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Mark W. Cunningham

Daniel P. Wolf

Katherine A. Sayler

Michael Milleson

Brittany Bankovich

See next page for additional authors

Authors

Mark W. Cunningham, Daniel P. Wolf, Katherine A. Sayler, Michael Milleson, Brittany Bankovich, Paul Schueller, Betsy S. Haley, Savannah Stura, and Michael J. Yabsley

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Distribution of *Baylisascaris procyonis* in Raccoons (*Procyon lotor*) in Florida, USA

Mark W. Cunningham,[1,7] Daniel P. Wolf,[1,6] Katherine A. Sayler,[1] Michael Milleson,[2] Brittany Bankovich,[1] Paul Schueller,[1] Betsy S. Haley,[3] Savannah Stura,[1] and Michael J. Yabsley[4,5] [1]Florida Fish and Wildlife Conservation Commission, Wildlife Research Laboratory, 1105 SW Williston Rd, Gainesville, Florida 32601, USA; [3]United States Department of Agriculture, Wildlife Services, 2820 E University Ave, Gainesville, Florida 32641, USA; [4]Southeastern Cooperative Wildlife Disease Study, 589 D. W. Brooks Dr, University of Georgia, Athens, Georgia 30602, USA; [5]United States Department of Agriculture, Wildlife Services, National Rabies Management Program, 1482 Tobe Wells Rd, Elberton, Georgia 30635, USA; [6]Warnell School of Forestry and Natural Resources, University of Georgia, Athens, Georgia 30602, USA; [6]Current address: United States Department of Agriculture, Veterinary Services, 8100 NW 15th Place, Gainesville, Florida 32606, USA; [7]Corresponding author (email: mark.cunningham@myfwc.com)

ABSTRACT: *Baylisascaris procyonis*, or raccoon roundworm, is an intestinal nematode parasite of raccoons (*Procyon lotor*) that is important to public and wildlife health. Historically, the parasite was uncommon in the southeastern US; however, the range of *B. procyonis* has expanded to include Florida, US. From 2010 to 2016, we opportunistically sampled 1,030 raccoons statewide. The overall prevalence was 3.7% (95% confidence interval=2.5–4.8%) of sampled individuals, and infection intensity ranged from 1 to 48 (mean±standard deviation 9.9±4.0). We found raccoon roundworm in 9/56 (16%) counties sampled, and the percent positive ranged from 1.1% to 13.3% of specimens collected per county. Including previously published data, *B. procyonis* was detected in 11 Florida counties. We used logistic regression to estimate the contribution of raccoon demographic variables and the presence of the endoparasite *Macracanthorhynchus ingens* to *B. procyonis* detection in Florida. Following the model selection process we found housing density, *M. ingens* presence, and urbanicity to be predictive of raccoon roundworm presence. We also found substantial among-county variation. Raccoon sex and age were not useful predictors. Public health officials, wildlife rehabilitators, wildlife managers, and others should consider any Florida raccoon to be potentially infected with *B. procyonis*, particularly in areas where housing density is high.

Key words: *Baylisascaris*, raccoon roundworm, zoonosis.

Baylisascaris procyonis is a nematode parasite of raccoons (*Procyon lotor*). The roundworm rarely causes disease in the definitive host; however, ingestion of embryonated *B. procyonis* eggs by some animal species and people may result in significant ocular, visceral, or often-fatal neurologic disease. In particular, the parasite may cause mortality in wild rodents and lagomorphs including the endangered Allegheny woodrat (*Neotoma magister*; LoGiudice 2003). In Florida, 23 species of rodents and lagomorphs are listed as Species of Greatest Conservation Need, including six beach mouse subspecies (*Peromyscus polionotus* subspp.), Key Largo woodrats (*Neotoma floridana smalli*), silver rice rats (*Oryzomys palustris natator*), and Sanibel Island marsh rice rats (*O. palustris sanibeli*), that may be at risk if exposed (Florida Fish and Wildlife Conservation Commission [FWC] 2012).

In people, particularly young children, *B. procyonis* may cause disease following ingestion of eggs present in soil or animal feces. Infected raccoons shed an immense number of eggs that persist in the soil for months or years, and the infective dose in people is low. Therefore, a better understanding of the prevalence of the parasite at more local scales (city-wide or statewide) is warranted (Page et al. 2009). In the US, the parasite is common in raccoons in many western states, the Midwest, and Northeast, and the prevalence may be as high as >80% (Kazacos 2001). Despite the distribution of raccoons throughout most of North America and Central America (Zeveloff 2002), raccoon roundworm has been rare or previously unrecognized in the Southeast US. Nevertheless, recent surveys have detected *B. procyonis* in isolated areas of the Southeast US states including Arkansas, Georgia, Louisiana, North Carolina, and Tennessee and several areas of Texas (Eberhard et al. 2003; Souza et al. 2009; Blizzard et al. 2010a; Kresta et al.

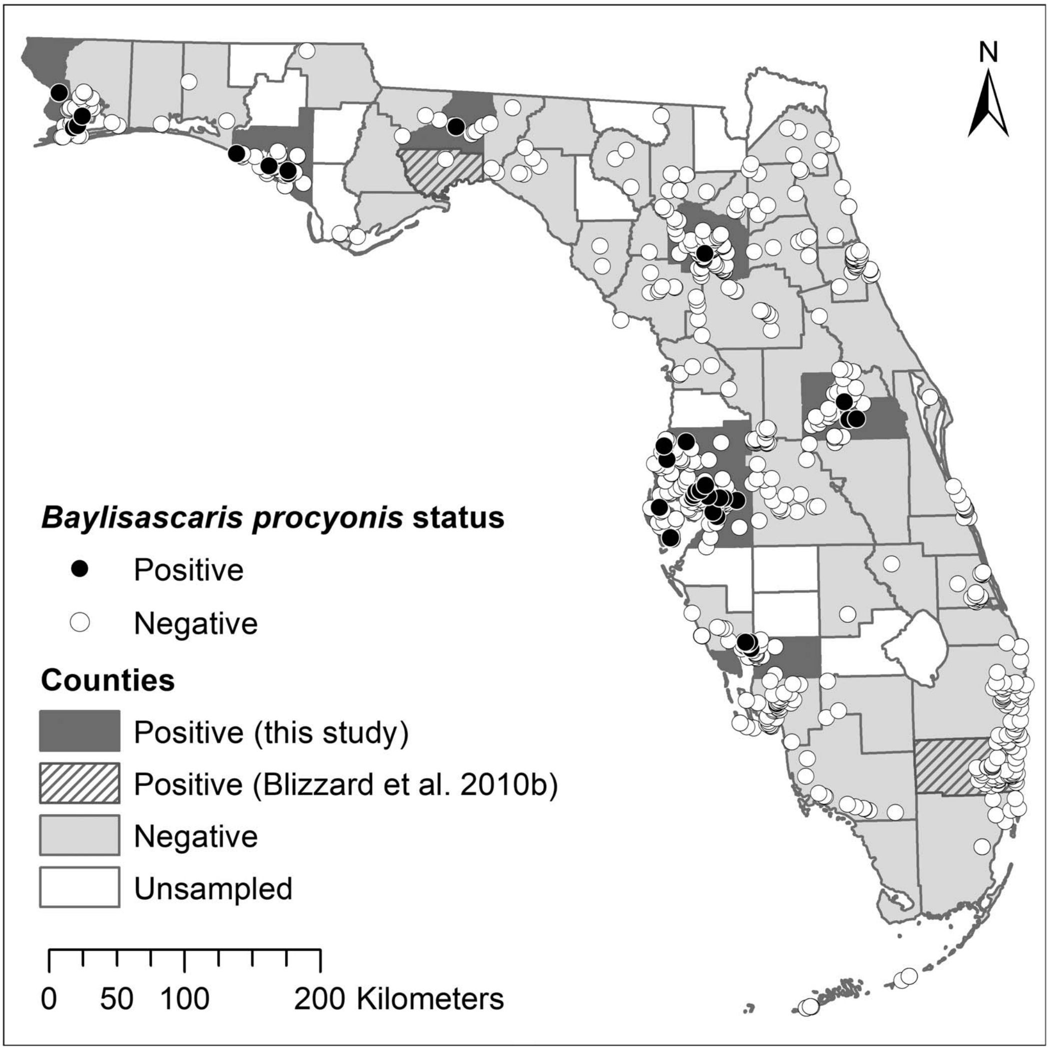

FIGURE 1. Counties and individual raccoons positive for *Baylisascaris procyonis* in Florida, US, using data from this study (2010–16) and previously published data (Blizzard et al. 2010b).

2010; Hernandez et al. 2013; Al-Warid et al. 2017; Gerhold et al. 2018). Historically, surveys in Florida, although limited in scope, have failed to detect the parasite (Forrester 1992; Kazacos 2001; McCleery et al. 2005). However, *B. procyonis* was confirmed in Florida between 2006 and 2010 from free-ranging road-killed raccoons in Wakulla and Leon counties and a raccoon submitted to a wildlife rehabilitation center in Broward County (Blizzard et al. 2010b). *Baylisascaris* sp. was also found in captive kinkajous (*Potos flavus*) in Miami-Dade County (Kazacos et al. 2011). The cause of the apparent introduction of *B. procyonis* to Florida is unknown but may be due to the translocation of wild or captive procyonids (Kazacos 2016). We conducted a statewide survey for *B. procyonis* to determine prevalence and factors that influence the probability of detection in Florida raccoons.

We collected raccoons from August 2010 to March 2016 statewide (Fig. 1). Sources included government agencies (34.6%), road kills (9.2%), wildlife rehabilitators (3.4%), nuisance wildlife trappers (2.4%), and other

(50.4%). Carcasses were processed either fresh or following freezing at –20 C. Data recorded at the time of raccoon collection included date, location, and habitat type, although completeness of data collection varied. At necropsy, raccoons were weighed, sexed, aged, and sampled. Age classes were assigned as either juvenile (<1 yr) or adult, based on tooth wear, weight, and reproductive development (Grau et al. 1970). Gastrointestinal tracts were removed, opened longitudinally, and examined for grossly visible endoparasites. Any parasites observed were counted and saved in 70% ethanol until morphological identification was performed using standard taxonomic keys (Sprent 1968).

From these samples we recorded both presence or absence and total number of *B. procyonis* observed for each raccoon. We performed logistic regressions to determine what factors influenced the probability of a raccoon found to be infested with at least one *B. procyonis* (hereafter roundworm presence). Specifically, we tested effects of housing density (units per hectare; US Census Bureau 2012), urbanicity (urban, suburban, rural; US Census Bureau 2012), sex, estimated age class (i.e., juvenile vs. adult), and presence of *Macracanthorhynchus ingens*, an acanthocephalan endoparasite of raccoons in Florida (Forrester 1992), on roundworm presence. All predictor variables except housing density were categorical. Because we observed only a limited number of positives, we used at most two categorical predictors and housing density in a single model. We fitted models containing all combinations of up to two categorical predictors, both with and without the effect of housing density. Additionally, we fitted an intercept-only null model that lacked any other predictor variables. We performed model selection based on Akaike's information criterion (AIC; Akaike 1973) with small sample size adjustment (AICc; Hurvich and Tsai 1989) and relative AICc weights to assess the most plausible combinations. Any model that had at least one tenth the relative AICc weight of the top model was considered plausible. A random effect for county was added to all models to account for spatial clustering of positive tests and any other spatial variation that was not accounted for by other predictor variables. Finally, we calculated variance inflation factors to ensure that there was no multicollinearity among predictor variables (performance package; Lüdecke et al. 2021). All analyses were conducted in R version 4.2.0 (R Core Team 2022).

We found *B. procyonis* in 38/1,030 (3.7%, 95% confidence interval [CI]=2.5–4.8%) of raccoons examined in 9/56 (16%) counties sampled in Florida. Including previously published data (Blizzard et al. 2010b), *B. procyonis* was detected in 11 Florida counties (Fig. 1). Prevalence within counties ranged from 1.1% to 13.3%. The mean (± standard deviation) intensity of infection was 9.9±4.0 (range:1–48).

In predicting *B. procyonis* detection, we found several combinations of categorical variables were plausible. The most plausible model included the effects of urbanicity, *M. ingens* presence, and housing density (Supplementary Table 1). Variance inflation factors were low (urbanicity=1.02, *M. ingens* presence=1.02, housing density=1.03), which indicated there was no multicollinearity. Although there was support for several models, Akaike weights indicated that the top model was 1.50, 1.82, and 3.25 times more plausible than those that included urbanicity and housing density, *M. ingens* presence and housing density, and urbanicity and *M. ingens* presence, respectively. Additional models were also supported to a lesser extent (Supplementary Table 1). Parameter estimates from the final model, which included a county random effect, indicated a positive effect of housing density, a positive, but not significant, effect of *M. ingens* presence, no significant urbanicity effects, and substantial among-county variation (Supplementary Table 2). Model selection supported including the effects of urbanicity and *M. ingens* presence, but since their confidence intervals overlapped zero their effects were indistinguishable from the intercept. While the differences among urbanicity categories were not statistically significant, the estimated

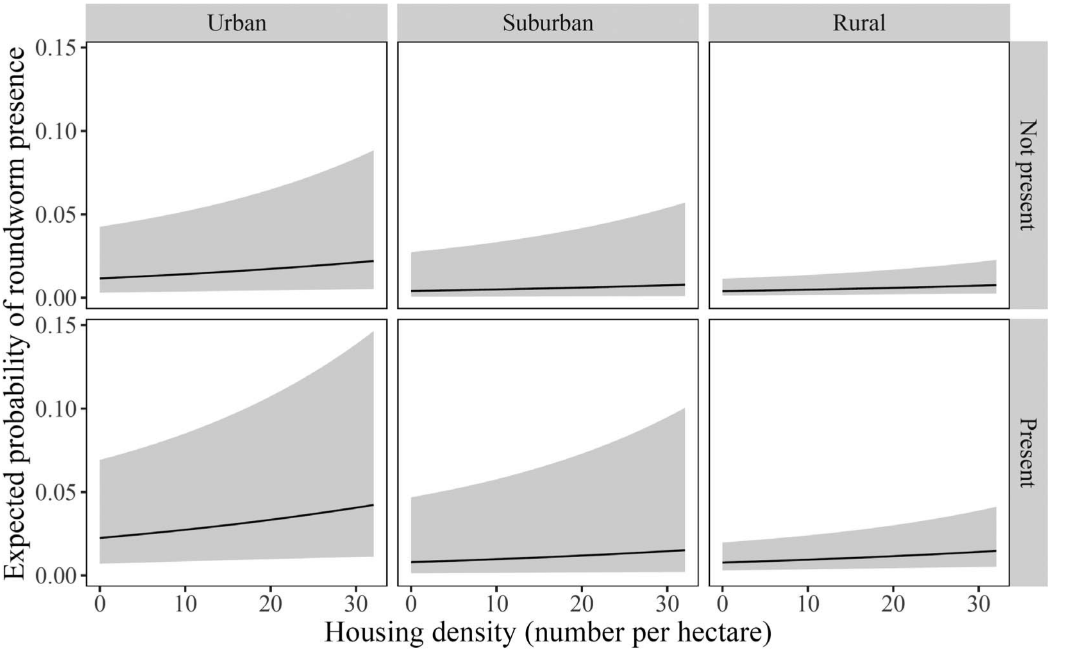

FIGURE 2. The modeled relationship between expected probability of raccoon roundworm (*Baylisascaris procyonis*) presence in Florida, US, and housing density for each urbanicity category and with *Macracanthorhynchus ingens* present or not, including the mean prediction (black line) and the 95% confidence limit (gray region).

probability of a positive test was highest in urban areas (Fig. 2). When *M. ingens* was not present, the expected probability of roundworm presence in urban areas ranged from 1.2% to 2.2% across the range of housing densities, whereas it ranged from about 0.4% to 0.8% for the urbanicity categories. When *M. ingens* was present, the expected probability of roundworm presence in urban areas ranged from 2.2% to 4.2% across the range of housing densities, whereas it ranged from 0.8% to 1.5% for the urbanicity categories. Taken together, our findings indicate that housing density was predictive of roundworm presence and that urbanicity and *M. ingens* presence are likely but less significant predictors.

Samples were collected opportunistically for this study from various sources, and data collection was often incomplete. This hampered more nuanced analyses of the data. Nevertheless, we found that *B. procyonis* is distributed widely in Florida, although at a low prevalence. Given the discontinuous distribution and variation in prevalence, there were probably multiple introductions of *B. procyonis* into Florida, or the parasite may have been present in Florida for some time but previously unrecognized. Further genetic analysis of Florida parasites and those of other states would be required to answer this question.

As observed in Ontario, Canada (French et al. 2020) and Georgia, US (Blizzard et al. 2010a), we found an increased prevalence of roundworms in raccoons collected in urban areas. This may be due to higher densities of raccoons in urban and developed areas (Prange et al. 2003; Slate et al. 2020); however, there is mixed support for the relationship between urbanization and *B. procyonis* infection in raccoons at broader geographic scales (French et al. 2019). In Florida, housing density appears to be predictive of *B. procyonis* detection, as has been observed in multiple other studies (Page et al. 2009; Straif-Bourgeois et al. 2020). We also found an association between *B. procynois* and *M. ingens* presence. While raccoons are the definitive hosts of these acanthocephalan parasites, intermediate hosts include infected beetles, woodroaches, and other arthropods. In urban areas or where housing density is highest, it is plausible there are more intermediate hosts present, as they may be attracted to raccoon latrines. This association suggests that raccoons can be infected with both parasites, which may occupy different niches within the host.

Management actions should be directed at preventing the spread of this parasite, reducing its prevalence near homes, and preventing exposure of people and wildlife to infected feces. Given our finding that housing density was a statistically significant predictor of roundworm presence, management actions should be focused on reducing raccoon latrines and other raccoon gathering areas in proximity to high housing density areas in Florida. Further management actions and preventative measures may include public education, regulatory action, raccoon control, and treatment of raccoons in some situations. Raccoons in wildlife rehabilitation facilities should be treated for *B. procyonis* upon intake and before release, using veterinary anthelmintics (Bauer and Gey 1995). Education of the public, wildlife rehabilitators, and wildlife trappers also is vital to mitigating the affects and spread of the parasite.

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SUPPLEMENTARY MATERIAL

Supplementary material for this article is online at http://dx.doi.org/10.7589/JWD-D-22-00115.

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