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# *Baylisascaris procyonis* in raccoons (*Procyon lotor*) from North Carolina and current status of the parasite in the USA

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**Abstract** *Baylisascaris procyonis* is an intestinal nematode of raccoons (*Procyon lotor*) that can cause fatal larva migrans in numerous species of birds and mammals, including humans. Historically, this parasite has been rare in the southeastern USA but recently has been reported in eastern Tennessee and isolated parts of Georgia and Florida. The objective of the current study was to investigate the distribution and prevalence of *B. procyonis* in raccoons from North Carolina. In western North Carolina, in counties bordering Tennessee, *B. procyonis* was detected in nine of 74 (12 %) raccoons sampled in 2010–2011. In general, worm burdens (average 20 worms) were low, but one raccoon had 122 adult worms. No difference was noted in prevalence by year or age, but significantly more males were infected compared with females. Sequences of the internal transcribed spacer 2 region from three samples were identical to *B. procyonis*. In central North Carolina (Guilford County), all 34 raccoons and 49 fecal samples tested were negative. Collation of data from previous studies conducted in the Southeast indicates that *B. procyonis* has been reported from numerous counties, but surveillance has been patchy and many negative results are >30 years old. These results indicate that *B. procyonis* is established in North Carolina and given the zoonotic and wildlife health implications of this parasite, additional surveillance in North Carolina and other southeastern states is warranted.

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## Introduction

*Baylisascaris procyonis*, an intestinal nematode of raccoons, is an important zoonosis. Although large numbers of *B. procyonis* adults may be present in the small intestine of raccoons, disease has rarely been reported (Carlson and Nielsen 1984), but when birds or other mammals, including humans, ingest larvated eggs, larvae can migrate through tissues and cause visceral, ocular larva migrams (OLM), and neural larva migrans (NLM). Over 90 species of birds and mammals are susceptible to infection, and often result in high morbidity or mortality of certain species of rodents, rabbits, and birds (Kazacos 2001). Clinical disease caused by the migration of the larvae depends on the host species, number of ingested eggs, and the tissues through which larvae migrate. In addition to raccoons, domestic dogs and some exotic pets (e.g., kinkajou [*Potos flavus*]) can serve as definitive hosts (Bowman et al. 2005; Kazacos et al. 2011).

Since first recognized in the 1980s, there have been at least 30 documented human NLM cases. Most diagnosed cases have been severe (usually fatal) with all but two

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survivors having mental or physical disabilities (Sorvillo et al. 2002; Pai et al. 2007; Haider et al. 2012; Peters et al. 2012; Hung et al. 2012). OLM results in mild sight loss to blindness (Goldberg et al. 1993). A dramatic increase in the number of cases was documented in recent years, but because people likely ingest small numbers of eggs, it is believed that a large number of infections are not diagnosed as low numbers of migrating larvae are less likely to cause significant lesions. Treatment of clinical baylisascariasis is complicated because few effective drugs cross the blood–brain barrier and infection is usually not diagnosed early enough for treatment to kill migrating larvae. However, administering albendazole rapidly after infection or development of clinical signs has resulted in recovery (Pai et al. 2007; Peters et al. 2012).

The highest prevalence rates for *B. procyonis* in raccoons have been reported in the northeastern, midwestern, mid-Atlantic, some western states (California, Washington, Oregon, and Colorado), and some regions of Texas (Fig. 1; Kazacos 2001; Long et al. 2006; Chavez et al. 2012). Recent reports in the southeastern USA suggest that this parasite is either spreading to new regions or has been present in unrecognized locales (Eberhard et al. 2003; Blizzard et al. 2010a, b). Because of the zoonotic and wildlife health implications of this parasite, we initiated this study to determine the prevalence and distribution of *B. procyonis* in the western and central regions of North Carolina. In addition, we collated published and unpublished reports to determine the current county-level distribution of *B. rocyonis* in the southeastern USA.

## Materials and methods

During 2010 and 2011, 108 raccoons were collected from six western counties ($n=74$) and one central county ($n=34$) of North Carolina (western counties ranged the entire border with Tennessee and the central county was Guilford County). An additional 49 fecal samples from Guilford County were collected and tested by fecal floatation. All animals were either captured in box traps (Tomahawk Live Trap Co., Tomahawk, WI, USA), baited with sardines or canned cat food, were surrendered alive to the Guilford County animal shelter or were fortuitous roadkill collections. Animals from western North Carolina were frozen and later necropsied at the Southeastern Cooperative Wildlife Disease Study (SCWDS) and the intestinal tract examined for *B. procyonis*. Animals obtained from the animal shelter were euthanized and the gastrointestinal tracts examined at North Carolina State University. If large nematodes were noted, they were collected and stored in 70 % ethanol for identification based on morphologic characteristics (Sprent 1968) and sequence analysis. To confirm the identity of worms obtained from a raccoon with only juvenile worms and another raccoon that had a single sex (female) infection, sequence analysis of the internal transcribed spacer 2 region was conducted using primers F3207 and R3720 as described (Blizzard et al. 2010a). Lastly, reports of *B. procyonis* presence or absence were extracted from various published resources and the unpublished clinical case files at SCWDS. Additional details for these data are provided in Fig. 2 legend.

Fisher's exact test was used to determine if differences existed between prevalence and gender and age class (for western counties only). Raccoons were classified as juve-

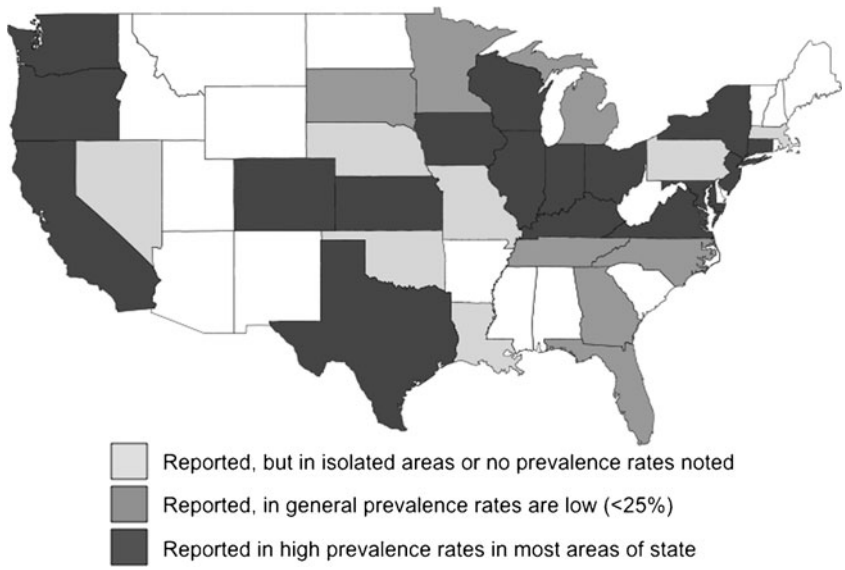


**Fig. 1** Current distribution and general prevalence rates of *B. procyonis* in raccoons throughout the USA. Unmarked states have no current data on the parasite in raccoons

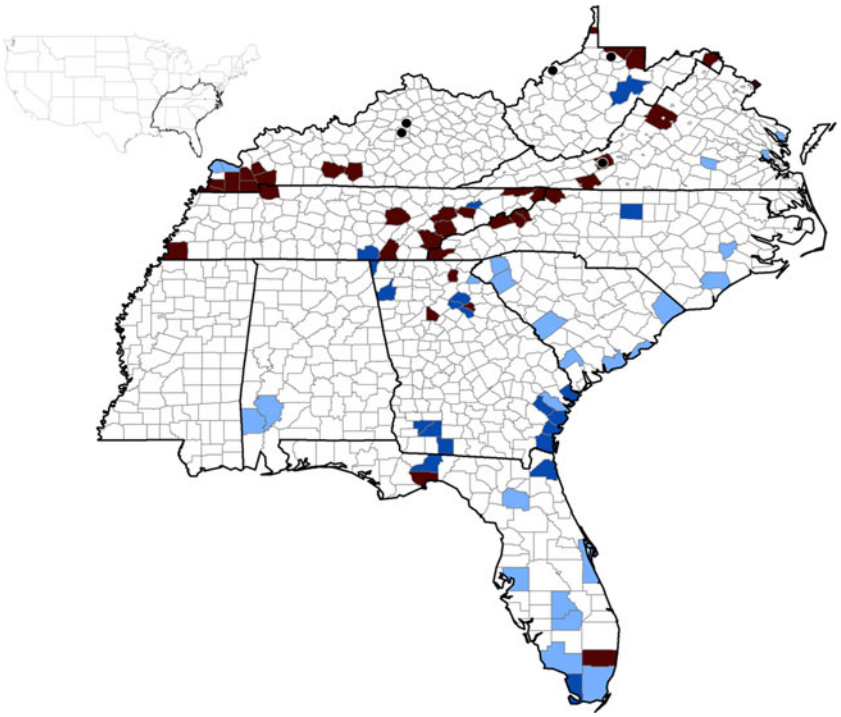

**Fig. 2** Current data on the distribution of *B. procyonis* in raccoons or raccoon scat samples in the southeastern USA. A color version of this figure is available online or in the PDF version. All positive counties from the literature, regardless of sample size, and the current study are noted in black (*red* in color version). Counties with negative results (sample sizes ≥10) reported since 2003 are shown in *dark gray* (*dark blue* in color version) while counties with negative results reported prior to 2003 are shown in *light gray* (*light blue* in color version). No survey reports were found for white counties. Counties with infected intermediate hosts are shown with *filled circles*. Note that a report of *B. procyonis* in Tennessee was not included due to lack of information on county of origin for raccoons, although the highest prevalence was noted in the "valley of East TN" (Bafundo et al. 1980). Similarly, a report from Georgia is not included due to lack of confirmation of identifications, lack of positive reports in subsequent surveys, and exact county of report (unknown number of positives among six raccoons from central Georgia (either Laurens or Peach counties); Babero and Shepperson 1958). Additionally, negative reports for raccoon populations in "coastal" and "inland" North Carolina, "coastal" and "inland" South Carolina, Georgia, and Florida were also excluded due to lack of county information (Harkema and Miller 1964). Data for raccoon infections for the figure were extracted from Harkema and Miller (1962), Johnson (1970), Smith et al. (1985), Cole and Shoop (1987), Jordan and Hayes (1959), Jones and McGinnes (1983), Price and Harman (1983), Schaffer et al. (1981), Jacobson et al. (1976), Kazacos and Boyce (1989), Yabsley and Noblet (1999), Lockhart (2007), Eberhard et al. (2003), Souza et al. (2009), McCleery et al. (2005), Forrester (1992), Owen et al. (2004), Munscher (2007), Blizzard et al. (2010a, b), and SCWDS unpublished clinical case data. References for infection of paratenic hosts are from Jacobson et al. (1976) and SCWDS, unpublished clinical case data

niles (<1 year) or adults based on weight, tooth wear, and development of reproductive organs.

## Results and discussion

Nine of 74 (12 %) raccoons from western North Carolina were infected with *B. procyonis* (Table 1). Significantly more males than females were infected (eight of 40 and one of 34, respectively, $p=0.032$). No differences were noted in prevalence between years (2010 (5/50) and 2011 (4/24)) or age (juvenile 2/17 and adult 7/57). Counties were recorded for 41 raccoons, of which infected raccoons were found in five of six sampled counties (Table 1). Most raccoons had low worm burdens (range of 1–18), but one raccoon was infected with 122 worms (Table 1). Sequences of the internal transcribed spacer 2 region from the three worms were identical to *B. procyonis* from the USA (Georgia, Kentucky, and Texas) and Japan (Genbank U94368). All of the 34 raccoons and 49 fecal samples from Guilford County were negative for *B. procyonis*.

Prior to this study, *B. procyonis* had not been reported in North Carolina, but had been reported in eastern Tennessee (Figs. 1 and 2; Souza et al. 2009). Two previous studies, both conducted over 30 years ago, had failed to detect *B. procyonis* in raccoons from North Carolina. Also, importantly, these surveys were conducted on central or coastal populations (62 coastal raccoons and 148 "inland" raccoons in Harkema and Miller (1964) and 10 raccoons from southeastern North Carolina (Schaffer et al. 1981)).

**Table 1** Results of *B. procyonis* surveillance in raccoons from North Carolina in 2010 and 2011

| Region and county | No. of positive/no. of tested (%) | Average worm burden (range) |
|---|---|---|
| Western region | | |
| Ashe | 1/7 (14) | 5 |
| Cherokee | 2/15 (13) | 8 (5–11) |
| Haywood | 0/4 | n/a |
| Madison | 1/2 (50) | 3 |
| Mitchell | 1/7 (14) | 7 |
| Yancey | 1/6 (17) | 6 |
| Unknown* | 3/33 (9) | 47 (1–122) |
| Total | 9/74 (12) | 19.8 (1–122) |
| Central region | | |
| Guilford | 0/34 (raccoons) | n/a |
| | 0/49 (fecal samples) | n/a |

[a]Either from Ashe, Mitchell, Yancey, Madison, Haywood, or Cherokee counties

A review of the literature shows that *B. procyonis* is widespread throughout the Appalachian mountains; however, outside the Appalachians, the parasite has only been reported in isolated populations in Georgia and Florida (Figs. 1 and 2; references for data used to generate Fig. 2 are provided in the legend). Significantly, many of the surveys conducted in the southeastern USA were conducted prior to 2003 and negative results that were derived from older surveys (some >50 years) are likely no longer valid due to recent findings of this parasite in new locales (e.g., western North Carolina, eastern Tennessee, Georgia, Florida, and Colorado) (Souza et al. 2009; Blizzard et al. 2010a, b; Chavez et al. 2012; this study). In addition, despite the large number of published and unpublished surveys collated in Fig. 2, the number of counties that have been examined are extremely limited, especially in areas near known positive counties. Some of these positive counties or areas near positive counties are major metropolitan areas where large numbers of people may be exposed to raccoon feces. Raccoons have adapted well to urbanization and can be found in high densities in cities and suburbs (Samson et al. 2012). However, many factors may influence infection dynamics in urban raccoons, some of which may be locale specific, as there is conflicting evidence on the impact of urbanization of raccoons on the prevalence or intensity of *B. procyonis* (Page et al. 2008; Blizzard et al. 2010a).

Given the increased recognition of *B. procyonis* in new locales in recent years, we believe that precautions should be taken when working with raccoon feces or in an area potentially contaminated with raccoon feces regardless of reports for the parasite in the area. This is highlighted by the diagnosis of a human *Baylisascaris* larva migrans case in Louisiana, a state where *B. procyonis* has only been reported in raccoons in unpublished reports and no details about its distribution or prevalence are known (Pai et al. 2007). In addition, in historically recognized endemic areas, reports of baylisascariasis in humans have increased in recent years (Peters et al. 2012; Hung et al. 2012; Kelly et al. 2012; Haider et al. 2012; CDC unpublished data). Of note is that raccoons are not the only host of *B. procyonis*. In 2010, a pet kinkajou purchased from a pet store in Tennessee was positive for *B. procyonis* and one other kinkajou from the same pet store was purchased by a North Carolina resident (Kazacos et al. 2011). Importantly, domestic dogs can serve as definitive hosts. Infected dogs represent an increased risk for humans to contact as infective eggs may be more accessible to humans compared with eggs from raccoon feces. Although isolated reports of *Baylisascaris* infections in dogs have been reported (Bowman et al. 2005), prevalence rates are unknown. Although canine intestinal infections can be diagnosed during a fecal exam, it could be misdiagnosed due to the egg morphologic similarities between *Toxocara canis* and *Toxascaris leonina*.

Although the public health threat of *B. procyonis* is evident, this parasite also poses a threat to wildlife and certain animals kept in captivity (e.g., in zoological parks). Fatal larva migrans in wildlife tend to be single-case reports but larger-scale mortality events have been documented in cottontail rabbits (*Sylvilagus floridanus*) and woodchucks (*Marmota monax*) in Virginia (Jacobson et al. 1976). *Baylisascaris* larva migrans is commonly reported in woodchucks resulting in these animals being regarded as rabies suspects due to increasing reports of rabies in this species (Fleming and Caslick 1978; Kazacos et al. 1981; Fishbein et al. 1986; Childs et al. 1997). In addition, at least one species, the Allegheny wood rat (*Neotoma magister*), a near-threatened rodent, is in decline, in part from mortalities caused by baylisascariasis (LoGiudice 2003).

In conclusion, we report the finding of *B. procyonis* in North Carolina extending the currently described range of this parasite in the southeastern USA. A review of raccoon parasite surveys indicates that few contemporary reports

exist for the determination of *B. procyonis* prevalence and distribution in the Southeast. To better understand the risk of this parasite to human and wildlife health, additional surveillance is needed to accurately determine the distribution of *B. procyonis*. Currently, the distribution appears to be disjunct but once *Baylisascaris* has been introduced into a population, it is likely to become established as eggs are highly resistant to degradation and can survive extreme temperatures and desiccation (Shafir et al. 2011).

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