REVIEW

Endoparasites of the Siberian tiger (*Panthera tigris altaica*)

Running title: Endoparasites of the Siberian tiger

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Author's contribution

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Abstract

There have been few reports on the diversity and prevalence of parasitic fauna of the endangered Siberian tiger, which inhabits the territory of the Russian Far East. The present review attempts to summarize the information about the parasitic fauna of wild Siberian tigers, which includes 15 helminths and 3 protozoan species. The most prevalent parasitic species was found to be *Toxocara cati*, followed by *Toxascaris leonina*. Another commonly recorded Platyhelminth species is *Paragonimus westermani*, which causes a lethal infection of the lung parenchyma in Siberian tigers. However, the information about infections by this fluke in the Siberian tigers is scarce, although *P. westermani* infections pose a serious health hazard to tiger populations. The nematodes *Aelurostrongylus abstrusus* and *Thomix aerophilus* are found in Siberian tigers with an occurrence rate of 2.3% and 19%, respectively. The information on the parasitic infestations

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of captive populations of Siberian tigers is also presented along with the sources of infection and hazards for the wild tiger populations in their natural environment.

Keywords: Siberian tiger; helminths; infection; parasites; protozoan.

Introduction

For wild animal populations, and especially for endangered species, infectious diseases including parasitic infections pose a serious health hazard. Parasites influence host survival and reproduction, and severe parasitic infections may be a major cause of mortality in young and weakened animals (Gulland, 1995; Murray *et al*.1999; Deem et al. 2001). There is a lack of adequate data on the parasitic fauna and their prevalence in wild large felids, though many of them are recognized as rare and endangered species (Macdonald and Loveridge 2010). The Siberian tiger is an endemic endangered species found in the areas of the Russian Far East, North Korea, and northeastern China. The Siberian tiger population in the Russian Far East has been gradually decreasing during the past century and currently counts only about 600 individuals (Caroll and Miquelle, 2006; Goodrich *et al*. 2010; Henry *et al*. 2009; Xiaofeng *et al*. 2011). Among the major causes of population decline are poaching, population fragmentation, and infections (Goodrich *et al*. 2010; Henry *et al*. 2009; Quigley *et al*. 2010; Simon *et al*. 2013).. Unfortunately, there are scant data and only a few sporadic reports on the diversity and prevalence of parasite fauna in the Siberian tigers both in the wild as well as in captivity. This review summarizes the available data on the parasites of wild and captive Siberian tigers with a particular focus on the risk of infections in the natural environment.

Helminths of Siberian tigers

Fifteen species of helminths have been reported in Siberian tigers, being most as the parasites of the digestive system (Gonzalez *et al*. 2007; Esaulova *et al*. 2010; Seryodkin *et al*. 2015). The overall prevalence is variable in reports due to the different origins of tigers (wild or captive) and the number of animals from which fecal samples were collected. The accurate determination of prevalence is further confounded due to the presence of duplicate fecal samples collected from the wild. When calculated from a small number of the selected samples, the parasite prevalence in the wild tigers was estimated to range from 72.5% to 100% (Gonzalez *et al*. 2007; Seryodkin *et al*. 2015).

The prevalence of *Toxocara cati*, the most frequently found intestinal helminth, ranges from 63.4% to 100% (Gonzalez *et al*. 2007; Seryodkin *et al*. 2015).

Hepaticola hepatica (Bancroft, 1893) eggs have also been found in Siberian tigers' feces with a prevalence of 1.5% to 2% (Esaulova et al. 2010; Seryodkin et al. 2015). *Hepaticola hepatica* (syn. *Capillaria hepatica*, *Calodium hepaticum* ect), a parasite of rodents, has a simple life cycle, with the female laying eggs in the liver parenchyma of the host, where they can hatch and become encapsulated in abscesses. Infection is acquired by the ingestion of a liver containing eggs or eggs on the ground, which have been released by the decomposition of the host. Numerous mammals serve as possible hosts for *H. hepaticola* (Nishigori, 1925). Siberian tigers can acquire the parasite by ingestion of already infested rodents or other mammals. However, the presence of *H. hepatica* in feces of the tigers may be a false indication due to the ingestion and transit of infected hosts.

The intestinal nematodes, such as *Strongyloides* sp. and *Ancylostoma* sp., have been occasionally reported in Siberian tigers with a prevalence of 33.3% and 50%, respectively (Gonzalez et al. 2007). *Strongyloides* spp. and other hookworm infections are quite common in domestic cats, and other carnivorous animals (Rogers, 1939; Hotez *et al*., 2004). *Aonchotheca putorii* is another parasitic nematode found in wild Siberian tigers with the prevalence of 39% and 14.8% in the Ussurisky and Sikhote-Alin Nature Reserves. The capillarid has a worldwide distribution, affecting domestic cats as well as different wild mammalian species like badgers, otters, minks, etc. (Butterworth and Beverly-Burton, 1981; Greve and Kung, 1983).

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Another reported nematode is *Toxascaris leonina* that has a prevalence of 33.3% in wild Siberian tigers (Gonzalez *et al*. 2007). Along with *T. cati, Toxas. leonina* is the most common geohelminth species affecting domestic and wild felids worldwide (Fisher, 2003; Okilewicz *et al*. 2012). A high prevalence (67%) of both species has been reported in the captive Siberian tigers from China (Peng *et al*., 2016). Cestodes from two genera have also been reported in Siberian tigers—*Taenia* sp. and *Spirometra* sp. with an occurrence rate of 3.5% (Esaulova *et al*. 2010; Seryodkin *et al*. 2015). The members of the genus *Spirometra* (Mueller, 1937) have a complex life cycle requiring two intermediate hosts, with copepods as the first intermediate host and, frogs, water snakes, and rodents as the second intermediate hosts (Mueller, 1974). Another dicrocoelid trematode, *Platynosomum fastosum* (Kossak, 1910) was recorded with a prevalence of 50% (Seryodkin *et al*. 2015); this fluke also has an indirect life cycle having snails as first intermediate hosts and lizards as the second intermediate hosts. Felids take up the parasite upon ingestion of the second intermediate host (Basu and Charles, 2014).

Major zoonotic flukes, such as *Paragonimus westermani* and *Clonorchis sinensis,* have been registered in wild Siberian tigers (Esaulova and Seryodkin, 2012; Seryodkin *et al*. 2015). Both these parasites occur in the Russian Far East (Choi, 1984;Kim, 1983; Posokhov *et al*. 1979). Oshmarin first recorded the presence of *P. westermani* in Siberian tigers in 1963 (Oshmarin, 1963),while Yudin and Yudina described growing spread of the parasite in the Siberian tigers (Yudin and Yudina, 2009). The high prevalence of *P. westermani* (52%) coupled with an intensity of 23–273 specimens was registered by Yudin and Yudina (2009) in the Sikhote-Alin Nature Reserve. The intensity of infection was found to be higher in the tigers older than two years, whereas *P. westermani* was not found in the tigers younger than 1.5 years (Yudin and

Yudina, 2009). The reports on C. *sinensis* in Siberian tigers are more numerous (Esaulova *et al*. 2010).

The lungworms, such as *Aelurostrongylus abstrusus* (Railliet, 1898) and *Thominx aerophilus* (Travassos, 1915), were recorded in the Siberian tigers with a prevalence of 2.3% and 19%, respectively (Seryodkin *et al*. 2015). Although these lungworms regularly infest domestic cats and dogs and a wide range of wild mammals, they have not yet been registered in other tiger species (Crum *et al*. 1978;Di Cesare *et al*. 2012; Traversa and Di Cesare, 2013). *A. abstrusus* has a worldwide distribution, with an indirect life cycle having felids as definitive hosts, a wide range of slugs and mollusks as intermediate hosts, and rodents, reptiles, and amphibians as auxiliary hosts (Di Cesare et al. 2016). *A. abstrusus* has also been registered in other wild felids such as Eurasian lynx (*Lynx lynx* L.), European wildcats (*Felis silvestris silvestris* Schreber, 1775), caracals (*Caracal caracal* (Schreber, 1776)), lions (*Panthera leo* L.), and cheetahs (*Acinonyx jubatus* Schreber, 1775); however, the data on the infestation of *A. abstrusus* in other tiger species are absent (Szczesna *et al*. 2006; Veronesi *et al*, 2016; West *et al*. 1977).

The eggs of the esophageal parasite *Eucoleus* sp. have been found in 0.78% of the fecal samples from tigers in the Sikhote-Alin Nature Reserve (Seryodkin *et al*. 2015).

a. Helminth diversity in a free raging habitat

Most of the information on the parasite fauna found in wild Siberian tigers comes from just three reports published in the last decade.

Most of the fecal samples of Siberian tigers were collected in the Sikhote-Alin and Ussurisky (Esaulova *et al*. 2010; Seryodkin *et al*. 2015). The highest number of fecal samples (n=142) were collected in the territory of Sikhote-Alin National Reserve in a course of 12 years, in which seven roundworm species, two tapeworm species, and one flatworm species were found. The overall prevalence was 72.5%, with *T. cati* being the most frequently found parasite, followed by *P. westermani* at 52% (Yudin & Yudina, 2009). Post-mortem examination of three tigers showed 68 and 18 specimens of *T. cati* in the intestine of two males and 28 specimens of

P. westermani were extracted from the lung of one female, in which two specimens of *T. cati* were also found in the intestine (Seryodkin *et al*. 2015).

From the Ussurisky Reserve over the course of one year, 99 fecal samples were collected. Five parasites were found in this study with an overall prevalence of 85.9% including four species of roundworms and one species of tapeworm. The most frequently occurring species was *T. cati* followed by *A. putorii* with the prevalence of 85.9% and 39%, respectively (Esaulova *et al*. 2010).

The Lazovsky and Sucan reserves yielded the lowest numbers of fecal samples (n=3) over the years. Six parasite species including four roundworms and one flatworm were found with an overall prevalence of 100%. The most frequently occurring species was *T. cati* followed by *P. fastosum* with a prevalence of 100% and 50%, respectively (Gonzalez *et al*. 2007) (Table 1).

Toxocara cati scored a high prevalence in all areas wherefrom fecal samples were collected. The parasite fauna of the tigers from the Sikhote-Alin and Ussurisky Reserves is similar, although the tigers from Ussurisky Reserve showed a greater diversity of parasites than tigers from the Sikhote-Alin Reserve. A high percentage of mixed-infections was registered in wild tigers: around 48.5% in tigers from the Ussurisky Reserve, 71.8% in samples from the Sikhote-Alin Reserve, and at least two or more species in all collected samples from the territories of Sucan and Lazovsky Reserves (Gonzalez *et al*. 2007; Esaulova *et al*. 2010; Seryodkin *et al*. 2015) (Fig. 1).

b. Helminth diversity in captivity

There is significantly scant information about the helminth infections in captive Siberian tigers. Two roundworm species, *T. cati* and *Toxas leonina*, with a prevalence of 67% in the captive Siberian tigers from China (Peng *et al*. 2016) and the eggs of *Toxas leonina* in feces from the Siberian tigers in the Dublin Zoo were found (Geraghty *et al*. 1981) (Fig. 1).

Protozoans of Siberian tigers

The data available on the protozoan parasitic fauna found in the Siberian tigers are very limited.

Most reports are based on the simple morphological identification of cysts and trophozoites (Gonzalez *et al*. 2007; Seryodkin *et al*. 2015). The protozoans, such as *Cystoisospora* spp. and *Giardia* spp., are commonly found in domestic and wild felids (Bjork *et al*. 2010; Patton and Rabinowitz, 1994;Tzannes *et al*. 2008). *Cystoisospora* spp. have been registered in both the captive and wild Siberian tigers, while *G. duodenalis* was found only in the captive Siberian tigers (Han *et al*. 2010; Li *et al*. 2015; Seryodkin *et al*. 2015). *Toxoplasma gondii* another major zoonotic feline parasite (Elmore *et al*. 2010) has been found both in the captive and wild Siberian tigers (De Camps et al. 2008; Domy and Fransen, 1989; Seryodkin *et al*. 2015; Yang *et al*. 2017).

a. Protozoan diversity in free raging habitat

A total of three protozoan species were found in wild Siberian tigers. The oocysts of *Cystoisospora* sp. appeared in 2.1% fecal samples collected on the territory of Sikhote-Alin Reserve. In total, 62% Siberian tigers were seropositive for *T. gondii* in Sikhote-Alin Reserve. The trophozoites of *Amoeba* sp. were found in one fecal sample out of three collected from the wild Siberian tigers on the territories of Lazovsky and Sucan Reserves (Gonzalez *et al*. 2007). *Amoeba* sp. is a significant protozoan parasite in nature that can cause granulomatous amebic encephalitis (Martinez and Janitsche, 1985). Although rarely found in animals, tigers have been known to be infected by ingesting water contaminated by *Amoeba* sp. According to some investigators, the infection may correlate with immunodeficiency (Gonzalez *et al*. 2007) (Fig. 2).

b. Protozoan diversity in captivity

Interestingly, protozoan infections are more frequently registered in captive tigers, as opposed to helminth infections. Protozoan parasites include *Cystoisospora* spp., *Giardia* sp., and *Toxoplasma gondii* (Han *et al*, 2010). *T. gondii* has been registered in captive Siberian tigers with a prevalence of 28.7% in the USA and 66.7% in Henan Province, China, respectively (De Camps *et al*. 2008; Domy and Fransen, 1989; Yang *et al*. 2017). A *Cystoisospora* sp., molecularly identified as *C. felis,* has been recorded in the captive Siberian tigers from the

Heilongjiang Province, China (Han *et al*. 2010). The species of *Giardia* have also been recorded in the tigers from the Zhengzhou Zoo in China (Li *et al*. 2015).

Infection risks in the natural environment

Captive and wild felids have been associated with a distinct parasitic fauna. A wider range of parasite species can be found in an association with the wild Siberian tigers than in captive ones, which may correlate with the number of animals investigated (Fig. 1). The studies on captive tigers have naturally been lesser than in the wild tigers. The prevalence and diversity of parasite fauna of the Siberian tiger depend on several factors such as the age of tigers, habitat and prey species. Unfortunately, the data on the sex and age of infected tigers are absent. Apparently, young age is an important risk factor associated with the parasitic infection, especially roundworms, as they have been demonstrated in domestic cats (Arbabi & Hooshyar, 2009). The habitat also has some influence on the parasite fauna owing to the different levels of soil and water contamination levels by helminth eggs and protozoan cysts, an abundance of definitive and paratenic hosts, and the parasite prevalence in them (Shock *et al*. 2011).

The second possible reason for this discord may be a significant difference between the diet of the wild and captive Siberian tigers. The studies based on the kill compositions for a 54-year period showed that the tiger's diet includes 15 species of wild mammals, domestic dogs, and livestock. The elk (*Cervus elaphus* L.) and wild boar (*Sus scrofa* L.) are two key components of their diet (Miquelle *et al*. 1996).

Around 20% of parasites found in the wild Siberian tigers have an indirect lifecycle with small vertebrates such as rodents, reptilians, and amphibians serving as intermediate hosts.

Since populations of reptiles and amphibians coinciding with that of the areas of Siberian tigers are rare, we can speculate that the infected rodents are the major source of infections. For example, in the territory of Sikhote-Alin National Reserve, the fauna of reptiles is represented by seven species, while the amphibian fauna is represented only by five species. On the other hand, the rodent fauna in the Reserve includes 20 species (http://sixote-alin.ru/web_inna/kadastr.html). The climatic conditions and temperature are not conducive to poikilotherm activity and abundance (Bullock, 1955).

The two major zoonotic flukes found in Siberian tigers *P. westermani* and *C. sinensis* do occur in the Far Eastern Region. Their life cycle includes fish as second intermediate hosts (Cyprinid fishes for *C. sinensis* and crayfish for *P. westermani*, respectively). The foci of clonorchiasis and paragonimosis are located around the Amur River in the Russian Far East and both infections are common in humans in the Primorye territory (Posokhov *et al*. 1979; Schwartz, 1980). Thus the presence of these flukes indicates that the tiger's diet also includes fish. The presence of *Spirometra* eggs and lungworm *A. abstrusus* larval stages in feces may imply that tigers also feed on small animals such as rodents, amphibians, and reptiles. The high prevalence of *P. westermani* also suggests that tigers regularly prey on infected wild boars, which serve as the reservoir hosts for this flatworm (Kim, 1983). There is almost no report on the feeding habits of Siberian tigers in captivity, although a few other indicates that their feed mainly consists of commercially available diets (Lewis, 2002; Vester *et al*. 2008).

C. putorii has a simple life cycle, with feces contaminated by helminth eggs being the major source of infections; and, according to reports, infesting a variety of wild carnivorous mammals with high prevalence rates (Cole and Shoop, 1987; Crum *et al*. 1978). Nine carnivorous species were infested in the Ussurisky National Reserve with the minimum prevalence of 5.1% registered in the brown bear (*Ursus arctos* L.) and the Asiatic black bear (*U. thibetanus* G. Cuvier, 1823) and the maximum prevalence at 64% recorded in the raccoon dog (*Nyctereutes procyonoides* (Gray, 1834)).

The tigers got infected by *T. cati* due to the ingestion of infective eggs and/or rodents containing larvae in their tissues (OLorcain, 1994). This nematode is frequently found in other wild felids in Far Eastern region, whose feces with eggs are the major source of environmental contamination.

For example, the prevalence of *T. cati* was 32% in Amur cat (*Prionailurus bengalensis euptilurus* (Elliot, 1871) and 37% in lynx (*Lynx lynx* L.) (37%) in the Ussurisky district.

Are parasites posing hazard for tiger populations?

Infectious diseases pose a serious health hazard to wild animal populations. Parasitic infections may influence population cycles (Hudson *et al*. 1998), resulting in a reduced host population (Anderson & May 1978), and also influence competitive fitness (Brassard *et al*. 1982; Scott 1988). Parasite prevalence and intensities tend to be dispersed with some individuals in the population having high parasitemia and most having low parasitemia (Scott 1988; MüllerGraf 1995; Junker *et al*. 2008).

Numerous reports on the Siberian tiger populations' abundance and mortality have been published in the last decade (Goodrich *et al*. 2008; Goodrich *et al*. 2010). Regular monitoring has been carried out for the Siberian tiger populations in the Sikhote-Alin Reserve; however, the data on fatalities caused by parasites are very limited. Yudin and Yudina (2009) reported lethal cases of *P. westermani* infections in the Siberian tigers where the death occurred directly because of the effect on the lung parenchyma and exhaustion caused by frequent infections. Feline lungworms, such as *A. abstrusus* and *C. aerophila,* pose a serious threat to Siberian tigers and frequently cause mortality of domestic cats. Some intestinal helminths, such as *T. cati* and *Toxas. leonina,* cause morbidity because of a high worm abundance and intensity, especially in young or weakened animals (Hendrix and Blagburn, 1983). The high percentage of mixed infections appearing in wild Siberian tigers is also a hazard for tiger populations, since the burden of one or both infectious agents may fluctuate and significantly influence the pathology of the infection (Cox, 2001; Telfer *et al*. 2010).

The comparison of the parasite fauna of Siberian tigers and other large wild felids shows that such nematode species as *T. cati*, *Toxas. leonina*, *Capillaria* spp., *Aelurostrongylus* spp., tapeworms from Taeniidae family, *Paragonimus* spp., protozoan parasites *Cystoisospor*a spp. and *T. gondii* frequently infect large wild felids. However, the literature data analysis shows that Sibarian tigers are infected by relatively small numbers of parasites than other wild felids (Table 2). The data on *Echinococcus* infections among wild Siberian tiger populations are absent; however, *Echinococcus* spp. infections are common among other mammals and humans in Russia (Konyaev et al. 2013). These facts can be related to the limited data on parasite infection in Siberian tigers compared with the data on parasites of other wild felids. Other factors, such as study design and methodology and the study area, can also influence the results of parasitological research.

Conclusions

The data on the parasite fauna of Siberian tigers provide new insight into the biology and ecology of these rare animals and put a question on the strategies employed for their feeding in captivity and conservation. At present, there is no way to explain the higher prevalence *T. cati* in Siberian tigers over other tiger species. The immunodeficiency states may be correlated with the high worm abundance or ingesting a large number of invasive eggs. Another interesting fact is the higher prevalence of *P. westermani* over *C. sinensis*, both being flatworms are frequently found in humans and animals in Far Eastern region. It may correlate with the higher prevalence of *P. westermani* in wild boars, which constitute the major food source of wild tigers, although, information about parasitemia in wild boars in Russian Far East region is absent. How parasitemia influences wild large felid species with respect to population fluctuations and health status require further investigations to gain insight about the parasite-parasite and parasite-host interactions in the wild Siberian tiger populations, especially in the light of current conservation efforts of the species.

Declarations

Abbreviations

Not applicable.

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Competing interests

Authors declare that they have no competing interests

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Table 1–The parasitic prevalence in the wild Siberian tigers

Parasite	Sikhote-Alin Reserve (Seryodkin et al. 2015)	Ussuriiskii Reserve (Esaulova et al. 2010)	Lasovsky and Sucan Reserves (Gonzalez et al. 2007)
Number of fecal samples collected	n=142	n=99	n=3
Toxocara cati	63.4%	85.9%	100%
Toxascaris leonina	-	-	33.3%
Aonchotheca putorii	14.8%	39%	-
C. aerophila	19%	-	-
Taenia sp.	3.5%	2%	-
Spirometra sp.	3.5%	-	-
Strongyloides spp.	Strongylata 2.1%	Strongylata 5%	50%
Eucoleus sp.	0.78%	-	-
Hepaticola hepatica	1.5%	2%	
Aelurostrongylus abstrusus	2.3%	-	-
Platynosomum fastosum	-	-	50%
Paragonimus westermanni	52% (Yudin &Yudina, 2009)	-	-
Ancylostomatidae sp.	-	-	33.3%

Table 2 Comparison of parasite fauna of Siberian tigers and other large wild felids

Parasite	*Panthera tigris altaica*	*Panthera onca* (Patton &Rabinovtz, 1994)	*Felix concolor* (Patton &Rabinovtz, 1994)	*Panthera leo* (Bjork et al. 2000)	*Panthera pardus* (Patton *et al*. 1994)	*Panthera tigris* (Patton *et al*. 1986
Nematoda						
Toxocara cati	+	+	+	+	+	+
Toxascaris spp.	+	+	-	+	+	+
Eucoleus sp.	+	-	-	-	-	-
Ancylostoma spp./Ancylostomatidae	+	+	+	+	+	-
Aelurostrongylus spp.	+	-	-	+	+	+
Alaria spp.	-		+	-	-	-
Galonchus perniciosus	-	-	-	+	-	-
Cylicospirura sp.	-	-	+	+	-	-
Dirofilaria sp.	-	-	-	+	-	-
Physaloptera sp.	-	-	-	+	-	-
Habronema sp.	-	-	-	+	-	-
Capillaria spp.	+	+	+		+	+
Mammomonogamus	-	-	-	-	+	+

sp.						
Molineus sp.	-	-	-	-	+	+
Spirometra sp.	+	-	+	+	-	-
Strongyloides sp.	+	-	-	-	-	-
Ollulanus tricuspis	-	-	-	+	-	-
Trematoda						
Paragonimus spp.	+	+	-	+	+	+
Platynosomum fastosum	+	-	-	-	-	-
Clonorchis sinensis	+	-	-	-	-	-
Diplostomulum cordatum (syn. *Pharyngostomum cordatum*)	-	-	-	+	-	-
Schistosoma sp.	-	-	-	+	-	-
Cestoda						
Taenia spp.	+	+	+	+	+	-
Diphyllobothrium sp.	-	+	-	+	-	-
Dipylidium sp.	-	-	-	+	-	-
Anoplocephalidae	-	-	-	+	-	-
Echinococcus spp.	-	+	+	+	-	-
Mesocestoides sp.	-		+	+	-	-
Acanthocephala						
Oncicola sp.	-	+	+	-	-	-
Protozoa						

Hammondia pardalis	-	+	+	-	-	-
Cystoisoapora spp.	+	+	+	+	+	-
Sarcocystis sp.	-	-	+	+	+	+
Giardia sp.	+	-	-	+	+	-
Toxoplasma gondii	+	+	+	+	+	-
Eimeria felina	-	-	-	+	-	-

Figure legends

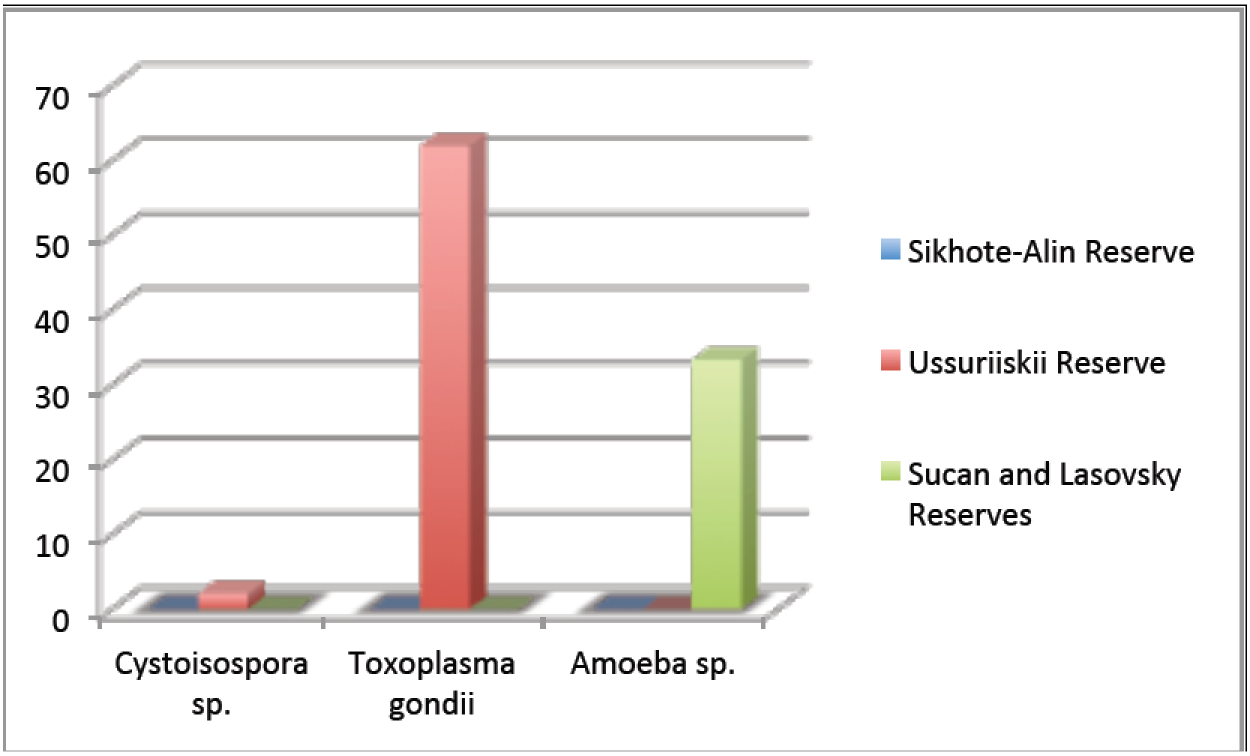

Figure 1. Helminth parasites of wild and captive Siberian tigers

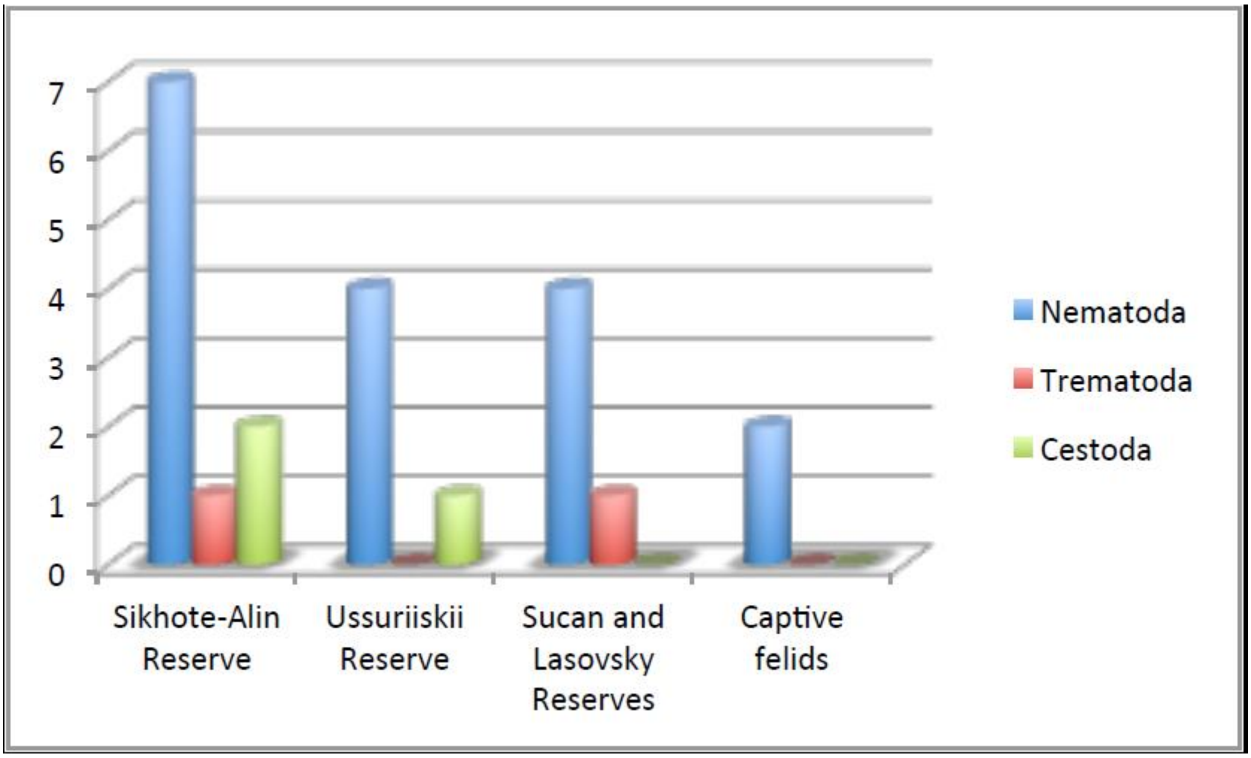

Figure 2. Protozoan parasites of wild Siberian tigers in different reserves