.*, 1985; Pence *et al.*, 1988; McKenzie and Davidson, 1989; Jarvis *et al.*, 2007; Sato *et al.*, 2008; Senlik *et al.*, 2011; Chaisiri *et al.*, 2017), and, to date, only seems absent in *Hylochoerus* in Africa and babirusas in Asia. Again, this phenomenon might be because of a lack of data for these species.

Generally speaking, helminth communities of wild suids in Africa have little in common with those of other pigs or pig-like hosts worldwide. A typically African genus that seems to have emerged within its African hosts and undergone successful

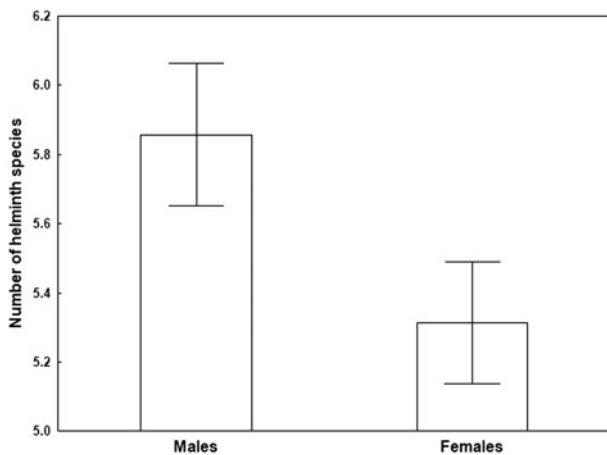



Fig. 3. Mean (\pm s.e.) number of helminth species harboured by male and female warthogs.

radiation in especially warthogs is *Daubneyia* Leroux, 1940. To date, *Daubneyia* is represented by 13 species in *Phacochoerus* and *Hylochoerus* (Ortlepp, 1964; Troncy *et al.*, 1973). Its counterpart in *S. scrofa* and, to an extent, in babirusas and peccaries is the genus *Oesophagostomum* Molin, 1861, with five species reported from these hosts (Troncy *et al.*, 1973; Horak, 1978; Munro *et al.*, 1990; Eslami and Farsad-Hamdi, 1992; Rajković-Janje *et al.*, 2002; Romero-Castañón *et al.*, 2008). A single species described from a warthog, *O. aethiopicum*, is likely a parasite of *Po. larvatus* (see above; Duthy, 1948; Ortlepp, 1964).

Interestingly, the lungworm genus *Metastrongylus* Molin, 1861 is absent from any of the wild African suids, but is species rich in *S. scrofa*, with a wide geographic range (Pence *et al.*, 1988; Humbert and Henry, 1989; Jarvis *et al.*, 2007; Sato *et al.*, 2008; Senlik *et al.*, 2011). Furthermore, it has also been recorded from domesticated and feral pigs in Africa (Horak, 1978; Fabiyi, 1979; Permin *et al.*, 1999). We believe that wild African suids in their natural environment had little exposure to earthworms, which serve as intermediate hosts for *Metastrongylus* spp. (Anderson, 2000), and that this parasite has been introduced into Africa and other parts of the world with the extensive translocation of domesticated pigs by humans.

Other genera, such as *Ascaris* Linnaeus, 1758 and *Bourgelatia* Railliet, Henry and Bauche, 1919 have a wide host range in Suidae and occur in wild suids in Africa as well as in *S. scrofa* and babirusas, but are represented by different species in different hosts (Troncy *et al.*, 1973; Foata *et al.*, 2006; Sato *et al.*, 2008; Widyarsi, 2011; Chaisiri *et al.*, 2017). Similarly, *G. versteri* parasitises *Po. larvatus* (Ortlepp, 1964), whereas its congener in *S. scrofa* and peccaries is *G. urosululatus* Alessandrini, 1909 (Rajković-Janje *et al.*, 2002; Foata *et al.*, 2006; Romero-Castañón *et al.*, 2008), while a further two species *G. longimucronatus* Molin, 1861 and *G. samoensis* Lane, 1922 occur in *S. s. leucomystax* in Japan (Sato *et al.*, 2008).

In conclusion, warthogs have the most diverse helminth assemblages of the three genera of wild suids in sub-Saharan Africa. Their helminth fauna is most similar to that of *H. meinerzhageni* and both hosts have few helminth species in common with *Po. larvatus*, possibly reflecting the closer phylogenetic relatedness of *Phacochoerus* and *Hylochoerus*. Despite some helminth species being shared by wild suids in Africa and other Suidae and/or Tayassuidae, the helminth faunas of these pig and pig-like hosts, are largely divergent. It is quite clear from the literature that there is paucity of data on helminth parasites of wild suids in Africa and a need for further studies, inclusive of all three host genera and covering a wider geographic range.

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Author contributions. LH, JB and KJ conceived the study. KJ, JB, MS and LH collected material. KJ and AS identified and counted the helminths. BRK and KJ analysed data and drafted the manuscript. All authors participated in finalising the manuscript.

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Ethical standards. All applicable institutional, national and international guidelines for the care and use of animals were followed.

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