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Effects of Urbanization on Prevalence of *Baylisascaris procyonis* in Intermediate Host Populations

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ABSTRACT: *Baylisascaris procyonis* is an intestinal parasite of raccoons (*Procyon lotor*) that can also infect humans and a wide range of wildlife species. Prevalence of *B. procyonis* in raccoon populations appears to decrease as the landscape urbanizes, but less is known about prevalence in the small-mammal intermediate hosts of the parasite. We measured prevalence of *B. procyonis* in populations of mice (*Peromyscus* spp.) in forest preserves along a gradient of urbanization in Illinois. Prevalence in the mouse intermediate host exhibited a trend opposite raccoons: prevalence increased as surrounding human population density increased. This counterintuitive result may be due to higher overall environmental loads of *B. procyonis* in urban areas due to higher raccoon densities. Our results emphasize the need to understand fully the transmission dynamics of *B. procyonis* in its definitive and intermediate hosts in order to design and implement effective strategies to mitigate zoonotic risks to humans.

Key words: *Baylisascaris procyonis*, *Peromyscus*, *Procyon lotor*, raccoon, urbanization.

Urbanization and habitat fragmentation have altered ecological processes in human-dominated landscapes. For example, increased resources in urban areas can change trophic interactions between predators and prey (Prange et al., 2004) and alter transmission dynamics of parasites that rely on those interactions (Bradley and Altizer, 2007). *Baylisascaris procyonis* is an intestinal parasite of raccoons (*Procyon lotor*) that uses small-mammal intermediate hosts to complete its life cycle (Kazacos, 2001). Small mammals are exposed when foraging in the feces of infected raccoons, which may contain large numbers of *B. procyonis* eggs (Kazacos, 2001). The larval stage of the parasite grows in the intermediate host, and the life cycle is completed when raccoons prey on small mammals (Kazacos, 2001). Raccoons may change their behavior in the presence of anthropogenic food sources (e.g., garbage; Prange et al., 2004), consuming fewer intermediate hosts and potentially interrupting the transmission cycle of the parasite (Page et al., 2008). Page et al. (2008) measured *B. procyonis* prevalence in raccoons across an urban-to-rural gradient and found that prevalence was lower in urban areas, despite higher raccoon densities. Less is known about prevalence in small-mammal intermediate hosts, particularly in suburban and urban areas. A complete understanding of the transmission dynamics of *B. procyonis* is important because it is a potential zoonotic threat that can cause central nervous system disease and death in humans (Sorvillo et al., 2002).

We measured *B. procyonis* prevalence in mouse (*Peromyscus* spp.) populations near Chicago, Illinois, USA. Mice are a common intermediate host of the parasite (Page et al., 2001b). Though both white-footed (*Peromyscus leucopus*) and deer mice (*Peromyscus maniculatus*) likely occurred at our study sites, we combined the species for analysis because of the difficulty of making a definitive species identification for many individuals. In the summers of 2006–2007, mice were removed from eight DuPage and Cook county forest preserves (Table 1). Sites were selected to represent a range of surrounding human population densities; we assumed higher densities correlated with greater urbanization and more anthropogenic food sources available to raccoons. A 0.68-km buffer region, representing the diameter of a typical suburban raccoon home range (Prange, 2004), was designated around each study site. Within

TABLE 1. Site characteristics for eight forest preserves near Chicago, Illinois, USA, including population density (in a 0.68-km buffer) around the preserve. The number of mice (*Peromyscus* spp.) captured, *n*, and the prevalence of *Baylisascaris procyonis* in the mouse population at each site are also shown.

Site	Latitude/longitude	Area (ha)	Population density (people/km^2)	*n*	Prevalence (95% credible interval)
Belleau	42°51′N, 88°16′W	49	1,590	28	0.29 (0.25–0.32)
Big Woods	41°47′N, 88°08′W	185	483	12	0.17 (0.10–0.23)
Crabtree	42°07′N, 88°09′W	486	349	17	0.41 (0.35–0.47)
Fischer	41°56′N, 87°57′W	60	882	40	0.40 (0.38–0.42)
Fullersburg	41°49′N, 87°56′W	91	738	26	0.42 (0.39–0.46)
Herrick Lake	41°49′N, 88°08′W	361	356	50	0.22 (0.20–0.24)
Maple Grove	41°47′N, 88°01′W	33	1,792	30	0.40 (0.37–0.43)
Timber Ridge	41°53′N, 88°10′W	471	1,227	18	0.33 (0.28–0.39)
Total				221	0.33 (0.33–0.33)

each buffer, human population density was calculated in ESRI ArcGIS 9 with the use of 2000 US Census block data (US Census Bureau, 2001).

Captured mice were weighed, examined to determine the sex, euthanized in accordance with an approved animal care and use protocol, and artificially digested with the use of an acid–pepsin solution (Page et al., 2011). The resulting liquid was examined under a dissection microscope and all *B. procyonis* larvae were identified and counted. We expected that prevalence and intensity of infection would be higher within the rural mouse populations, reflecting greater prevalence in the raccoon definitive host (and therefore the environment) at those sites (Page et al., 2008).

Prevalence was calculated as the proportion of mice with at least one larva. Intensity of infection was calculated as the number of larvae per infected mouse. Prevalence and intensity were analyzed with the use of a logistic-Poisson mixture model incorporating fixed and random effects. Briefly, the infection status u_i of a given mouse i was modeled as $u_i \sim \text{Bernoulli}(p_i)$, where p_i, the probability of infection, was related to predictor variables with the use of a logit link function. Conditional on infection ($u_i=1$), intensity was modeled as $b_i \sim \text{Poisson}(\lambda_i)$. Mean intensity λ_i was related to predictors with the use of a log-link function. A normal error term ε_i was included in the linear predictor for λ_i; this parameter allowed us to account for overdispersion in the intensity data better (Kéry, 2010). Human population density, year, and the sex and mass of mice were considered as predictor variables for both the prevalence and intensity portions of the mixture model. Site was considered a random effect.

This model was fit in a Bayesian framework with uninformative priors (Kéry, 2010) with the use of R 2.10.0, WinBUGS 1.4.3, and the R package R2WinBUGS. WinBUGS uses Markov chain Monte Carlo (MCMC) techniques to sample from the joint posterior distribution of all parameters. Convergence of MCMC chains was assessed by calculating the Gelman-Rubin diagnostic (Brooks and Gelman, 1998) for each estimated parameter. To assess model fit, we conducted a posterior predictive check in which Pearson's chi-square residuals of the observed data were compared to the residuals of a new, simulated data set based on the model (Kéry, 2010).

Between 12 and 50 mice were removed from each of the eight sites. In total, 221 mice were tested for *B. procyonis* infection. Probability of infection at individual sites ranged from 17% to 42%, and was 33% across all sites (Table 1). Overall, prevalence was slightly higher in our study than the 28% observed by Page et al. (2001a) in a fragmented agricultural land-

TABLE 2. Estimated parameter values for the mixture model of probability of mouse (*Peromyscus* spp.) infection with *Baylisascaris procyonis* and, conditional on infection, intensity of infection.

Parameter	Covariate type	Mean	95% credible interval[a]	f [b]
Predictors of probability of infection p (logit link)				
2007 year effect	Indicator	−1.21*	(−1.88, −0.60)	1.00
Sex (male=1)	Indicator	0.56	(−0.08, 1.25)	0.95
Mass	Continuous	0.36*	(0.01, 0.73)	0.98
Population density	Continuous	0.38*	(0.08, 0.73)	0.99
Predictors of mean intensity (log link)				
2007 year effect	Indicator	−0.94*	(−1.89, −0.25)	1.00
Sex (male=1)	Indicator	0.12	(−0.29, 0.74)	0.64
Mass	Continuous	0.02	(−0.21, 0.24)	0.56
Population density	Continuous	0.16	(−0.11, 0.40)	0.84

[a] Middle 95% of the parameter's posterior distribution.

[b] Probability the parameter value has the same sign as the mean; high values of f indicate the covariate likely has an effect on probability of infection or intensity.

* Value is statistically different from 0; that is, the 95% credible interval does not include 0.

scape in Indiana and the 29% prevalence that Eagan (2009) found in a similar agricultural landscape. Prevalence was much higher than the 6% observed in a large, intact forest by Page et al. (2001a).

The mixture model fit the data adequately based on the posterior predictive check. The Bayesian analysis we performed yields entire posterior distributions for model parameters, allowing us to make probabilistic statements about their values. We concluded a given parameter had an effect on the response variable if the 95% credible interval (the middle 95% of the parameter's posterior distribution) did not include 0. For the prevalence (logistic) portion of the mixture model, the 2007 year effect was different from 0 and negative, indicating lower prevalence overall in the second year of the study (Table 2). Probability of parasite infection (p_i) was positively related with surrounding human population density; 99% of the parameter's posterior distribution was positive (Table 2). P_i was also positively related to individual mouse mass and there was evidence that male mice were more likely to be infected (Table 2).

The results were similar for the intensity (Poisson) portion of the mixture model. The 2007 year effect was different from 0, with intensity lower in the second year of the study (Table 2). The relationship between intensity and human population density was positive but not strong (the 95% credible interval overlapped 0, and only 84% of the posterior distribution was positive; Table 2). Likewise, mouse mass and sex were unrelated to intensity (Table 2).

We did not find support for our hypothesis that probability and intensity of *B. procyonis* infection in mice would be negatively related to urbanization. In fact, probability of infection (p_i) was positively related to human population density (Table 2). This relationship is opposite to that described by Page et al. (2008) in the raccoon definitive host: Prevalence in raccoons was higher at rural sites than in suburban and urban sites.

One explanation for these contrasting trends in prevalence in the intermediate and definitive hosts of *B. procyonis* may be that higher raccoon densities in urban areas (Riley et al., 1998; Prange et al., 2004) more than compensate for lower *B. procyonis* prevalence in urban populations of raccoons (Page et al., 2008) yielding higher overall environmental loads of the infective parasite eggs. If the number of infective *B. procyonis* eggs in the environ-

ment increases with urbanization, the probability that small mammals encounter and become infected with the parasite should also increase. Future studies of the parasite in intermediate hosts should measure the density and infection status of latrines at each site; this measure of environmental load of *B. procyonis* is likely to be better than using raccoon prevalence for predicting prevalence in intermediate hosts.

We did not measure raccoon density or prevalence of *B. procyonis* in raccoons at the forest preserves used in this study. Therefore, we cannot rule out an alternative scenario that raccoon density or prevalence at our sites did not follow the rural to urban gradient observed by Page et al. (2008), and this unobserved information influenced the trends we observed in the intermediate host population. If prevalence in raccoons increased with urbanization at our sites because of, for example, increased density and contact rates (Gompper and Wright, 2005), we could expect the same positive relationship between urbanization and prevalence in intermediate hosts. However, all of our study sites fall within the Chicago-area landscape in which Page et al. (2008) found a difference in prevalence between rural and urban raccoon populations, so it is likely that prevalence of *B. procyonis* in raccoons at our sites follows the same pattern.

In addition to the effects of urbanization, we found evidence that male mice and heavier mice were more likely to be infected with *B. procyonis* (Table 2). Male *Peromyscus* spp. have larger home ranges than females (Wolff, 1985), possibly increasing the probability that they contact infective eggs at a latrine. Body mass has been positively correlated with survival in mice (Fleming and Rauscher, 1978; Schug et al., 1991). A longer life span may also increase the probability of infection, as well as allow more time to accumulate a large *B. procyonis* burden.

This study provides further evidence that the transmission dynamics of *B. procyonis* are impacted by urbanization. Future studies should simultaneously quantify levels of *B. procyonis* in raccoons, intermediate hosts, and in the environment (latrines) across a wide gradient of urbanization. A better understanding of how transmission changes in human-dominated landscapes will inform efforts to minimize the exposure of humans and wildlife species to this potentially deadly parasite.

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