Veterinary Parasitology: Regional Studies and Reports 16 (2019) 100275

Contents lists available at ScienceDirect

Veterinary Parasitology: Regional Studies and Reports

journal homepage: www.elsevier.com/locate/vprsr

Review

Baylisascaris procyonis infection in raccoons: A review of demographic and environmental factors influencing parasite carriage

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ARTICLE INFO

Keywords:
Baylisascaris procyonis
Demographic factors
Environment
Procyon lotor
Raccoon
Risk factor

ABSTRACT

Baylisascaris procyonis, the roundworm of raccoons (*Procyon lotor*), is an emerging helminthic zoonosis in North America. Since the larval form is capable of causing neurological disease in more than 150 species of birds and mammals including humans, understanding factors that influence carriage of the parasite by raccoons is important for mitigating risk. This review examines the current literature to identify major demographic and environmental risk factors associated with *B. procyonis* carriage in wild raccoons. Raccoon age and season of sample collection were most commonly identified as risk factors, with increased prevalence found in juvenile animals and when sample collection occurred in the fall. Human urbanization and agricultural land use were also observed as potential risk factors; however, there are inconsistencies in the direction of influence these risk factors have on the prevalence of infection. Further investigation into the role of environmental risk factors is required to better understand how human activities influence parasite carriage in raccoons. Additionally, future research using multivariable statistical models guided by epidemiological principles to control for confounding variables and identify interaction effects will help clarify the effect of these demographic and environmental factors. Developing a better understanding of the primary risk factors for parasite carriage in raccoons will help identify areas of higher risk for environmental contamination and will aid in the development and refinement of education and management programs to reduce the risk of human exposure.

1. Introduction

The raccoon (*Procyon lotor*) is a common mesopredator native throughout much of North and Central America, and has been introduced into parts of Europe and Asia (Gehrt, 2003). These effective urban invaders are often found in close proximity to humans, making use of readily available habitat and food sources (Rosatte, 2000). In addition to causing significant destruction of property, raccoons are carriers of multiple pathogens that are transmittable to humans and domestic animals (Rosatte et al., 2010).

The raccoon roundworm, *Baylisascaris procyonis*, is an emerging helminthic zoonosis and is common in raccoons throughout most of their North American range (Sorvillo et al., 2002; Graeff-Teixeira et al., 2016). The genus *Baylisascaris,* first described in 1968 by Sprent in his assessment and reclassification of ascarid species, consists of 10 species, of which *B. procyonis* appears to be the most pathogenic in aberrant hosts (Tiner, 1953; Sprent, 1968; Kazacos, 2016). *Baylisascaris procyonis* can cause significant neurological and ocular disease in many animals, including humans, as a result of aggressive larval migration (Tiner, 1953; Page et al., 2001b).

Raccoons are the primary host for the adult stage of *B. procyonis* and become infected through one of two routes: direct ingestion of infective eggs, or ingestion of larvae encysted in a paratenic host. Adult *B. procyonis* reside in the small intestine of raccoons and do not typically produce clinical disease (Kazacos, 2001); however, heavy burdens have been associated with intestinal impaction (Stone, 1983; Carlson and Nielsen, 1984). Typically, paratenic and aberrant hosts (primarily small mammals and birds) become infected through incidental ingestion of infective eggs while foraging for seeds and other food items in raccoon latrines (Page et al., 1998). As eggs are very resistant in the environment, latrines can contain infective eggs years after they are no longer used by raccoons, making them important persistent sources of infection (Kazacos, 2001; Hirsch et al., 2014; Smyser et al., 2015).

The significant disease potential of *B. procyonis*, and its role in

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https://doi.org/10.1016/j.vprsr.2019.100275
Received 23 August 2018; Received in revised form 22 December 2018; Accepted 18 February 2019
Available online 21 February 2019
2405-9390/

human disease, has prompted much ecological and epidemiological research into this parasite (Graeff-Teixeira et al., 2016). One approach to disease management includes the control of factors known to be associated with infection, and a major intention of epidemiological studies is to identify such risk factors (Lanfranchi et al., 2003; Stallknecht, 2007; Ryser-Degiorgis, 2013). Risk factors can be very diverse and can be related to host level factors such as age and sex, as well as environmental factors, including host population density and anthropogenic land use differences (Ryser-Degiorgis, 2013; McDonald et al., 2018). Additionally, both behavioural and climatic changes, often jointly represented by season, can have significant influences on disease transmission and persistence within a population (Ryser-Degiorgis, 2013). Understanding the factors influencing the likelihood of individual animals or populations being infected with a zoonotic pathogen is important for developing surveillance and prevention protocols, as well as appropriate education plans.

In this review, we examine the current understanding of demographic and environmental factors that influence *B. procyonis* carriage in raccoons. We also aim to identify potential risk factors that warrant further investigation to determine their role in parasite carriage by raccoons.

2. Methodology for literature review

Based on the focus of this review, we developed the following search string (Raccoon* OR *Procyon lotor*) AND (*Baylisascaris procyonis* OR Roundworm*) AND (Prevalence OR “Risk Factor*” OR Ecology). We examined the current literature in Medline, Web of Science and CABdirect on March 14, 2017, producing 88 unique results. The string was then repeated substituting *Ascaris procyonis* for *B. procyonis* in order to capture earlier records; this added 2 additional articles. We did not include any limits based on publication date. Papers were excluded if they were not written in English or French, were human or paratenic case reports or, in a small number of cases, if the document could not be obtained. Seventy-five unique results were retained. To supplement these papers, a citation search of the initial 75 papers was performed, as well as consultation with experts, and an additional 94 relevant, obtainable documents were also reviewed. Reviewed material included peer-reviewed papers, theses, conference proceedings, book chapters and technical reports. Of the total 196 documents reviewed, 92 were research papers that reported either the presence of, or risk factors associated with, *B. procyonis* infection in raccoons.

3. Known distribution and prevalence of *Baylisascaris procyonis*

First identified in 1933 in a captive raccoon from a New York zoo (McClure, 1933), *B. procyonis* is believed to be distributed throughout Canada and the majority of the United States where raccoons are found, with surveillance studies finding the prevalence as high as 86% and latrine contamination as high as 100% (Snyder and Fitzgerald, 1987; Evans, 2002; Fig. 1).[1] In general, the average local prevalence of *B. procyonis* in raccoons in the United States declines from north to south, although the second highest prevalence currently reported is in California (Kazacos, 2001; Moore et al., 2004). *Baylisascaris procyonis* has also been introduced into Europe, and identified in captive raccoons in Japan and China (Miyashita, 1993; Hohmann et al., 2002; Matoba et al., 2006; Bartoszewicz et al., 2008; Popiołek et al., 2011; Davidson et al., 2013; Karamon et al., 2014; Xie et al., 2014).

[1] Although there are a few studies that report 100% of animals investigated being infected, they were not used to determine the highest regional prevalence due to very low sample size (e.g., $n = 11$ from one site, Park et al., 2000).

4. Risk factors for carriage of *Baylisascaris procyonis* in raccoons

In early studies, evaluation of *B. procyonis* was limited to prevalence studies and range expansion in the definitive host; however, more recently there has been increased reporting of risk factors associated with *B. procyonis* infection in raccoons. Most frequently, host age and sex, as well as season of sampling have been examined (e.g., Snyder and Fitzgerald, 1985; Kidder et al., 1989; Robel et al., 1989; Ching et al., 2000; Page et al., 2009; Yeitz et al., 2009; Weinstein, 2016). Additionally, assessment of environmental factors, focusing on the effects of human land use, has become a significant area of study to provide a more holistic understanding of the driving factors behind the prevalence and intensity of infection in raccoons. A summary of host and environmental risk factors associated with *Baylisascaris procyonis* carriage in raccoons with suggestions for areas that would benefit from further research is provided in Fig. 2.

4.1. Age

Raccoon age is generally considered one of the major risk factors for *B. procyonis* infection, with juvenile animals being more likely to be infected. Many studies that have evaluated risk factors support this conclusion (Snyder and Fitzgerald, 1985; Snyder and Fitzgerald, 1987; Kidder et al., 1989; Robel et al., 1989; Evans, 2001; Page et al., 2009; Yeitz et al., 2009; Blizzard et al., 2010a; Cottrell et al., 2014). Juvenile raccoons are believed to be susceptible to infection through ingestion of eggs, whereas it is thought that adults must ingest larvae found in paratenic hosts (Kazacos, 2001). Additionally, it is believed that immunity to larvae is developed following primary exposure in young animals, which decreases burdens of parasites in future infections (Reed et al., 2012). Supportive of this, Weinstein (2016) found that in California, 100% of the raccoons between 4 and 7 months of age were infected with *B. procyonis* ($n = 64$); additionally, both prevalence and intensity of infection were lower in adult animals. This is consistent with the work of Snyder and Fitzgerald (1985) and Jardine et al. (2014) who found higher prevalence and intensity of infection in juvenile raccoons in Illinois and Ontario. In contrast, a single study from Manitoba found that the prevalence of infection was close to four times higher in adult animals as compared to juveniles; this relationship became more pronounced when evaluating heavier vs lighter animals (Sexsmith et al., 2009).

Nevertheless, some researchers have noted no statistical differences in infection prevalence between raccoon age categories (MacKay et al., 1995; Souza et al., 2009; Chavez et al., 2012; Samson et al., 2012; Hernandez et al., 2013; Pipas et al., 2014; Page et al., 2016; Al-Warid et al., 2017). In many of these studies, the authors describe limitations, such as subjective classification of age or small sample sizes, that may explain the lack of detected difference. For example, MacKay et al. (1995) noted that although they identified a 29% difference in prevalence between juveniles and adults, this was not statistically significant, likely due to their small sample size. Souza et al. (2009) also suggested that collection of animals late in the year may have played a role as the distinction between age classes becomes more ambiguous at this time. Nevertheless, the lack of differences may be real. For example, two studies performed in Tennessee and three studies performed in Texas were consistent in their findings that there was no difference in infection prevalence between juveniles and adults (Smith et al., 1985; Kerr et al., 1997; Long et al., 2006; Souza et al., 2009; Kresta et al., 2010). Kresta et al. (2010) proposed that recent range expansion could explain the lack of difference between age groups, through insufficient environmental contamination to infect juvenile animals.

The differences in routes of parasite acquisition as well as behavioural changes are likely the major drivers for the often significant differences in prevalence of *B. procyonis* infections in adult and juvenile raccoons. Given that juvenile animals are the individuals who disperse to new areas, it is likely that they may play a major role in the

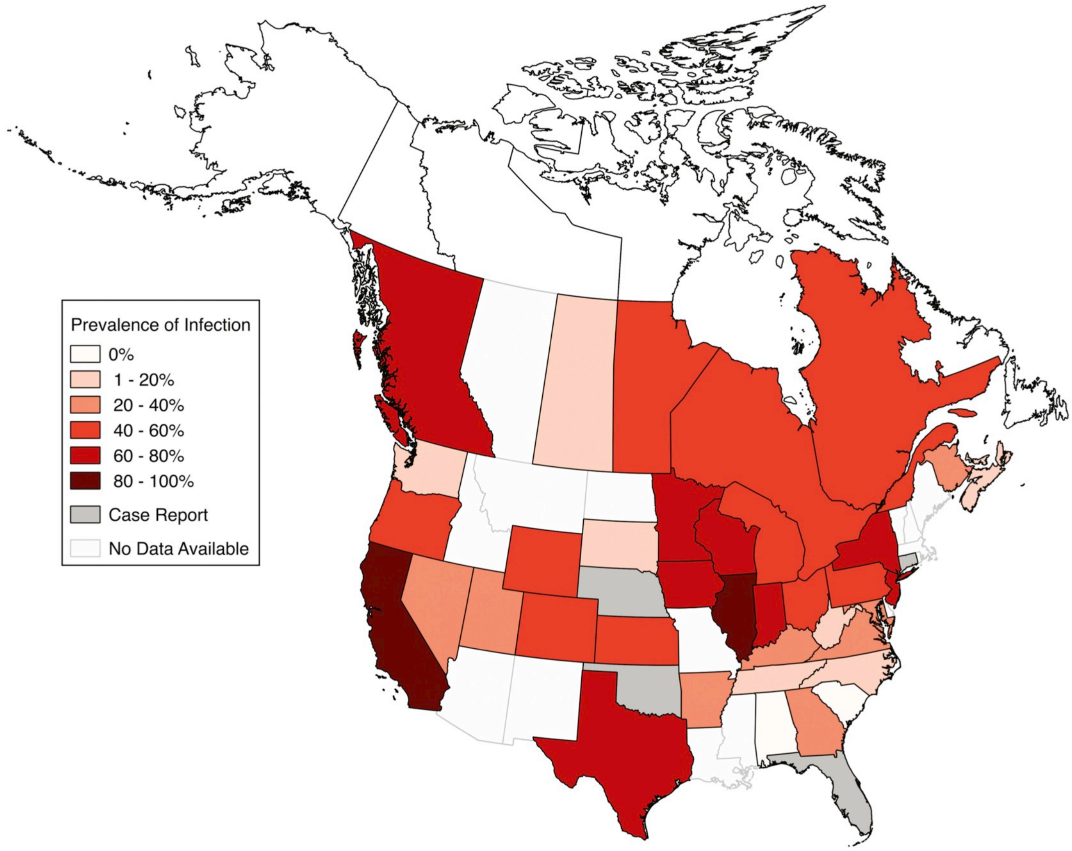

Fig. 1. Map demonstrating the highest prevalence of *Baylisascaris procyonis* reported in the literature for each state and province in the United States and Canada. Case reports refer to identification of *B. procyonis* in individual raccoons. Latrine studies were excluded given that they better represent environmental contamination than true prevalence (generated using additional data from Kazacos, 2016).

maintenance and spread of *B. procyonis* in the environment (Gehrt, 2003; Kresta et al., 2010).

4.2. Sex

Males are often identified as being at higher risk of parasitism for a number of reasons including; increased exposure to parasites through their propensity for roaming and the theorized testosterone-induced immune suppression (Wirsing et al., 2007). The idea of male-biased parasitism is supported by several studies including one in Kentucky, which found that male raccoons had a significantly higher prevalence of infection as compared to females (Cole and Shoop, 1987). The authors suggested that transmammary/transplacental transmission of the parasite in raccoons may reduce the prevalence and intensity of intestinal infection in adult females as larvae remain in the tissues prior to transmission to the offspring rather than maturing in the small intestine; however, the aforementioned routes of transmission of *B. procyonis* are not currently supported in the literature (Kazacos, 2001; Kazacos, 2016). Similar results were obtained by Page et al. (2009) who offered a different explanation; they suggested that given their large home ranges, male raccoons were more likely to encounter infected rodents. Further support for male-biased parasitism has been found in Illinois, California, and North Carolina (Snyder and Fitzgerald, 1985; Evans, 2001; Hernandez et al., 2013).

Despite these examples, most studies on *B. procyonis* in raccoons have found no differences in infection prevalence between sexes regardless of sampling methodology (Smith et al., 1985; Snyder and Fitzgerald, 1987; Robel et al., 1989; Ching et al., 2000; Gompper and Wright, 2005; Wirsing et al., 2007; Sexsmith et al., 2009; Souza et al., 2009; Yeitz et al., 2009; Blizzard et al., 2010b; Chavez et al., 2012; Samson et al., 2012; Xie et al., 2014; Pipas et al., 2014; Page et al., 2016). Cottrell et al. (2014) examined fecal samples collected from trapped and road-killed animals and found only a 1.5% difference in prevalence between males and females. Similar results were obtained by Kresta et al. (2010) when examining carcasses; they noted that this was unsurprising given the lack of differences in environmental exposure between sexes.

Interestingly, there are two studies that demonstrate interactions between sex and other variables. Jardine et al. (2014) found interactions between sex and season as well as sex and urbanization. The authors identified that urban male raccoons had a higher odds of infection than urban females in the spring (March – June), however in the summer/fall (July – October), this relationship reversed and urban females were more likely to carry the parasite. For rural animals, female raccoons were more likely to be infected than males in the summer/fall, and although there was no difference in the odds of infection between males and females in the spring, females had higher intensities of infection (Jardine et al., 2014). Kidder et al. (1989) observed a relationship between age, sex and season, noticing that in the fall juvenile males were four times more likely than juvenile females to be infected, and that in all other seasons, adult males were less likely to be infected than would be expected. Although the relationships between sex and season are opposite for these two studies, they both highlight an important concept; as Kidder et al. (1989) point out, making conclusions about the relationship between sex and infection rates without considering the strong seasonality of this parasite may result in misleading conclusions. This emphasizes the importance of considering how risk factors interact with each other to obtain a more holistic understanding of parasite ecology.

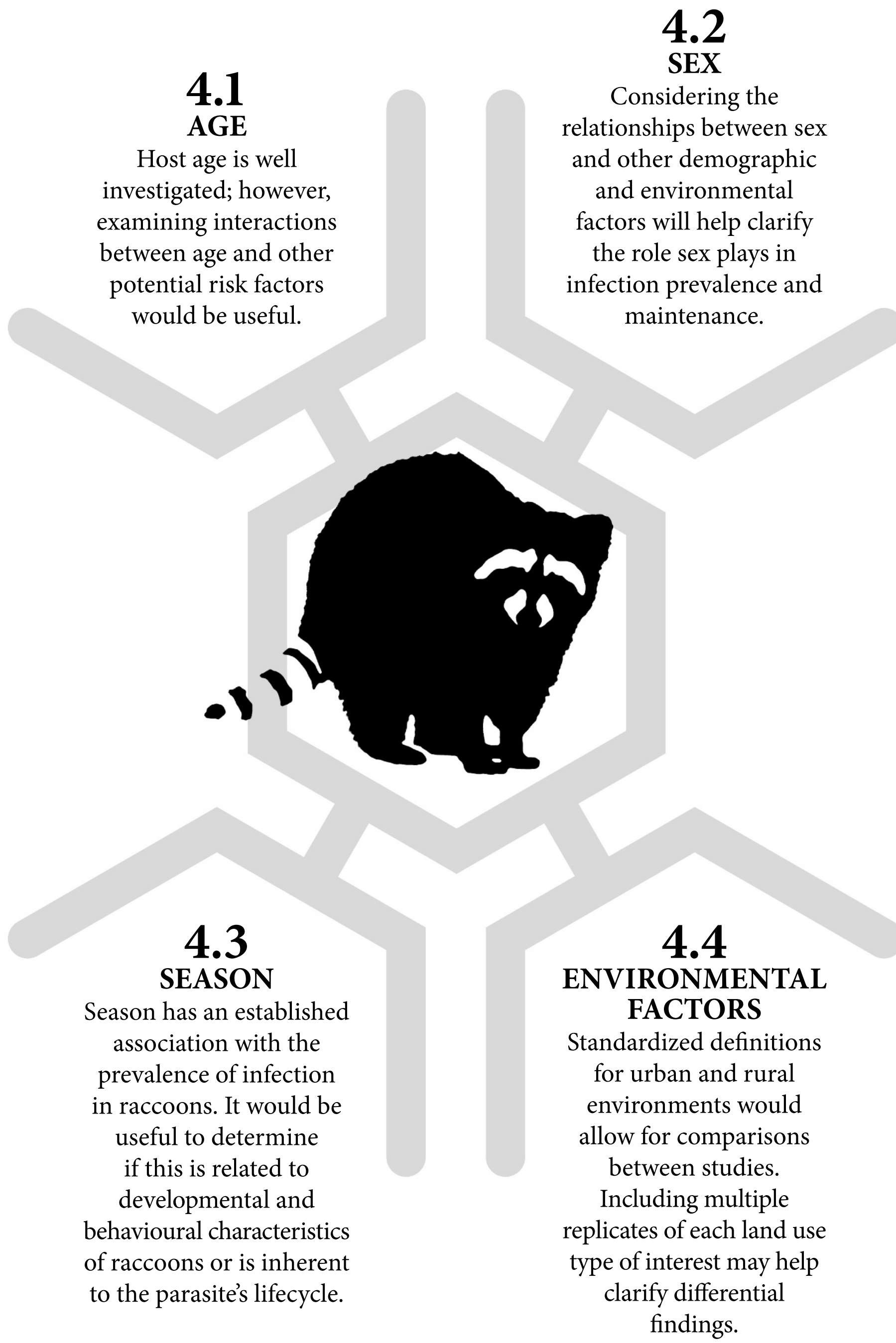

Fig. 2. Host and environmental risk factors associated with *Baylisascaris procyonis* carriage in raccoons with suggestions for areas that would benefit from further research.

4.3. Season

Evidence exists to support the idea that there is strong seasonality in recruitment and retention of *B. procyonis* infection in raccoons in temperate regions (Kidder et al., 1989; Jardine et al., 2014). The parasite typically experiences an increase in prevalence as well as intensity of infection in raccoon hosts in the fall, followed by a decline through the winter months (Page et al., 2009; Page et al., 2016). Multiple theories have been offered to explain the fluctuations, both to explain the rise in the fall as well as the decline in the winter. The leading explanation for the winter decline is that raccoons undergo a "self-cure" in northern environments, when decreased food intake and reduced body mass do not support continued worm survival (LoGiudice, 1995; Kazacos, 2001; Page et al., 2009). Northern raccoons have been observed to lose 50% of their body mass over the winter (Mech et al., 1968; Gehrt, 2003). The higher *B. procyonis* prevalence observed in the fall is thought to be associated with raccoon development (Rosatte, 2000). Given the 2-month pre-patent period in young animals, there is an increase in prevalence and egg shedding in the late summer and fall (Kidder et al., 1989). Additionally, the spike in the fall correlates with weaning and dispersal of juvenile raccoons, a period of time when they are actively foraging and exploring, increasing their risk of infection (Page et al., 2016). It has also been suggested that seasonal changes in food preferences may alter exposure to eggs and larvae (Page et al., 2016).

Numerous studies of the Northeastern and Midwestern United States as well as Ontario have demonstrated the aforementioned seasonal trend of infection in raccoons (e.g., Page et al., 2009; Cottrell et al., 2014; Sarkissian et al., 2015). In a study of raccoon fecal samples in upstate New York, Kidder et al. (1989) noted that despite collecting for 11 months, 80% of the positive samples were collected in the fall. Similarly, a study carried out on carcasses from 7 Midwestern states found that 61% of positive animals were collected in October and November (Page et al., 2005). In an evaluation of parasite populations within raccoon hosts in the Midwestern United States, Page et al. (2016) found that the intensity of *B. procyonis* infection peaked in the fall. Interestingly, they noted that the worm burden increased from July to December, then declined steadily in the first half of the year.

There are two northern studies that did not find seasonal differences in prevalence; however, both are limited in their findings. The first is a study from Winnipeg, Canada, in which samples were collected from both trapped raccoons and latrines between May and August, representing only one season; the authors noted that in this northern environment, raccoon activity is extremely limited between October and March (Sexsmith et al., 2009). The second was performed in Oregon; as the authors identify, statistical power was limited due to the very small number of winter samples (Yeitz et al., 2009). Nevertheless, the lack of seasonal differences may have been related to other factors including habitat differences and localized raccoon behaviour that have not yet been examined.

It has been argued that seasonal trends may not be present in southern regions of the United States (Blizzard et al., 2010a; Page et al., 2016). This is often explained by the more constant climate, and less dramatic shifts in resource availability observed in the south (Blizzard et al., 2010a). Nevertheless, most studies in the southern states that have examined seasonality of prevalence have found the same increase in prevalence in the fall and subsequent decline in the winter (Smith et al., 1985; Evans, 2001; Evans, 2002; Weinstein, 2016). This finding is consistent regardless of sample type; Smith et al. (1985) performed necropsies on raccoons in Kentucky and Tennessee and found the prevalence of adult *B. procyonis* peaked in the fall, and was lowest in the winter and summer. Similarly, using both individual fecal samples as well as those from raccoon latrines in Orange County, California, Evans (2001, 2002) found the number of eggs/g of feces increased in the fall with a significant winter decline. The occurrence of this temporal pattern in both northern regions and milder southern climates helps support the theory that fluctuations in infection prevalence and intensity are based on raccoon age structure and the significance of juvenile animals in transmission dynamics (Page et al., 2009; Kazacos, 2016; Page et al., 2016).

4.4. Environmental factors

In seeking to understand the epidemiology of *B. procyonis*, environmental factors have been evaluated in many different ways. Most frequently, researchers have examined the impact of urbanization, (i.e., human density), or human land use, (e.g., agricultural, developed, or forested), on the prevalence of *B. procyonis* infection in raccoons. To a lesser extent, soil type, habitat fragmentation and other environmental components, such as road density, have been assessed as risk factors for infection. In central and eastern Texas, Kresta et al. (2010) evaluated soil ecotype in order to determine which habitats best facilitated *B. procyonis* infection in raccoons. They determined that clay-based soils were associated with a higher prevalence of infection in raccoons as compared to loam soils, and suggested this was related to environmental moisture retention and small particle size of the soil; both of which would increase the likelihood of transmission to paratenic hosts by improving viability and keeping eggs at or near the surface (Kresta et al., 2010).

4.4.1. Urbanization

Given that humans and raccoons often live in close proximity in urban areas, assessment of the relationship between urbanization and *B. procyonis* prevalence in raccoons is common. Generally, raccoon population densities are highest in residential areas, likely related to increased anthropogenic resources (Prange et al., 2003; Wright and Gompper, 2005). There is mixed support for the relationship between urbanization and *B. procyonis* infection in raccoons; the direction of the relationship varies between studies. It has been demonstrated in Georgia that both prevalence and intensity of *B. procyonis* infection are highest in urban/suburban raccoons when compared to their rural counterparts (Blizzard et al., 2010a). By comparison, two studies in the Midwestern US found a lower prevalence of infection in animals from urban areas (Page et al., 2005; Page et al., 2008). To further confuse the issue, other studies carried out in the United States have found no difference in the prevalence of infection between animals collected from urban and rural environments (Jacobson et al., 1982; Cottrell et al., 2014; Pipas et al., 2014).

It has been proposed that rural environments, specifically agricultural areas, frequently have clustered or aggregated resources, potentially increasing animal contact rates and leading to increased parasite transmission (Gompper and Wright, 2005). Additionally, lower prevalence in urban environments may be due to differences in dietary sources for raccoons based on their habitat; raccoons in urban environments tend to rely more on anthropogenic food sources as compared to their non-urban counterparts (Page et al., 2008; Hirsch et al., 2014). On the other hand, the significant increase in raccoon density and contact rates in urban settings may result in high parasite loads in the environment, leading to higher prevalence of infection (Kellner et al., 2012; Graeff-Teixeira et al., 2016).

4.4.2. Agricultural land use

Many studies have focused on the relationship between *B. procyonis* infection in raccoons and agricultural land use. This is significant given that the primary paratenic hosts, *Peromyscus* spp. mice, thrive in fragmented environments (Beasley et al., 2013). There is general agreement among studies that agricultural land use is related to an increase in the prevalence of *B. procyonis* infection in raccoons. However, there is a lack of consistency regarding the type of land usage that may be associated with a reduced risk of infection.

As early as 1987, Cole and Shoop (1987) observed that although only 30% of assessed raccoons were infected with *B. procyonis,* 81% of these infected individuals came from an agricultural area in Kentucky. In Ohio, researchers found that the prevalence of infection in raccoons was positively associated with increased agricultural land use, and negatively associated with increased urbanization (Ingle et al., 2014). Robel et al. (1989) examined animals from a rural community and an unexploited forested area in Kansas; the prevalence of *B. procyonis* infection was higher in raccoons from the rural area compared to animals collected from the forest. Samson et al. (2012) examined multiple environmental factors, including distance to an urban area, road density, and human population, which were used as proxies for urbanization, as well as classifying surrounding areas by land use. The authors found no association with the markers of urbanization; they did find, however, that the prevalence of infection increased as the amount of agricultural land increased and forested land decreased within a raccoon's habitat. Given the suspected importance of *Peromyscus* spp. mice in the lifecycle of *B. procyonis*, a small number of studies have examined the prevalence of larvae in rodents in relation to environmental characteristics (Kellner et al., 2012). Based on studies in Illinois and Indiana, researchers have suggested that the prevalence and intensity of infection in paratenic hosts increases with increased agricultural fragmentation of forested areas (Page et al., 2001a; Beasley et al., 2013) as well as with increased human density, a marker for urbanization (Kellner et al., 2012). It has been suggested that the parasite is more common in mice from agricultural settings because of increased exposure to eggs as a result of changes in raccoon behaviour and distribution in agricultural environments (Page et al., 2001a; Beasley et al., 2013). Alternatively, it is possible that increased densities of mice in such environments could drive the greater prevalence by increasing transmission of the parasite to its definitive host (Samson et al., 2012). These findings provide further support for the idea that agricultural environments are more effective for the maintenance of the *B. procyonis* lifecycle.

5. Limitations

5.1. Potential limitations with reported data

When comparing reports of prevalence, it is crucial to consider the method of sample collection as this can bias the reported data. Generally, the prevalence of *B. procyonis* is measured in one of three ways: necropsy, fecal collection from live animals, or fecal samples collected from raccoon latrines. These varied methods, in addition to season of collection, can result in dramatically different estimates (Page et al., 2012). Necropsy with intestinal incision and visualization of individual parasites is considered the gold standard, and provides individual-level infection rates (Page et al., 2005; Sexsmith et al., 2009; Samson et al., 2012). This approach allows for inclusion of pre-patent and male only infections which would not otherwise be identified (Page et al., 2005).

Fecal samples from individual raccoons allow one to identify patent infections as well as the dynamics of egg shedding (Page et al., 2005; Graeff-Teixeira et al., 2016). However, in such studies, the overall prevalence of infection in the population can be underestimated by as much as 30%, missing pre-patent and male only infections (Evans, 2001; Page et al., 2005; Cottrell et al., 2014). This is further exacerbated by the irregular egg production of female *B. procyonis*, leading to intermittent shedding (Reed et al., 2012). Examination of fecal samples has merit in situations where researchers want to study *B. procyonis* without permanent removal of individuals from the population (Page et al., 2005), and is useful if researchers are interested in identifying when eggs are being shed into the environment. Fecal collection is also often a simpler way to collect samples when volunteers are involved in the surveillance process (Samson et al., 2012).

By comparison, latrine samples are most useful for identifying environmental contamination and associated human risk, as latrines are the point source for environmental spread of eggs (Page et al., 2005; Smyser et al., 2010). Furthermore, this sample collection method is often less labour intensive, given the lack of raccoon capture, allowing efficient surveillance of a population (Smyser et al., 2010). Nevertheless, this type of sampling does not provide insight on animal-level prevalence as multiple infected individuals may have defecated at the same site, or a single infected raccoon may have contaminated multiple latrines (Page et al., 2005; Hirsch et al., 2014). Additionally, since eggs can remain present and viable for many years following deposition (Kazacos and Boyce, 1989), seasonal or annual trends may be masked.

5.2. Potential limitations with reported risk factors

Similar to the potential biases associated with reporting and interpreting prevalence data, bias can be introduced in the evaluation of individual risk factors associated with parasite infection. In the case of *B. procyonis*, it is important to consider the season and duration of the sample collection period used in the study. As indicated above, there is evidence of strong seasonality related to risk of infection in raccoons (Kidder et al., 1989; Kazacos, 2001). Thus, sample collection limited to only a portion of the year has the potential to alter the observed associations between host, environmental factors, and prevalence and intensity of infection.

In wildlife studies, particularly those which rely on submissions or other forms of opportunistic sampling, unequal sample distribution among groups and subsequent small sample sizes are difficult to avoid; variations in sample size among comparison groups may limit the statistical power of risk factor analyses and, as a result, fail to identify differences (Stallknecht, 2007).

An additional difficulty is associated with the evaluation of the influence of environmental factors. The lack of consistent definitions for urban and rural environments as well as differences in land use classifications can make direct comparisons between studies difficult. Finally, as discussed above, investigating risk factors without consideration of interactions between variables, as well as the influence of confounding variables, may result in incorrect interpretation of the risk factors' true effect (Kidder et al., 1989).

6. Conclusions and future directions

As a zoonotic pathogen, the raccoon roundworm poses a potential health risk to humans, as well as both wild and domestic animals. The broad range of species that can be infected by the larval stage of the parasite, as well as the severity of clinical disease, makes this parasite an important focus of study (Graeff-Teixeira et al., 2016). Despite many descriptive studies on *B. procyonis*, consensus regarding predominant risk factors for carriage in raccoons is limited. At this time, the role of urbanization and human land use modification, and their relationship to *B. procyonis* prevalence in raccoons is unclear. Gaps in the literature and conflicting findings limit the extent to which the influence of environmental factors on parasite carriage is understood. Consequently, further examination of varied land use classifications and environmental factors that influence habitat composition may help identify the habitats most suited to transmission of *B. procyonis*.

Investigation into interactions between various risk factors is also an important area of further research, as identified by a limited number of studies (Kidder et al., 1989; Jardine et al., 2014).The presence of these unaccounted for interactions could potentially explain the variation in importance of risk factors found in different studies. For example, if there is a true interaction between sex and season, then results of investigations into seasonality may depend on the distribution of sexes sampled.

As both *B. procyonis* and its definitive host spread to new environments and continents, becoming increasingly global in distribution, surveillance is of utmost importance; continued monitoring and detailed investigations into the epidemiology of this parasite are crucial to develop, focus and refine management protocols and public education programs in high risk areas to minimize the risk of human exposure (Graeff-Teixeira et al., 2016).

Funding

Shannon French was supported by an Ontario Veterinary College PhD scholarship.

Declarations of conflict of interest

None.

Ethical statement

No animals were used in the development of this review article.

Appendix A. Supplementary figure

A supplementary figure related to this article can be found online at https://doi.org/10.1016/j.vprsr.2019.100275.

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