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Endoparasite infection hotspots in Estonian urban areas

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Abstract

The human–animal bond is beneficial for human health, but companion animals also pose a potential threat as vectors of zoonotic parasites, especially in urban areas where both human and dog densities are high. However, the knowledge about parasitic spillover in the urban environment is relatively scarce. The aim of the present study was to reveal which factors determine parasitic contamination in Estonian towns and provide up-to-date information about intestinal parasites of the Estonian dog population. In total, 657 samples of dog excrement was collected over one year of investigation from five towns in Estonia. Generalized linear mixed models were used to evaluate factors predicting infection risk in urban areas. In general, infection risk and intensity models predicted higher infection with endoparasites for small dogs in smaller towns, especially in apartment-house districts and in potential hazard zones. Helminth eggs and *Giardia*/*Cystoisospora* oocysts were detected in 64 samples, with an overall prevalence of 9.8%.

Introduction

The domestic dog was domesticated 12–15,000 years ago and has since become one of the most popular pet animals (Morey, 1994). During the long association of human–dog relationships, the role of dogs has changed from hunting and guarding companions to family members. Increasing numbers of dog ownership in the world (FEDIAF, 2018) indicate that dogs are beloved pets, despite rapid urbanization and modern lifestyles. Several studies have proven the benefits of dog ownership – for example, offering companionship, decreasing stress levels and increasing physical health (Paul *et al.*, 2010; Curl *et al.*, 2016; Dall *et al.*, 2017). However, besides the benefits, dogs may carry several parasite species that can affect the health of dog owners.

Zoonotic parasites like *Toxocara canis*, *Taenia* sp., *Echinococcus granulosus*, *E. multilocularis* and *Giardia* sp. carried and transmitted by dogs have a wide geographic distribution (Bugg *et al.*, 1999; Dyachenko *et al.*, 2008; Barutzki & Schaper, 2011). Infections with these parasites may cause serious health problems for humans, especially for small children, elderly and immunocompromised people. Due to the close contact with humans, dogs have a high potential to act as vectors in human infections. More importantly, dogs share the same parasite species with their wild relatives, some of them – for example, the red fox (*Vulpes vulpes*) and raccoon dog (*Nyctereutes procyonoides*) – with high and increasing population numbers in Europe (Contesse *et al.*, 2004; Kauhala & Kowalczyk, 2011; Vuorisalo *et al.*, 2014). Although direct contact between pet dogs and wild canids is probably not common, sharing the same living space may favour parasite transmission in the environment. It is suspected that parasite spillover occurs and is very likely in urban green areas as these places attract wildlife by providing opportunities for both foraging and hiding (Deplazes *et al.*, 2004; Eckert & Deplazes, 2004; Bateman & Fleming, 2012). Dog owners, spending time in parks, recreational areas and in children's playgrounds, tend to take their pets with them (Traversa *et al.*, 2014), and a scarcity of suitable dog walking sites in towns also forces owners to walk their dogs in green areas.

Previous studies indicate infection gradients from heavily infected hosts in rural areas towards decreased infection intensity in the urban environment for several parasite species (Fischer *et al.*, 2005; Studzińska *et al.*, 2017). However, high human and dog population densities in urban areas is a serious risk factor (Otranto *et al.*, 2015). Parasitic contamination of the urban environment with dog intestinal parasites is well documented in several studies (Mizgajska, 2001; Talvik *et al.*, 2006; Dado *et al.*, 2012; Blaszkowska *et al.*, 2013; Ferreira *et al.*, 2017; Otero *et al.*, 2018) and the role of pet dogs as the main distributers of common canine parasites – *Toxocara* spp. – to the city environment has also been demonstrated (Nijsse *et al.*, 2015). However, urban areas include several zones, some of them more suitable for host–parasite contact. So far, there is little knowledge about factors influencing parasitic infections inside towns.

Estonia is located in the temperate continental climate zone in north-eastern Europe. The climate is influenced by the Atlantic Ocean and Baltic Sea; while continental climate is prevalent in most of the country, the western part of Estonia is characterized by milder, maritime climate elements. Average air temperatures range from 18°C in July to −6°C in February. Based on the World Bank, Estonia is a post-soviet country with a high-income economy. According to Statistics Estonia, the current population number is 1.3 million, of which 63% live in urban areas (Statistics Estonia, 2012).

Dogs are common pets in Estonia, with an estimated dog population of 210,000 (FEDIAF, 2018), of which 10,000 are supposed to be abandoned or stray (ESDAW, 2017). Generally, stray dogs do not pose a threat in larger towns where animal shelters have been established. Also, larger municipalities provide advantages – for example, free waste bags for pets and dog-walking zones, which are not usually available in smaller towns.

There is also little information about dog-transmitted parasites in Estonia. Talvik *et al.* (2006) reported *T. canis* infection in 2.7% of investigated dog excrement collected in Tartu. Comparing dog infection in the areas of low and high human population density, they revealed higher infection in private-housing areas, despite the fact that the number of dogs was higher in apartment-house regions (Talvik *et al.*, 2006). Serological analyses concerning human population groups more often exposed to parasites – for example, medical and veterinary students, veterinarians and hunters – have also revealed higher prevalence with zoonotic dog parasites, like *Toxocara* and *Echinococcus* (Remm and Remm, 2014; Lassen *et al.*, 2016). The aims of this investigation were to (i) determine the factors influencing parasite contamination in urban areas and (ii) identify dog-transmitted endoparasites in Estonian urban dogs.

Materials and methods

In total, 657 samples of dog excrement was collected over one year (2013–2014) of investigation. Our investigation involved five Estonian towns located in several parts of Estonia. Of these five towns, three towns (Tartu, Elva and Kunda) were visited regularly and two towns (Pärnu and Rakvere) were visited unregularly by the authors. Sample collection was conducted in three small towns (less than 20,000 inhabitants) and in two larger towns (more than 40,000 inhabitants in the study period). The small towns comprised Rakvere, with 29 samples collected, Kunda, with 89 samples, and Elva, with 102 sample. The larger towns were Tartu and Pärnu, with 400 and 37 samples collected, respectively. The sampling sites inside towns were selected on the map depending on the housing type. In every town, sample collection was performed in detached house and densely populated apartment-house regions. In total, 17 sampling sites were selected. In both housing types, excrement was collected from sidewalks (maximum 0.5 m of road verge) and green areas (lawns, parks and playgrounds). As green areas are limited in towns and are often used by dog walkers, we documented all fitness trails and public playgrounds in sample collection sites. People, especially children, have a possibility to acquire infection with endoparasites when spending time in these areas. In later data analyses, recreational zones, as well as sampling sites in open school parks and sidewalks in the immediate vicinity of nurseries, were treated as potential hazard zones.

The sampling season (spring, summer, autumn, winter) was fixed according to meteorological seasons. In sampling sites, all fresh-appearing excrement was collected from the ground into separate plastic bags. We estimated dog size by modifying the method widely used for identifying wild mammal species. According to this, the size and shape of faeces is host-specific – even with similar diet, smaller animals generally produce smaller excrement. However, it is important to note that the current method for differentiating dog sizes by excrement may not be applicable for dog populations on a larger scale because of the vast variation between dog breeds and sizes. The diameters of the excrement samples were measured and divided as follows: excrement with a diameter <15 mm was determined as 'small'; excrement with a diameter of 15–20 mm was classed as 'medium'; and excrement with a diameter >20 mm was classed as 'large'. According to this, 173 samples of excrement were identified as small, 132 samples as medium and 144 samples as large. For 208 samples, excrement diameter could not be measured and for statistical analyses an additional group for unmeasured samples was created.

The collected excrement was deep frozen at −80°C for a minimum of seven days in order to inactivate highly pathogenic *Echinococcus* eggs, as both *E. granulosus* and *E. multilocularis* are present in Estonia (Laurimaa *et al.*, 2015a, b). Thawed samples were analysed using the concentration flotation technique (Roepstorff & Nansen, 1998) and identification of parasites was based on morphological characteristics. Infection prevalence was defined as the presence of parasitic oocysts/eggs in excrement, and infection intensity was determined as the number of oocysts/eggs per sample.

Statistical analyses were performed by R (R Core Team, 2018). For evaluating the infection risk with endoparasites, generalized linear mixed models (package glmmTMB) were used with binomial distribution (Brooks *et al.*, 2017). Negative binomial distribution was used to identify factors affecting infection intensity with endoparasites and roundworms (as the most prevalent parasite group).

Models contained infection risk (0 = uninfected, 1 = infected) or intensity of the infection (detected parasitic oocyst and egg count) and at least one of the following independent variables: 'excrement size', 'town size', 'housing type', 'season' and 'potential hazard zone'. The random variable included location (town). Models were compared using Akaikes' information criterion corrected for small samples (Burnham & Anderson, 2004). Furthermore, we summed the weights (w) of the same factors presented in one model set calculating the relative variable importance (RVI). Subsequently, the package DHARMa (Hartig, 2018) enabled us to control the distribution of the residuals and to estimate dispersion for the best models.

Results

Coprological examination revealed the presence of five parasite species or genera from the analysed dog excrement (table 1). The overall prevalence of dog endoparasites in the investigated towns was 9.8%, and the most prevalent parasites in our sample were nematodes *Uncinaria stenocephala* and *Toxocara* spp.

Modelling infection prevalence and intensity in dogs yielded with several good models in one model set. As all investigated factors were present in the best models with similar effects (supplementary table S1), only the statistics of the first model is explained

Table 1. The prevalence of dog endoparasites in Estonian towns.

Analysed samples	Tartu $N = 400$	Elva $N = 102$	Kunda $N = 89$	Pärnu $N = 37$	Rakvere $N = 29$	No. of samples $N = 657$
Positive samples of endoparasites						
Toxocara spp.	9	5	4	2	2	22
Prevalence	2.3%	4.9%	4.5%	5.4%	6.9%	3.4%
Uncinaria stenocephala	12	3	7	1	0	23
Prevalence	3.0%	2.9%	7.8%	2.7%	–	3.5%
Capillaria sp.	1	1	0	0	0	2
Prevalence	0.3%	0.9%	–	–	–	0.3%
Taeniidae	2	0	1	0	0	3
Prevalence	0.5%	–	1.1%	–	–	0.5%
Giardia/Cystoisospora	7	1	1	5	0	14
Prevalence	1.8%	1.0%	1.1%	13.5%	–	2.1%
Total	31 7.8%	10 9.8%	13 14.6%	8 21.6%	2 6.9%	64 9.8%

in the text. The random factor 'town' had none or minor variance inside the investigated towns, indicating little infection variance between towns. When estimating the precision of the best models ($\Delta AICc < 2$) via DHARMa, uniform distribution appeared and overdispersion was not detected.

When modelling dog infection prevalence with endoparasites, four equally good models with low model weights appeared (table 2). Comparing small excrement with other size classes and assuming that excrement size correlates with dog size, the models predicted lower infection prevalence for larger ($\beta_{Large} = -1.0$, standard error (SE) = 0.4) and medium-sized ($\beta_{Medium} = -1.2$, SE = 0.5) dogs. Similarly, infection prevalence was lower for unmeasured ($\beta_{Unmeasured} = -1.0$, SE = 0.4) excrement. In two analysed housing types, models predicted higher endoparasite prevalence in apartment-house districts ($\beta_{ApartmentHouse} = 0.9$, SE = 0.3) than in detached-house regions. In comparison with winter, dog infection prevalence increases in spring ($\beta_{Spring} = 0.7$, SE = 0.5) and in autumn ($\beta_{Autumn} = 0.6$, SE = 0.4) but decreases in summer ($\beta_{Summer} = -0.7$, SE = 0.6). Comparing with large towns, infection prevalence was higher in smaller towns ($\beta_{SmallTown} = 0.8$, SE = 0.3). All good models contain the factors 'excrement size', 'housing type' and 'season', which had a moderate effect on infection prevalence according to the RVI test (table 3).

Dogs' infection prevalence with roundworms was predicted by five equally good models (table 4). According to the first model, nematodes had higher infection prevalence in small towns ($\beta_{SmallTown} = 1.0$, SE = 0.4) instead of large ones. According to the housing type, dogs in apartment-house regions have higher infection prevalence with nematodes ($\beta_{ApartmentHouse} = 0.7$, SE = 0.4) than in detached-house regions. In comparison with winter, the infection prevalence was higher in spring ($\beta_{Spring} = 1.3$, SE = 0.6) and autumn ($\beta_{Autumn} = 0.4$, SE = 0.4) and decreases in summer ($\beta_{summer} = -0.4$, SE = 0.7). Dogs have higher infection prevalence with nematodes in potential hazard zones ($\beta_{PotentialHazardZone} = 0.6$, SE = 0.3) than on the streets. Compared with small dogs, infection prevalence with nematodes was lower among large ($\beta_{Large} = -1.2$, SE = 0.6) and medium-sized dogs ($\beta_{Medium} = -0.9$, SE = 0.5). Similarly, the infection prevalence was lower for unmeasured ($\beta_{Unmeasured} = -0.3$, SE = 0.5) samples. Considering the results of the RVI test (table 5), the factors 'town size', 'season', 'district' and 'potential hazard zone' have moderate effects on infection prevalence, while the effect of 'excrement size' was rather weak.

The infection intensity with endoparasites was explained by four equally good models (table 6). According to the first model, infection intensity was higher in apartment-house districts ($\beta_{ApartmentHouse} = 2.3$, SE = 0.7) than near detached houses. Infection intensity depended on the season: compared with winter, infection increased in spring ($\beta_{Spring} = 1.1$, SE = 1.0) and autumn ($\beta_{Autumn} = 2.2$, SE = 0.8) but decreased in summer ($\beta_{Summer} = -0.7$, SE = 1.1). The model also indicated intensive infection for excrement with small diameter size compared with large ($\beta_{Large} = -1.5$, SE = 0.8), medium ($\beta_{Medium} = -1.7$, SE = 1.0) or unmeasured ($\beta_{Unmeasured} = -1.4$, SE = 0.8) excrement. Comparing infection prevalence in small and larger towns, the best model predicts higher infection intensity in small towns ($\beta_{SmallTown} = 1.5$, SE = 0.8). The RVI indicates strong effect for the factors 'housing type' and 'town size', while the other three investigated factors had rather weak effect toward infection intensity (table 7).

Three equally good models determined the factors influencing infection intensity with roundworms (table 8). Again, roundworm intensity was significantly higher in apartment-house regions ($\beta_{ApartmentHouse} = 2.1$, SE = 0.6) than in detached-house areas. In the two investigated town types, dogs had higher infection intensities with roundworms in small towns ($\beta_{SmallTown} = 2.4$, SE = 0.7) than in large ones. Compared with winter, the infection intensity decreased in summer ($\beta_{Summer} = -1.7$, SE = 0.8) but increased in spring ($\beta_{Spring} = 1.3$, SE = 0.9) and autumn ($\beta_{Autumn} = 0.6$, SE = 0.8). According to the RVI test, only 'housing type' and 'town size' had strong effect toward roundworm intensity, while the factors 'season' and 'excrement size' indicated moderate effects (table 9).

Table 2. Generalized linear mixed models (GLMM) of dog infection risk with endoparasites.

No.	Model	K	AICc	ΔAICc	ω
1.	**E + D+S + TS + (T)**	**10**	**368.9**	**0**	**0.22**
2.	**E + D+S + TS + PHZ + (T)**	**11**	**369.3**	**0.4**	**0.18**
3.	**E + D+S + PHZ + (T)**	**10**	**370.2**	**1.3**	**0.11**
4.	**E + D + S +(T)**	**9**	**370.4**	**1.5**	**0.11**
5.	E + D + PHZ + (T)	7	371.9	3	0.05
6.	E + D + (T)	6	372.1	3.2	0.04
7.	E + D + TS	7	372.8	3.8	0.03
8.	D + S + (T)	6	372.8	3.8	0.03
9.	E + S + PHZ + (T)	9	372.8	3.9	0.03
10.	E + D + TS + PHZ + (T)	8	372.8	3.9	0.03
11.	D + S + PHZ + (T)	7	373.4	4.4	0.02
12.	D + S + TS + (T)	7	373.5	4.6	0.02
13.	E + S + TS + PHZ + (T)	10	373.7	4.8	0.02
14.	E + PHZ + (T)	6	373.9	5	0.018
15.	D + S + TS + PHZ	8	374.5	5.6	0.013
16.	E + S + TS + (T)	9	374.6	5.7	0.013
17.	E + S +(T)	8	374.8	5.9	0.012
18.	S + PHZ + (T)	6	375.7	6.7	0.008
19.	E + TS + PHZ + (T)	7	375.8	6.8	0.007
20.	D + PHZ + (T)	4	376.7	7.8	0.004
21.	E + TS + (T)	6	377	8.1	0.004
22.	S + TS + PHZ + (T)	7	377.6	8.6	0.003
23.	S + TS + (T)	6	378	9.1	0.002
24.	D + TS + (T)	4	378.5	9.5	0.002
25.	D + TS + PHZ + (T)	5	378.8	9.8	0.002
26.	TS + PHZ + (T)	4	380.1	11.2	<0.001

The best models are in bold. K, number of estimated parameters for given model; ΔAICc, AICc−minAICc; ω, AICc weights; D, district; S, season; E, excrement size; TS, town size; (T), town; PHZ, potential hazard zone.

Table 3. Results of the relative variable importance test for infection risk with endoparasites.

Variables	E	D	S	TS	PHZ
Importance	0.89	0.88	0.80	0.56	0.51
N containing models	15	15	15	15	15

D, district; S, season; E, excrement size; TS, town size; PHZ, potential hazard zone.

Discussion

Dogs are among the commonest pet animals worldwide, and they can host a number of important zoonotic parasites. Understanding the factors influencing the spread of parasitic diseases may help to reduce infections in pet animals and humans. Here, we used dog excrement, collected from the streets and green areas of Estonian towns, to identify environmental contamination with zoonotic parasites. While the effect of the season has been described earlier (Shimizu, 1993; Avcioglu & Burgu, 2008; Blaszkowska *et al.*, 2013), we demonstrated that infection prevalence also depends on town size and identified infection hotspots in towns. In Estonia, parasitic contamination is concentrated in areas of high human density, in areas dominated by multi-stored apartment blocks and in potentially hazardous zones, including playgrounds, recreational areas and near schools/nurseries. This study also suggests that endoparasite infection in Estonian urban dogs depends on dog size.

In Estonia, stray dogs are uncommon, especially in larger towns, and dog owners are obliged to remove pet excrement from public areas. We assume that excrement contamination in towns is caused by irresponsible dog owners who do not remove pet faeces and fail to perform regular antiparasitic treatment. Excrement collected in public areas is, thus, a useful tool for determining environmental contamination with endoparasites. However, scats collected during field work provide little background information about the investigated hosts. Previously, only excrement location has been used to identify risk factors for parasite transmission in different areas (Antolová *et al.*, 2004; Dubná *et al.*, 2007; Dado *et al.*, 2012).

We expected to find higher infection prevalence in large dogs that are taken for longer walks, probably outside of towns, or kept outside as guard dogs in areas of detached housing. Instead, our investigation revealed that smaller excrement is more frequently infected and contains significantly higher parasite burdens than large excrement. Our results are in accordance with previous studies, where endoparasite transmission by puppies is well described (Fontanarrosa *et al*, 2006; Barutzki & Schaper, 2011). However, small-sized dogs may also pose a threat in towns by contaminating the environment with endoparasites. In the last decade, small dogs have become increasingly popular pets in the US and elsewhere (Ferdman, 2015; Teng *et al.*, 2016), and the situation appears similar in Estonia. Although we could not differentiate between puppies and small dogs, our result is alarming, as both puppies and small dogs are highly attractive to children and probably have a higher degree of physical contact with humans (e.g. being carried, petted, etc.) than larger dogs. Equally, elderly people may prefer small dogs, as they are more affordable and easier to handle than medium or large dogs. Thus, it is likely that people underestimate the risk of disease transmission and infection associated with small dogs.

The lower infection prevalence and intensity in larger dogs may reflect owner awareness. Pullola *et al.* (2006) demonstrated that veterinarians are the main source of information about dog parasites. Although similar analysis has not been conducted in Estonia, it is likely that the same applies. Antiparasitic treatment of dogs twice or four times a year depending on the dog's lifestyle is recommended by veterinary practices in Estonia. It is possible that larger dogs are perceived to be at a higher risk of lifestyle-related health problems, including parasite infection, since they generally engage in more frequent off-lead outdoor activities, and, as a consequence, receive more frequent antiparasitic treatment.

The current study reveals that parasite infection prevalence is higher in smaller than in larger towns. Previous studies have demonstrated higher endoparasite infection prevalence among rural dogs than urban dogs (Habluetzel *et al.*, 2003; Soriano *et al.*, 2010; Bwalya *et al.*, 2011). Thus, parasite prevalence appears to decline along a gradient from rural areas towards city centres (Fischer *et al.*, 2005; Studzińska *et al.*, 2017). In smaller towns, there may be restricted availability of areas suitable for dog

Table 4. Generalized linear mixed models (GLMM) selection of dog infection risk with roundworms.

No.	Model	K	AICc	ΔAICc	ω
1.	**TS + S+D + E + PHZ + (T)**	**11**	**312.6**	**0.0**	**0.16**
2.	**TS + S+D + PHZ + (T)**	**8**	**313.2**	**0.6**	**0.11**
3.	**TS + S + D + (T)**	**7**	**313.4**	**0.8**	**0.10**
4.	**TS + S + D + E + (T)**	**10**	**313.6**	**1.0**	**0.10**
5.	**TS + S + PHZ + E + (T)**	**10**	**313.7**	**1.1**	**0.09**
6.	TS + D + PHZ + E + (T)	8	315.3	2.8	0.04
7.	TS + S + PHZ + (T)	7	315.6	3.0	0.03
8.	S + D + PHZ + (T)	7	315.7	3.1	0.03
9.	TS + D + PHZ + (T)	5	315.9	3.3	0.03
10.	S + D + PHZ + E + (T)	10	316.0	3.4	0.03
11.	S + D + (T)	6	316.2	3.6	0.03
12.	S + PHZ + E + (T)	9	316.3	3.7	0.03
13.	TS + S + E + (T)	9	316.4	3.8	0.02
14.	TS + PHZ + E + (T)	7	316.5	3.9	0.02
15.	TS + D + (T)	4	316.6	4.0	0.02
16.	D + PHZ + (T)	4	316.6	4.0	0.02
17.	TS + D + E + (T)	7	316.7	4.1	0.02
18.	D + PHZ + E +(T)	7	316.9	4.3	0.02
19.	S + PHZ + (T)	6	316.9	4.4	0.02
20.	S + D + E + (T)	9	317.1	4.6	0.02
21.	TS + S + (T)	6	317.2	4.6	0.02
22.	TS + PHZ + (T)	4	317.3	4.7	0.02
23.	PHZ + E + (T)	6	317.7	5.1	0.01
24.	D + E + (T)	6	318.3	5.7	0.01
25.	TS + E + (T)	6	318.6	6.0	0.01
26.	S + E + (T)	8	319.6	7.0	0.01

The best models are in bold. K, number of estimated parameters for given model; ΔAICc, AICc−minAICc; ω, AICc weights; D, district; S, season; E, excrement size; TS, town size; (T), town; PHZ, potential hazard zone.

Table 5. Results of the relative variable importance test for infection risk with roundworms.

Variables	TS	S	D	PHZ	E
Importance	0.79	0.78	0.73	0.66	0.57
N containing models	15	15	15	15	15

D, district; S, season; E, excrement size; TS, town size; PHZ, potential hazard zone.

walking, and, conversely, easier access to rural trails. In addition, opportunistic mesocarnivores, like the red fox, raccoon dog and badger (*Meles meles*), may occur more frequently in and around smaller towns, presenting a potential source of infection with zoonotic parasites (Deplazes *et al*., 2004; Bateman & Fleming, 2012).

As both human and dog activity are heterogeneously distributed in space, we expected to find infection hotspots inside towns. Based on the results of an earlier study by Talvik *et al*. (2006), we expected to find higher infection prevalence in regions dominated by detached housing, as these often contain few walking areas for dogs, while gardens are attractive to urban foxes, which probably contribute to environmental spillover (Contesse *et al*., 2004; König, 2008). In fact, we recorded higher endoparasite prevalence and intensity in regions dominated by apartment blocks. It is possible that dogs living in detached houses are kept in yards, with less access to streets, compared with dogs from apartments that are walked more widely by their owners at least once a day. As the density of humans and pets is probably highest in areas dominated by apartment blocks, it is also likely that endoparasites are also concentrated in the green areas surrounding apartment blocks.

In the current study, potential hazard zones consisting of recreational sites and green areas near schools and nurseries function as infection hotspots. These are mainly areas where people tend to walk their dogs daily, resulting in higher environmental contamination and an increased amount of contact between dogs. Thus, the infection cycle may be 'closed' in the apartment-house region (Azam *et al*., 2012). Poor excrement-removal practice also supports higher endoparasite prevalence in soil. Similarly, Dubná

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Table 6. Generalized linear mixed models (GLMM) selection of infection intensity in dogs.

No.	Model	K	AICc	ΔAICc	ω
1.	**D + S+E + TS + (T)**	**12**	**673.7**	**0**	**0.22**
2.	**D + S + TS + (T)**	**9**	**674**	**0.3**	**0.19**
3.	**D + S + E + TS + PHZ + (T)**	**13**	**674.8**	**1.2**	**0.12**
4.	**D + S+E + (T)**	**11**	**675.1**	**1.5**	**0.10**
5.	D + S + E + PHZ + (T)	12	675.8	2.1	0.07
6.	D + E + (T)	8	675.8	2.2	0.07
7.	D + S + TS + PHZ + (T)	10	676	2.4	0.06
8.	D + S + (T)	8	677.5	3.9	0.03
9.	D + E + TS + (T)	9	677.6	3.9	0.03
10.	D + E + PHZ + (T)	9	677.7	4	0.02
11.	PHZ + S + D + (T)	9	679	5.3	0.01
12.	D + E + TS + PHZ + (T)	10	679.6	5.9	0.01
13.	S + E + TS + PHZ + (T)	12	681.2	7.5	0.005
14.	D + TS + (T)	6	681.2	7.6	0.005
15.	D + PHZ + (T)	6	681.5	7.8	0.004
16.	S + E + TS + (T)	11	682.4	8.8	0.002
17.	D + TS + PHZ + (T)	7	683.2	9.5	0.001
18.	S + TS + (T)	8	683.6	9.9	0.001
19.	S + E + PHZ + (T)	11	684.3	10.7	0.001
20.	S + TS + PHZ + (T)	9	685.1	11.4	<0.001
21.	E + S + (T)	10	686.2	12.5	<0.001
22.	E + PHZ + (T)	8	689.2	15.5	<0.001
23.	E + TS + (T)	8	689.6	15.9	<0.001
24.	E + TS + PHZ + (T)	9	690.9	17.2	<0.001
25.	S + PHZ + (T)	8	691.1	17.4	<0.001
26.	TS + PHZ + (T)	6	701.9	28.2	<0.001

The best models are in bold. K, number of estimated parameters for given model; ΔAICc, AICc−minAICc; ω, AICc weights; D, district; S, season; E, excrement size; TS, town size; (T), town; PHZ, potential hazard zone.

Table 7. Results of the relative variable importance test for infection intensity in dogs.

Variables	D	TS	S	E	PHZ
Importance	0.99	0.84	0.68	0.66	0.34
N containing models	15	15	15	15	15

D, district; S, season; E, excrement size; TS, town size; PHZ, potential hazard zone.

et al. (2007) suggested that the occurrence of *Toxocara* eggs was high in public parks of urban areas because of the growing dog population and due to the relatively small dog walking areas. Our finding is important from an epidemiological perspective and is consistent with theoretical models linking host density to the opportunity of a parasite to invade a population of hosts (Morand & Poulin, 1998).

Various studies have demonstrated significant seasonal variation in endoparasite infection prevalence and the viability of parasite eggs in soil/excrement (Shimizu, 1993; Avcioglu & Burgu, 2008; Blaszkowska *et al.*, 2013). Our study revealed highest endoparasite prevalence and intensity in dogs in spring and in autumn and lowest in summer, which is in accordance with previous investigations (Shimizu, 1993; Avcioglu & Burgu, 2008). Helminth eggs in the environment are damaged by heat and ultraviolet (UV) radiation (Chernicharo *et al.*, 2003), which are highest in summer in temperate regions. Thus, egg survival is probably facilitated by a long-lasting autumn because of the decreased heat and UV radiation. It has been shown that helminth eggs and larvae can survive the winter in soil under thick snow cover (Ghadirian *et al.*, 1976). On the other hand, some authors have explained increased infection risk in spring and in autumn in relation to a higher birth rate of puppies in these seasons (Shimizu, 1993; Avcioglu & Burgu, 2008). However, modern dog breeding, especially in urban regions, is unaffected by seasons (Engle, 1946) and puppies are born more continuously, resulting in constant helminth egg spillover throughout the year.

Data on parasitic infection in Estonian urban dogs is restricted to one study carried out more than a decade ago (Talvik *et al.*, 2006). According to that investigation, the prevalence of infection

Table 8. Generalized linear mixed models (GLMM) selection of infection intensity with roundworms.

No.	Model	K	AICc	ΔAICc	ω
1.	**D + TS + S + (T)**	**9**	**543.1**	**0**	**0.29**
2.	**D + TS + E + (T)**	**9**	**544.4**	**1.3**	**0.15**
3.	**D + TS +(T)**	**6**	**545.0**	**1.9**	**0.11**
4.	D + TS + S + PHZ + (T)	10	545.1	2	0.11
5.	D + TS + S + E + (T)	12	545.6	2.4	0.08
6.	D + TS + E + PHZ + (T)	10	546.5	3.4	0.05
7.	D + TS + PHZ + (T)	7	546.9	3.8	0.04
8.	D + E + (T)	8	547.1	4	0.04
9.	D + TS + S + E + PHZ + (T)	13	547.3	4.2	0.03
10.	D + E + PHZ + (T)	9	549.1	6	0.01
11.	D + S + (T)	8	549.3	6.2	0.01
12.	TS + E + (T)	8	549.8	6.7	0.01
13.	D + S + E + (T)	11	550.0	6.9	0.009
14.	TS + S + (T)	8	550.1	7	0.009
15.	D + PHZ + (T)	6	550.7	7.6	0.007
16.	TS + S + PHZ + (T)	9	551.0	7.8	0.006
17.	D + S + PHZ + (T)	9	551.0	7.9	0.006
18.	TS + E + PHZ + (T)	9	551.4	8.3	0.005
19.	D + S + E + PHZ + (T)	12	551.5	8.4	0.004
20.	TS + S + E + PHZ + (T)	12	551.6	8.5	0.004
21.	TS + S + E + (T)	11	551.7	8.6	0.004
22.	TS + PHZ + (T)	6	554.0	10.9	0.001
23.	E + PHZ + (T)	8	554.9	11.8	<0.001
24.	S + E + PHZ + (T)	11	556.8	13.7	<0.001
25.	S + E + (T)	10	557.4	14.3	<0.001
26.	S + PHZ + (T)	8	557.6	14.5	<0.001

The best models are in bold. K, number of estimated parameters for given model; ΔAICc, AICc−minAICc; ω, AICc weights; D, district; S, season; E, excrement size; TS, town size; (T), town; PHZ, potential hazard zone.

Table 9. Results of the relative variable importance test for infection intensity with roundworms.

Variables	D	TS	S	E	PHZ
Importance	0.96	0.91	0.57	0.41	0.29
N containing models	15	15	15	15	15

D, district; S, season; E, excrement size; TS, town size; PHZ, potential hazard zone.

with geohelminths among Estonian dogs was rather low (2.7%), compared with the corresponding figure from the present study (7.2%). It is possible that the difference is affected by relatively small sample size of the previous study by Talvik *et al.* (2006). Ten years ago, owners more often allowed their dogs to roam out of sight. People also had less knowledge about dog hygiene, which resulted in lower deworming rates and infrequent excrement removal. It is important to note that according to the current study there has been a shift of endoparasite prevalence from regions dominated by detached housing to those dominated by apartment blocks. It is likely that ten years ago more dogs were freely roaming in regions of detached housing, leading to high endoparasite prevalence in such areas. Both Talvik *et al.* (2006) and our study suggest that the main helminths in Estonia are geohelminths *U. stenocephala* and *Toxocara* spp. Previously, Fahrion *et al.* (2011) showed that most of the excreted *Toxocara* spp. eggs in the environment belong to *T. canis.* Although the prevalence of *Giardia* and *Cystoisspora* was not high, these parasites can rapidly spread among dogs inhabiting the same areas, as shown by Bugg *et al.* (1999) in Australia, where dogs only treated with anthelmintics targeting roundworms were infected by *Giardia* sp. On the other hand, protozoans like *Giardia*, *Cryptosporidium* and *Cystoisospora* are often overlooked by common microscopy, as shown by McGlade *et al.* (2003).

Given the rapid urbanization of Estonian red fox populations (Plumer *et al.*, 2014), more attention should be paid to the single findings of *Taeniidae* eggs. Morphologically, eggs from genera *Taenia* and *Echinococcus* are indistinguishable. In recent studies, the eggs of *E. granulosus* from dog excrement and *E. multilocularis* from urban fox excrement were found in Tartu (Laurimaa *et al.*, 2015a, b) and cosmopolitan parasites including *Toxocara* sp. and *Taeniidae* have been shown to be common in Estonia (Talvik *et al.*, 2006; Laurimaa *et al.*, 2015a). Thus, human contact with zoonotic dog parasites are very likely to occur in Estonia (Remm and Remm, 2014; Lassen *et al.*, 2016).

Summary

The current study revealed the presence of infection hotspots in Estonian towns. According to our investigation, dogs in small towns harbour more gastrointestinal parasites than in larger towns, while infective stages of parasites are concentrated in potential hazard zones (playgrounds, recreational areas) and areas surrounded by apartment blocks. It is likely that infection hotspots are formed in areas where both dog and human numbers are high and a limited number of green areas are extensively used for dog walking. In addition, we wish to emphasize the role of small dogs as potential vectors for endoparasite transmission.

Thus, preventive measures (scat removal and pet deworming) should target dog owners in small towns and around apartment-house regions. However, the role of small dogs as parasitic disease transmitters is alarming because humans may underestimate them as disease vectors. Therefore, it is essential to inform the public of exposure to zoonotic parasites, especially via small dogs.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0022149X19000920.

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