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PATTERNS OF LATRINE USE BY RACCOONS (*PROCYON LOTOR*) AND IMPLICATION FOR *BAYLISASCARIS PROCYONIS* TRANSMISSION

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ABSTRACT: Mammals often use latrine sites for defecation, yet little is known about patterns of latrine use in many common species such as raccoons (*Procyon lotor*). Because raccoon latrines are important foci for the transmission of raccoon roundworm (*Baylisascaris procyonis*), documenting metrics of raccoon latrine use may have public health implications. Although some studies have provided evidence that multiple raccoons visit single latrine sites, exact latrine visitation patterns of raccoons have never been documented. We monitored raccoon latrine usage using proximity-logging collars placed at 15 latrine sites. We found that latrine sites were visited by multiple raccoons (range 1–7), and raccoons visited as many as six latrines during a 2-wk period. No sex differences were found in the number of latrines visited or time spent during visits. We posit that the use of multiple latrine sites by raccoons may lead to the pattern that rates of *B. procyonis* infection at latrines are greater than infection rates found in individual raccoon fecal samples. This in turn could lead to greater transmission of *B. procyonis* to paratenic hosts. Our results support the conclusion that raccoon latrines can be major foci for the infection and spread of *B. procyonis*.

Key words: *Baylisascaris procyonis*, latrine, *Peromyscus*, *Procyon*, raccoon, roundworm, zoonosis.

INTRODUCTION

Repeated defecation at the same location is a common behavior in mammals, especially carnivores (Gorman and Trowbridge 1989). Mammal latrines often play a role in communicating territoriality and space use, reproductive status, and environmental conditions (Brown and Macdonald 1985). Although it has been observed that raccoon (*Procyon lotor*) latrine sites are often located on top of logs, tree stumps, rocks, and tree limbs and at the base of trees (Kazacos and Boyce 1989, 1995) little is known about how or why raccoons use latrines. Page et al. (1999) monitored raccoon latrines with remote cameras and reported frequent visitations by raccoons and other mammals. However, it was not possible to determine the number of individual raccoons that visited each latrine or the number of latrines each raccoon visited. Although it is plausible that raccoons use latrines for chemical communication in the same manner as other mammals (Eisenberg and Kleiman 1972), the exact function of raccoon latrines is still unknown.

Many carnivore species deposit feces in latrines near territorial borders; these latrines often function to demarcate and defend territories (Kruuk 1972). Alternately, some species concentrate latrines in the core of their home range (Gorman 1990; Sillero-Zubiri and Macdonald 1998), which may be a more effective strategy to advertise territorial boundaries in species with large home ranges (Gorman and Mills 1984). In contrast to species with strong patterns of territoriality, for raccoons, territorial defense has only been observed in males, and this occurs only in low-density populations (e.g., Gehrt et al. 2008; Pitt et al. 2008). In high-density populations, both males and females have largely overlapping home ranges (Prange et al. 2004). Given that raccoons are not strongly territorial, why are raccoon latrines a common occurrence? Raccoons may use latrines to communicate something other than territorial boundaries. For example, carnivore latrines commonly play some role in mating and mate defense (Roper et al. 1986), and many species exhibit seasonal and sex differences in latrine use that are consistent with latrine usage for olfactory communication (Kruuk 1972; Woodroffe and Lawton 1990; Jordan et al. 2007).

Patterns of latrine use by raccoons are also important for reasons of public health, because these sites are often infested with eggs of raccoon roundworm (*Baylisascaris procyonis*; Page et al. 2005). *Baylisascaris procyonis* is a common nematode that affects raccoons and over 90 other species of wild and domestic animals (Kazacos and Boyce 1989). When *B. procyonis* eggs are ingested by a nonraccoon host, the larvae can migrate to the brain and eyes, causing severe disease and death (Wise et al. 2005; Shafir et al. 2006). Infective *B. procyonis* eggs can remain viable in the environment for 10 yr or more (Kazacos 1983, 2001) and sites with high concentrations of eggs, such as raccoon latrines, are believed to be particularly important for spreading infection (Page et al. 1998, 1999). *Baylisascaris procyonis* is particularly harmful to young children and has now been classified as an emerging helminthic zoonosis (Sorvillo et al. 2002). Because raccoons are the primary host species for *B. procyonis*, further knowledge about the reasons why raccoons deposit feces in latrines is important for understanding the potential risk of *B. procyonis* transmission to humans and other animals.

There are two major pathways of *B. procyonis* transmission in raccoons. The first is direct ingestion of infected eggs, which occurs when juvenile raccoons ingest eggs found on the fur of their mother or contact eggs at contaminated dens or latrine sites (Kazacos 2001; Wise et al. 2005). Once a juvenile raccoon has become infected, this triggers an immune response that greatly reduces the likelihood of repeated infection via direct ingestion of eggs (Kazacos 2001). For this reason, naïve juvenile raccoons are the most susceptible to infection. Higher rates of *B. procyonis* infection in juveniles have been found in multiple studies, and these juveniles may be particularly important in driving population-level infection rates (Snyder and Fitzgerald 1985; Page et al. 1999, 2009a). The second major transmission pathway is the ingestion of *B. procyonis*–infected hosts, which are typically small rodents such as deer mice (*Peromyscus* spp.; Kazacos 2001). Rodents often become infected when foraging for seeds found in raccoon scat (Page et al. 2001a, b). These rodent intermediate hosts are crucial for maintaining *B. procyonis* infections in adult raccoons.

Quantifying latrine usage in raccoons is important because the *B. procyonis* prevalence rates at latrines should vary depending on the number of infected raccoons that use that latrine. This in turn will affect the degree to which *B. procyonis* is transmitted to intermediate hosts or humans. In an earlier study of *B. procyonis* prevalence in Ned Brown Forest Preserve, Illinois, USA, Page et al. (2009a) found that 27% of necropsied raccoons were infected with *B. procyonis* and 15% of fecal samples were positive. The *B. procyonis* prevalence at latrine sites was slightly higher than the prevalence in fecal samples taken from captured raccoons in the same area (May–June, 10% positive; October–November, 30% positive; L. Page pers. comm.). It is unknown if this difference was driven by repeated feces deposition from the same individual or by multiple raccoons visiting each latrine site. In this study, we document and quantify latrine usage in a high-density urban raccoon population to determine if raccoon latrine visitation patterns could alter rates of *B. procyonis* at latrine sites and thus have implications for human health. Because raccoons in this population do not exhibit clear territorial behavior, we hypothesized that latrine function is not related to territoriality and that latrines play some other role in olfactory communication between raccoons. If latrines play a role in raccoon communication, latrine visitation patterns can be used to understand patterns of sociality, and these focal points for raccoon social interactions could also function as focal points for disease transmission. If true, we predict that 1) latrine sites should be visited more frequently than control sites, 2) each latrine should be visited by multiple raccoons, and 3) individual raccoons should visit multiple latrines.

MATERIALS AND METHODS

We investigated latrine use in the Ned Brown Forest Preserve in Cook County, northeastern Illinois, USA. More specifically, we monitored latrines in the Busse Woods portion of the forest preserve, which is the same area where *B. procyonis* levels were documented by Page et al. (2009a, 2011). The raccoon population in the preserve has been studied since 1995, and much information has been published regarding the demography, genetics, and social system of this population (Prange et al. 2003, 2004, 2011; Gehrt and Prange 2007; Hauver et al. 2010). This population is characterized by high raccoon densities (50/km^2), extensive sociality between males, and a lack of territoriality (Prange et al. 2003, 2004, 2011; Hirsch et al. 2013a, b). During June 2004, we fitted 42 raccoons (20 male, 22 female) in a 20-ha portion of Busse Wood with proximity-logging radio collars (Sirtrack Ltd., Havelock North, New Zealand). These raccoons represented close to 100% of the adult raccoon population in the core study area in the preserve, although the proportion of collared adults in the core area decreased over time (Prange et al. 2011). Proximity collars emit a unique identification code over an ultrahigh frequency (UHF) channel, which is detected by other collars. When two collars are within 1–2 m, the collars record the raccoon identity and duration of the association (Prange et al. 2006). The information downloaded from these collars can be used to determine patterns of social association between raccoons (Hirsch et al. 2013a, b). We also manually radio tracked all raccoons to determine if the latrines fell within their home ranges. A minimum of 30 locations per season for each raccoon were used to determine home range size (Seaman et al. 1999).

We placed proximity-logging collars at latrine sites to record the frequency and duration of raccoon latrine visits. Because UHF signals can be blocked by objects in the field, we placed proximity detectors beneath logs at latrine sites and tested the UHF ranges to make certain that raccoon collars were detected when the raccoon was on top of or immediately next to the latrine. During 2004 we located five raccoon latrines and monitored raccoon activity at these locations for 2 wk (1–8 and 13–20 October 2004). During 2005 we located 10 latrines and monitored them for 2 wk (18 October–2 November 2005). The 15 latrines were separated by 5–575 m. We also placed proximity-logging collars at 21 control locations to determine if raccoons visited latrines more often than control locations (five during 2004 and 16 during 2005). Collars at these control locations were placed at fallen logs or tree bases, which simulated locations where latrines were found. Statistical tests were performed using JMP 5.1 (SAS Institute, Cary, North Carolina, USA).

RESULTS

After exclusion of raccoons whose home ranges did not overlap with the latrine sites, died before monitoring of the latrines, or had malfunctioning collars during this period, 25 raccoons were available to visit the latrines during 2004 (12 males, 13 females) and 2005 (13 males, 12 females). On average, each latrine during 2004 or 2005 was visited by 4.1 raccoons ($\pm$1.7 SD, range=1–7). Each latrine was visited by raccoons an average of 9.1 times over the 2-wk study periods (range=2–20, SD=5.26), which was significantly more than control locations (mean=4.2, analysis of variance [ANOVA], $F_{1,35}=8.10$, $P=0.007$). The average time lag between successive raccoon visits was 24.3 hr (range=8 sec to 160.7 hr, SD=32.6 hr). Raccoon latrine visits were generally brief (mean=24.2$\pm$27.4 sec, range=1–135 sec), and although males spent more time at latrines than females, this result was not statistically significant (females=20.2$\pm$24.8 sec, males=8.1$\pm$29.4 sec, ANOVA,

$F_{1,135}$ 2.91, $P=0.09$). The average number of latrines visited by individual raccoons increased during 2005 because twice as many latrines were monitored. Raccoons visited an average of 0.9±1.1 latrines during 2004 (range=0–3), and 2.15±2.0 latrines during 2005 (range=0–6). No sex differences in the number of latrines visited were found (number of latrines visited per individual during 2004–2005: females=2.9±1.7, males=3.2±2.1, ANOVA, $F_{1,18}$=0.116, $P=0.74$). Latrines used by the same raccoon were spaced a maximum of 458 m apart. Typically only one or two new scats were deposited over the 2-wk period at each latrine (mean=1.5±0.71).

DISCUSSION

If raccoon latrines primarily play a role in territoriality, we predicted that raccoons in this high-density population would not frequently use latrines. The opposite pattern was observed, and individual raccoons used as many as six latrines in a 2-wk period, spaced as far as 458 m apart. Raccoon latrine sites were visited by up to seven different raccoons during the 2-wk periods. We found no significant sex differences in visitation rates or length of time spent at the latrines. This result suggests that raccoons were not using latrines to communicate reproductive status during the study period. However, we did not monitor latrines during the mating season, which is when we would expect sexual differences to be expressed most strongly. Even if latrines are foci for sexual communication, the frequent use of latrines outside the mating season supports the hypothesis that latrines serve other functions as well. We also found no differences in the number of latrines used by males and females. Although it is plausible that males and females use latrine sites differently, we found no strong evidence of sexual differences in this study. In contrast, a previous study documented greater *B. procyonis* infection rates in males in the same raccoon population, which could conceivably be influenced by differential latrine usage during the mating season (Page et al. 1999). We suggest that additional studies are needed, particularly during the mating season, to better elucidate the potential social or communicatory functions of raccoon latrine sites.

Smyser et al. (2010) found that the average number of fecal samples found at raccoon latrines averaged 1.7 (range 1–30). The number of scats deposited per latrine in our study was similar (1.5 deposits per 2-wk period). A greater number of fecal deposits should result in higher *B. procyonis* infection rates, but because *B. procyonis* eggs can remain viable for years, the probability of *B. procyonis* at a latrine site should also be related to the longevity (or total usage over time) of the latrine. It is plausible that latrine usage and defecation rates may be significantly higher during warmer months, because the seasonal increase in anthropogenic foods in the forest reserve leads to greater activity and food ingestion (Prange et al. 2004). If correct, the latrine usage patterns in this study are a conservative estimate, and latrines may receive more raccoon visitors and fecal deposits during months when more food is available. However, *B. procyonis* presence typically peaks during October–November; thus, other factors such as the demographic structure of the raccoon population may be more important drivers of *B. procyonis* infection rates than the number of fecal deposits (Kazacos 2001; Page et al. 2005). Because we were not able to locate all latrines within the home ranges of our study raccoons, the number of latrines used per individual was likely higher than the numbers we report.

In addition to food quantity, raccoon diet can play a role in *B. procyonis* transmission. Page et al. (2009a) found the highest levels of *B. procyonis* in agricultural areas where raccoons frequently raided corn fields. The remaining corn kernels found in raccoon feces provide an excellent and highly desired food resource for rodents (Page et al. 2001c). In contrast, the urban raccoons in our study area eat large amounts of refuse and fewer fruits and seeds. This may provide less food for rodents, which could help explain the lower rates of *B. procyonis* in this urban study area compared to agricultural sites. In addition, because urban raccoons may be less reliant on vertebrate prey, urban raccoons should consume fewer rodents that are potentially infected (Prange et al. 2004; Page et al. 2009a). Even though *B. procyonis* prevalence is higher in raccoons living near agricultural fields, prevalence of *B. procyonis* in this urban population (27% of captured individuals: Page et al. 2009a) still poses a risk to public health.

The presence of multiple raccoons at a latrine site could help to explain the results of Page et al. (2005), who found *B. procyonis* in up to 30% of latrines, whereas the *B. procyonis* prevalence in raccoon fecal samples in the same population averaged 15%. Alternately, multiple fecal deposits by the same individual could result in higher infection rates at latrines than individual fecal samples. We posit that future investigators should use remote cameras pointed at latrine sites or genetic analyses to determine the exact number of fecal deposits left by individual raccoons. Regardless of the mechanisms, the pattern that multiple raccoons visit the same latrine, and the fact that one raccoon can deposit *B. procyonis* at multiple locations throughout its home range, should lead to increased transmission. For example, if raccoons exclusively used one latrine site per animal, the spatial distribution of infection risk could have been much smaller than the patterns seen here. By depositing their feces at multiple locations, it is easier for raccoons to spread *B. procyonis* eggs to the home ranges of other raccoons and paratenic hosts. This is particularly important when a significant proportion of the raccoon population is not yet infected with *B. procyonis* (e.g., populations with juvenile-biased age structures). The use of multiple latrine sites will also increase the number of potential infection sites for intermediate hosts. *Peromyscus* spp., which are believed to be the most important intermediate host for *B. procyonis* (Page et al. 2001a,b), have been observed to cache seed-laden feces inside or close to their nests, and this increased time spent in contact with raccoon feces leads to a greater probability of *B. procyonis* infection (Page et al. 2001b). *Peromyscus* spp. have relatively small home ranges (average 590 m^2; Wolff 1985) compared to raccoons (Ned Brown raccoon home range size=25.2–52.8 ha; Prange et al. 2004); thus, if individual raccoons used only one latrine, they would be able to provide infected fecal material to only a small proportion of mice in their home range. By distributing their feces to numerous latrine locations, raccoons are spreading infected material to many more *Peromyscus* spp. home ranges.

The pattern of multiple raccoons visiting the same latrine should also lead to greater rates of *B. procyonis* transmission due to changes in rodent behavior. When raccoon latrines contain undigested seeds, these sites attract foraging rodents (Page et al. 1999, 2001a, b). When this food resource is continually replenished through additional fecal deposits, these latrine sites could become predictable sources of food for rodents, and rodents may visit these sites more frequently than other areas where resource availability is unpredictable. Given the high transmission rates of *B. procyonis* to mice at raccoon latrine sites, these repeated visitations probably increase the likelihood of raccoons transmitting *B. procyonis* to intermediate hosts. As the number of individual raccoons that use a particular latrine increases, the likelihood that that a latrine contains *B. procyonis* eggs will also increase (Smyser et al. 2010). Therefore, even when *B. procyonis* is found at a relatively low frequency, the proportion of infected latrines can be higher than the proportion of infected individuals if infected individuals deposit feces at numerous latrines. Changes in raccoon behavior may, in turn, affect the prevalence of *B. procyonis* at latrine sites. For example, an increase in home range overlap and an increase in the number of individuals visiting the same latrines could partially explain the increase in *B. procyonis* in a raccoon population that was experimentally provisioned with artificial food resources (Wright and Gompper 2005).

The patterns we observed have potential implications for the management of *B. procyonis*. The use of latrines by multiple raccoons is consistent with previous studies showing that raccoon latrines are focal points for infection, and supports the conclusion that these sites are dangerous to humans (Page et al. 2005, 2009b). Because raccoons can transmit rabies virus as well as *B. procyonis*, the distribution of baits containing recombinant rabies vaccines (Johnston et al. 1988) or anthelmintic drugs (Smyser et al. 2013) is increasingly being used as a public safety measure. The pattern of latrine use we observed indicates that latrine sites and the structures on which they are typically found (e.g., logs, stumps, etc.) may be effective locations to deploy baits, helping to more efficiently direct these disease controls to the target species.

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