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Long-Tailed Macaques (*Macaca fascicularis*) in Urban Landscapes: Gastrointestinal Parasitism and Barriers for Healthy Coexistence in Northeast Thailand

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Abstract. Gastrointestinal parasites have diverse life cycles that can involve people, animals, and the environment (e.g., water and soil), demonstrating the utility of One Health frameworks in characterizing infection risk. Kosumpee Forest Park (Thailand) is home to a dense population of long-tailed macaques (*Macaca fascicularis*) that frequently interact with tourists and local residents. Our study investigated the presence of zoonotic parasites, and barriers to healthy co-existence by conducting stool analysis on macaques ($N = 102$) and people ($N = 115$), and by examining risk factors for infection with a household questionnaire ($N = 95$). Overall, 44% of macaques and 12% of people were infected with one or more gastrointestinal helminths, including *Strongyloides* spp., *Ascaris* spp., and *Trichuris* sp. An adults-only generalized linear mixed model identified three factors significantly associated with human infection: household size, occupational exposure, and contact with macaque feces at home. Participants identified both advantages and disadvantages to living in close contact with macaques, suggesting that interventions to improve human and animal health in Kosumpee Forest Park would be welcome.

INTRODUCTION

Long-tailed macaques (*Macaca fascicularis*) are distributed across much of mainland Southeast Asia and many of its islands.[1] In Thailand, long-tailed macaques are the most common and widespread of six sympatric macaque species, occupying 91 known sites across the country.[2–4] Similar to other Southeast Asian populations, wild macaques in Thailand live in isolated pockets because of anthropogenic land-use modifications that caused habitat fragmentation, such as urban expansion and the conversion of natural forests to agricultural land.[1] Macaque populations successfully occupy a variety of natural habitats, such as rainforest, riverine, mangrove, and coastal areas, and often reside along forest edges, putting them in close proximity to human settlements, where their likelihood of interaction with people is higher than that of other primate species.[1] The frequency of these interactions is especially high when wild long-tailed macaques reside in city centers, temples, and forest parks frequented by local and/or foreign tourists.

Most Thai people observe Theravada Buddhism, which promotes offering food to temple macaques to gain spiritual merit. Such food provisioning can have unintended consequences such as increasing macaque population densities above the carrying capacity of an environment and encouraging macaques to seek food from people rather than to forage naturally. Together, these factors drive conflicts (e.g., crop raiding, property damage, and physical injury) that negatively impact healthy human–macaque coexistence. Furthermore, macaques and people living in close proximity risk zoonotic pathogen transmission via contaminated food and/or water, infected vector species, aerosols, direct contact (e.g., via wounds or fecal-oral transmission), and through the buildup of infective gastrointestinal parasite life stages in shared environments.[1,5,6] Nonhuman primates may carry or be affected by pathogens that also infect humans, including filoviruses such as Ebola,[7] herpes B virus,[8] tuberculosis,[9] norovirus,[10] and simian retroviruses.[11] A particular area of risk in a shared natural environment is the possibility of transmission of gastrointestinal parasites shed in feces[6] including *Giardia, Cryptosporidium*,[12] and various helminths.[13] Few studies to date however have systematically assessed this risk.

Over the last few decades, gastrointestinal parasitism has declined significantly in Thai people, due in part to a national program aimed to promote anthelmintic use, to improve sanitation infrastructure, and to improve public awareness.[14] According to a national survey conducted in 2009, 18% of 15,555 participants were infected with one or more helminths, with the highest prevalence (26%) observed in the northeast where *Opisthorchis viverrini*, *Strongyloides stercoralis*, hookworms, and intestinal flukes were regarded as regional priorities.[15] A study conducted in 2008[16] reported that long-tailed macaques from two northeastern forest parks (Kosompee and Don Chao Pu) were infected at far higher levels (up to 75% prevalence) than adjacent human populations. Two potentially zoonotic nematodes, *Strongyloides fuelleborni* and *Trichuris* sp., were significantly more prevalent in macaques dependent on human-provisioned food versus those that foraged naturally.[16] Gastrointestinal parasitism in people and macaques is influenced by a variety of factors, including diet, age, population density, and contact with infected individuals in shared environments.

Issues negatively impacting healthy human–macaque coexistence are likely to be exacerbated because 1) the human

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population is increasing, 2) a national strategy to sustainably manage macaque populations is still in development, and 3) food provisioning is connected with cultural, religious, and economic (i.e., tourism) well-being for people. Baseline observations of pathogen prevalence and human–macaque interactions are essential for informing strategies and policy decisions for organized, sustainable, and humane conflict mitigation in high contact areas. Anthropogenic changes to natural and human-built environments continue to influence human and animal health, and for this reason, we used an interdisciplinary One Health approach to characterize relationships between people and macaques in northeastern Thailand. As part of a 3-year project addressing human–primate conflict and coexistence in Thailand, the goals of this study were 1) to characterize the prevalence and intensity of gastrointestinal parasites in people and long-tailed macaques with overlapping living space, and 2) to investigate human, animal, and environmental barriers to healthy human–macaque coexistence.

METHODS

Study site. Kosumpee Forest Park is a 0.2-km^2 wildlife refuge located in Kosum Phisai district, Maha Sarakham Province in northeast Thailand (Figure 1; lat. 16°15′N, long. 103°04′E). This mixed deciduous forest is home to a population of approximately 730 free-ranging long-tailed macaques, distributed among five social groups.[17] Average group sizes ranged between 67 and 217 individuals (averages based on three high-confidence counts). In addition, there were approximately 18 adult extra-group males often observed traveling alone in the village area to the outer boundary of the population's range. These males were also observed to move in and out of the groups on occasion. One community, made up of three smaller villages, surrounds the southern edge of the park and is home to approximately 1,077 households (4,235 residents).[18] A Buddhist monastery and secondary school are also located next to this park boundary. Agricultural land used by residents for cultivation of rice and

FIGURE 1. (**A**) Macaque facial injury (Credit: Randall C. Kyes), (**B**) macaques line a road separating Kosumpee Forest Park from the surrounding villages (Credit: Gemina Garland-Lewis), (**C**) child attempting to feed a macaque (Credit: Randall C. Kyes), and (**D**) macaques swarm a van filled with tourists and food (Credit: Randall C. Kyes). This figure appears in color at www.ajtmh.org.

other cash crops is located north of the park, east across the Chi River, and directly to the west. Food supplementation from forest staff and especially park visitors paired with severe habitat fragmentation has resulted in a macaque population density (approximately 3,670 individuals/km^2) that far exceeds the park's carrying capacity and what can be supported by natural food sources.[17] Known issues in this area include frequent fighting between macaques both within and among groups, naive/inappropriate visitor behavior (e.g., teasing macaques with food), and macaques raiding food from houses and gardens (Figure 1A–D).

The study was conducted over a 3-month period from September 18 to December 23, 2016. During this period, our study team worked in the Kosumpee Forest Park and the adjacent villages to document barriers to healthy coexistence between people and macaques. That time period denotes the end of the rainy season, with temperature ranging from 22.3 to 30.8°C and the average monthly precipitation decreasing to 72 mm versus 266 mm the previous month.[19] Four researchers documented human–macaque interactions over an 84-day period and collected fecal samples from identified macaques. Macaque-ranging limits outside the forest park were established by systematically interviewing homeowners along roadways to document macaque sightings within the previous 12 months; ranges denote the furthest sighting from the park boundary before three consecutive negative responses.[17] Four researchers recruited local residents from the surrounding villages in October 2016 to provide stool samples for parasitological analysis and to participate in a household survey focused on human health, the built environment (artificial environments built by humans), and animal contact. This article was written following Checklist for One Health Epidemiological Reporting of Evidence (COHERE) standards for reporting One Health epidemiological studies.[20]

Macaque fecal analysis. To collect identifiable samples, each macaque sampled was photographed and entered into a photographic directory (a database containing face shot, age/sex designation, and unique morphological features) that we had created to assist in identifying group members and which allowed for subsequent confirmation of social groups.[17] Direct counts of group members were typically conducted in the early morning as groups first entered open areas in the park area. Standard morphological descriptors were used to estimate age so that very small monkeys with a black "natal" coat were categorized as infants (< 1 year), juveniles (1–3 years) were distinguished based on relative small size, and all others were categorized as subadults or adults. We aimed to collect biological samples within the park from 15 to 25 macaques per social group for parasitological analysis. Fresh feces eliminated from identified macaques were immediately collected from the ground, placed in collection tubes containing 10% formalin, sealed, labeled, and stored at room temperature until they could be transported to a diagnostic laboratory at Khon Kaen University at the end of the study period. Two grams of feces from each animal was analyzed using the formalin–ethyl acetate sedimentation technique.[21] Three slides per sample (100 µL per slide) were examined at ×10 and ×40 magnification, and animals were considered parasitized if ova, cysts, or larvae were observed on one or more slides. Infection intensity was approximated by quantifying ova, cysts, or larvae per gram of feces. This laboratory analysis allowed us to identify parasite life states to the genus level, but not always to the species level.

Human surveys and stool analysis. The total human study area comprised a group of three villages adjacent to the southern border of Kosumpee Forest Park and bordered by major thoroughfares on the eastern, western, and southern edges. We separated our study area into three strata with the intention of oversampling residents living closest to the forest with greatest exposure to macaques (Figure 1; strata 1 – $N = 50$; strata 2 – $N = 36$; strata 3 – $N = 15$). Major roadways within each stratum delineated neighborhoods, within which proportional sampling occurred. If a resident was unavailable after repeated visits, then recruiters proceeded to the next adjacent home.

Before recruitment, the research project was introduced at a community meeting with village leaders and advertised via loud speakers located around the villages. Two teams, each composed of one Thai translator and one qualitative researcher, recruited household members to complete a questionnaire and provide a stool sample. Households were excluded if no resident was willing to answer questions on behalf of the family, if no adult (≥ 21 years) was available to consent or capable of understanding the consent form, if the adult was unwilling to provide a stool sample, or if no resident was home after three attempts over multiple days. Questionnaires were administered in Thai and included a semi-structured section that was audio-recorded, transcribed, and translated to English. Topics included household health and demographics (e.g., diet, medical history, and income), contact with animals (e.g., livestock, pets, macaques, and other wildlife), and the built environment (e.g., water sources, soil exposure, and protection from disease vectors). We asked the adult respondent and one child aged 4–13 years (if resident) to each provide a stool sample. Samples were stored in sealable, pre-labeled tubes containing 10% formalin and analyzed at Khon Kaen University using the same protocol as for macaques.[21]

Statistical methods. This dataset was analyzed using SAS (version 9.4; SAS Institute, Inc., Cary, NC) and tested for significance using a 5% cutoff. We used a two-sided Fisher's exact test to detect differences in parasite prevalence between age groups, sexes, and social groups (excluding extra-group males), using the Freeman–Halton extension to expand contingency tables when necessary. The Mann–Whitney *U*-test was used to detect intensity differences between age groups and sex, and the Kruskal–Wallis *H*-test to assess differences between social groups. Semi-structured interview questions were transcribed, translated to English, and then independently reviewed by two authors to assign content themes. Potential risk factors for human parasitism, including information about contact with macaques, were transformed into categorical variables and assessed by generalized linear mixed (GLM) models with infection status as the outcome. Independent variables were assessed by univariate analysis and those with a P-value < 0.2 were included in the GLM models. Two models were assessed: 1) children nested at the household level and 2) adults only. Respondents who completed the questionnaire but provided no stool sample were excluded from the analysis. The strength of association between risk factors and infection status was reported as an odds ratio (OR) with 95% confidence interval (CI).

Research team. Our research team comprised multiple disciplines, including primatology (R. C. K. and S. K.), human medicine (P. R. and H. N.), veterinary medicine (S. K.), anthropology (V. R.), parasitology (S. K., N. P., and J. M. S.), conservation biology (G. G. L., R. C. K., and P. K.), and environment/resource studies (P. T., T. T., P. K., and E. G.). The multidisciplinary approach allowed the team to engage community stakeholders with various interests pertaining to human and/or macaque health, community infrastructure, and forest management.

Ethics statement. The conduct of this study was approved by the National Research Council of Thailand (project ID: 2016/048). This study received Institutional Review Board (IRB) and Institutional Animal Care and Use Committee (IACUC) approval for human and animal research subjects through the University of Washington (protocol numbers 51546 and 3143-04, respectively). It also received IRB and IACUC approval through Mahasarakham University (protocol numbers 037/2016 and 0009/2016, respectively). This research complied with the American Society of Primatologists' "Principles for the Ethical Treatment of Nonhuman Primates." At the local level, the research was approved by leaders from the three villages making up the study site and by administrators from Kosum Phisai Hospital and Kosumpee Forest Park. Human participants were informed that their participation was voluntary, that they could withdraw at any time, and that questionnaire responses and stool analysis results would be kept confidential. Participants were informed of their stool results and offered treatment at the Kosum Phisai Hospital, if necessary. Overall study results were reported to local residents/participants at an open community meeting at the conclusion of the study period.

RESULTS

Macaque fecal analysis. We collected fecal samples from 102 of the 734 (14%) macaques estimated to live in Kosumpee Forest Park. Sampled macaques were disproportionately female (70 of 102; 69%), and were mostly adults (69 of 102; 68%), followed by juveniles (17 of 102; 17%), subadults (10 of 102; 10%), and infants (six of 102; 6%). Fecal specimens were collected from 10% to 25% of macaques in each social group except for extra-group males (6%). Overall, 35% (36 of 102) of macaques were infected with one or more gastrointestinal nematodes, which included hookworms, *Trichuris* sp., *Ascaris* spp., and *Strongyloides* spp. (Table 1). Parasite species richness was low in our study, as we detected a single parasite species in just more than half of infected macaques (55%), and two or three parasite species (31% and 14%, respectively) in the remainder. Nonpathogenic protozoa observed in these primates included *Entamoeba coli* (27%) and *Endolimax nana* (2%). In this study population, overall infection prevalence was higher in males (53%, 17 of 32) than in females (27%, 19 of 70, $P = 0.01$) and in infants/juveniles compared with subadult/adults. *Trichuris* sp. and hookworm spp. prevalence was significantly higher in the infant/juvenile group (Table 1). Hookworm prevalence also differed among social groups ($P = 0.037$) and was significantly higher in males (40.6%, 13 of 32) than in females (14.3%, 10 of 70; $P = 0.005$). Overall infection prevalence of the other helminth species did not differ by social group or sex. Our estimate of infection intensity was generally consistent for parasite species by age, sex, and group, except for hookworm intensity, which was significantly higher in immature (infant/juvenile) macaques compared with subadults and adults ($P = 0.02$).

Human surveys and stool analysis. Of the 170 households visited, 22 homeowners were not home after repeated visits, 47 were unwilling to take part, and 101 agreed to participate in our study. The most common reasons for refusal were aversion to providing a stool sample or unwillingness to sign the Thai language consent form. Of the recruited households, one-fifth provided a child's stool sample (20 of 101) and almost all provided an adult stool sample (95 of 101). Six households where an adult completed the questionnaire did not provide a stool sample despite repeated visits and were removed from the analysis.

Adult respondents were predominantly female (64% of 95), had completed postsecondary education, lived in a household with a median of four residents, and were evenly distributed among income quintiles (Table 2). Putative risk factors for gastrointestinal infection in people included raw meat or fish consumption, washing hands with water only, and working in gardens or farms. Approximately half of the respondents owned dogs and approximately one-third owned livestock. Many reported seeing macaques on their property or in their home (81%), but few had ever been bitten or scratched (4%) and few reported interactions between macaques and pets (6%).

Overall, 12% of 115 participants were infected with one or more gastrointestinal parasites, with *Strongyloides* spp. present most often, followed by *O. viverrini*, *Taenia* spp., and *Ascaris lumbricoides* (Table 3). Parasite species richness in the human study population was similar to that of macaques, with one participant infected by three parasite species and all others infected with a single species. Questionnaire responses indicated that 10 participants had been infected in the past, that many were unsure if they had been infected (30

Table 1

Prevalence and intensity of gastrointestinal parasites in immature (infant/juvenile) and adult (subadult/adult) long-tailed macaques residing in Kosumpee Forest Park, Thailand (*N* = 102)

	Subadults/adults (*N* = 79)				Infant/juvenile (*N* = 23)				Overall (*N* = 102)				Comparison	
		Intensity*				Intensity*				Intensity*			Prevalence†	Intensity‡
Parasite	*n* (%)	Mean	Median	SD	*n* (%)	Mean	Median	SD	*n* (%)	Mean	Median	SD	(*P*-value)	(*P*-value)
Trichuris sp.	10 (13)	6.8	3.3	8.6	10 (44)	79.5	10.8	157	20 (19.6)	43.2	5.8	114	**0.02**	0.053
Strongyloides spp.	1 (1.3)	2	2	–	1 (4.3)	3	3	–	2 (2.0)	2.5	2.5	2–3	0.40	0.317
Hookworms	10 (13)	65.8	35.0	72.9	13 (57)	911	112	1,193	23 (23)	543	80	981	**< 0.001**	**0.020**
Ascaris spp.	1 (1.3)	40	40	–	0 (0)	–	–	–	1 (1.0)	40	40	–	–	–
Overall infection	21 (27)	–	–	–	15 (65)	–	–	–	36 (35)	–	–	–	**0.001**	–

SD = standard deviation. Bold font indicates significance (*P*-values< 0.05).
* Eggs or larvae per gram feces.
† Fisher's exact test.
‡ Mann–Whitney *U*-test.

TABLE 2

Demographics, animal contact, and built environment characteristics of respondents and their households near Kosumpee Forest Park, Thailand

Descriptor	*N* (%)	Univariate odds ratio (95% confidence interval)
Participant demographics (*N* = 115)		
Female	74 (64)	REF
Male	41 (36)	1.18 (0.35–3.92)
Age (years)		
4–13	20 (17)	N/A
18–64	67 (58)	1.05 (0.30–3.70)
> 65	28 (24)	REF
Highest education degree (adults)		
No degree	36 (38)	5.43 (1.05–28.2)
High school/GED	19 (20)	5.07 (0.82–31.4)
Postsecondary	40 (42)	REF
Human household factors (*N* = 95)		
Household size (# residents/dwelling)		
1–3	43 (45)	REF
4–6	49 (52)	0.23 (0.06–0.89)
7–9	3 (3)	1.70 (0.14–20.8)
Household income (Thai baht)		
< 9,210	16 (17)	REF
9,221–14,450	14 (15)	2.41 (0.44–13.1)
14,451–21,533	15 (16)	0.67 (0.09–4.8)
21,534–34,775	11 (12)	0.43 (0.037–5.04)
> 34,775	16 (17)	N/A
RF/DK	23 (24)	N/A
Handwashing technique*		
Soap and water	80 (84)	1.15 (0.23–5.7)
Hand sanitizer	10 (11)	1.52 (0.29–8.04)
Rinse with water	42 (44)	0.45 (0.13–1.56)
Other	45 (47)	1.13 (0.36–3.52)
Weekly Raw meat/fish consumption*		
Beef	29 (31)	1.89 (0.59–6.05)
Pork	2 (2)	6.15 (0.36–105)
Fish	1 (1)	N/A
Gardening/crop production		
Yes	47 (49)	1.76 (0.54–5.70)
No	48 (51)	REF
Environmental household factors		
Distance to Forest Park†		
Strata 1	49 (52)	0.74 (0.13–4.4)
Strata 2	31 (33)	1.9 (0.34–10.7)
Strata 3	15 (16)	REF
Drinking water source*		
Bottles	72 (76)	0.51 (0.15–1.73)
Tank/cistern	23 (24)	1.9 (0.58–6.54)
City supplied	2 (2)	6.15 (0.36–105)
Other (*e.g.*, well and spring)	6 (6)	N/A
Food waste disposal*		
Trash pickup	71 (75)	2.24 (0.46–10.8)
Fed to animals	31 (33)	0.52 (0.13–2.0)
Composted	16 (17)	2.3 (0.62–8.5)
Window screens		
All windows	16 (17)	N/A
Some	25 (26)	1.18 (0.33–4.3)
None	49 (52)	REF
RF/DK	5 (5)	N/A
Animal household factors		
Pet ownership (any)*	56 (60)	0.44 (0.14–1.4)
Dog(s)	41 (43)	0.47 (0.13–1.6)
Cat(s)	14 (15)	0.94 (0.19–4.8)
Other (e.g., bird, fish, and reptiles)	11 (12)	0.54 (0.06–4.6)
Livestock ownership (any)*	29 (31)	1.32 (0.40–4.4)
Cattle	2 (2)	N/A
Poultry	26 (27)	1.59 (0.48–5.3)
Swine	5 (5)	4.3 (0.66–28.7)
Macaques and/or feces at home		
Yes	38 (40)	4.8 (0.99–23.3)
No	57 (49)	REF

(continued)

TABLE 2

Continued

Descriptor	*N* (%)	Univariate odds ratio (95% confidence interval)
Occupational animal contact		
Yes	14 (15)	2.76 (0.71–10.7)
No	77 (82)	REF
Missing	4 (4)	N/A

N/A = not applicable; REF = referent group; RF/DN = refuse/do not know.
* Multiple responses were permitted; REF = no.
† See Figure 1.

of 101), and that 22 households used anthelmintics to treat gastrointestinal parasites either once previously or routinely. Parasite infection was not associated with respiratory symptoms ($P = 0.25$) or gastrointestinal discomfort ($P = 0.21$). Univariate analysis identified seven variables associated with infection status, using the cutoff of $P < 0.2$ (Table 2). These were household size, handwashing using water only, presence of monkeys or their feces at home, pet ownership, swine ownership, highest education degree (adults), and occupational exposure to animals (adults). Stratum and other environmental household factors, household ages, gardening, and raw meat consumption were not statistically significant. In the household GLM model (including both children and adults), only one variable was significantly associated with parasite infection. Residents in households with four to six occupants experienced odds of infection seven times lower than homes with one to three occupants. In the adults-only GLM model, those residing in homes with four to six people experienced a 20-fold decrease in infection odds versus those with one to three people; those with occupational exposure to animals experienced a 16-fold decrease over those with no exposure; and those with macaques or their feces at home had a 14-fold increase in infection (Table 4).

Human attitudes toward macaque contact. Data collected through the audio-recorded section of the questionnaire indicated that awareness of zoonotic disease transmission was poor, with half of respondents aware that diseases could spread from animals to people or that animals could carry asymptomatic infections. Most respondents did not believe that diseases could pass from infected people to animals (78%). Few adults (1%; one of 101) or their children (4%; two of 56) had physical contact with macaques; however, 48% (47 of 99) could remember an incident where a community member or tourist was injured by a macaque.

Respondents commonly attributed these incidents to inappropriate human behavior (e.g., teasing/harassing macaques) or to lack of knowledge (e.g., tourists who fed macaques by hand rather than leaving food on the ground). Respondents emphasized the importance of respecting macaques, not only to avoid physical injury but also because mishandling them led to bad karma and future unfortunate events. Most believed that living next to Kosumpee Forest Park offered advantages (74%; 64 of 86), such as opportunities to watch or feed macaques, enjoy nature, forage in the forest, and live in a locale that attracted tourism. However, 95% (89 of 95) identified disadvantages to living with macaques; these focused on property destruction, food theft, and risk of disease transmission. Respondents who affirmed recent changes in macaque behavior over time described increased "naughtiness" such as entering the villages and individual homes, using power lines to travel within villages,

TABLE 3

Prevalence and intensity of gastrointestinal parasites in children (< 18 years) and adults (≥ 18 years) residing near Kosumpee Forest Park, Thailand (N = 115)

Parasite	Prevalence, *n* (%)			Intensity*		
	Child (N = 20)	Adult (N = 95)	Overall	Mean	Median	Standard deviation
Opisthorchis viverrini	0 (0)	6 (6.3)	6 (5.2)	5.8	4.2	5.7
Strongyloides spp.	0 (0)	8 (8.4)	8 (6.9)	14.0	8.3	15.7
Taenia spp.	0 (0)	1 (1.1)	1 (0.9)	187	187	–
Ascaris lumbricoides	0 (0)	1 (1.1)	1 (0.9)	3.3	3.3	–
Overall infection	0 (0)	14 (15)	14 (12)	–	–	–

* Eggs or larvae per gram feces.

aggressively seeking food, no longer fearing humans, and mimicking human activities such as drinking from beverage bottles. These changes were attributed to increased macaque population size and inadequate food to support the population. Nearly all households reported visiting the forest park (96%; 97 of 101), and many described feeding the macaques out of pity because they were too thin.

DISCUSSION

In this study of a shared human and macaque environment, we identified human exposure to macaques or their feces at home as a risk factor for human parasitism, but occupational contact with animals associated with a protective effect. We identified multiple concerns for sustainable coexistence, which included the presence of zoonotic parasites, unsafe human behaviors while feeding macaques, residents' reports of an expanding macaque population, and property damage. Our interviews of residents confirmed that most residents value the presence of macaques in Kosumpee Forest Park and are open to solutions for promoting shared human, animal, and environmental health. Finally, we established baseline estimates of human and macaque parasite prevalence in an area that is undergoing rapid urbanization and where human–macaque interactions are increasing.

TABLE 4

Generalized linear multivariate analysis to assess the strength of association between household and individual risk factors and human parasitism in the Kosumpee Forest Park area, Thailand

Variable	Household model OR (95% CI)	Adult model OR (95% CI)
Household size (#)		
1–3	REF	REF
4–6	**0.14 (0.03–0.68)**	**0.05 (0.004–0.51)**
7–9	0.51 (0.03–9.28)	1.40 (0.07–28.9)
Highest education degree (adults)	N/A	–
No degree	–	2.93 (0.39–22.3)
High school/GED	–	4.63 (0.50–43.3)
Postsecondary	–	REF
Rinsing hands with water (handwashing technique)*	2.27 (0.499–10.3)	N/A
Macaques and/or feces at home*	5.43 (0.898–32.8)	**13.9 (1.1–183)**
Occupational animal contact*	N/A	**0.04 (0.003–0.43)**
Pet ownership*	N/A	2.22 (0.38–12.5)

CI = confidence interval; N/A = not applicable; OR = odds ratio; REF = referent group. Bold font indicates significance (P-values< 0.05).
* Referent = no.

Our parasite analysis identified parasites previously reported in both people and animals, including *Taenia* spp., *Trichuris* sp., and hookworms. Only *Ascaris* and *Strongyloides* spp. were found in both people and macaques; however, our laboratory methods did not allow us to differentiate *S. stercoralis*, which infects people, from *S. fuelleborni*, which infects people and primates. Possibly, the *Stronglyoides* spp. observed in macaques and people was *S. stercoralis*, as this species passes commonly as larvae in stool, whereas *S. fuelleborni* passes commonly as eggs.[22] Molecular characterization of *Strongyloides* specimens would be required to confirm species identity. Similarly, at least one *Trichuris* subspecies was observed in both wild nonhuman primates and humans; however, eggs of zoonotic and nonzoonotic subspecies are identical and would require differentiation at the molecular level.[16] The presence of *Strongyloides* in macaques suggests a buildup of infective life stages in the environment due to soil contamination with human or macaque excreta. Longitudinal datasets reporting helminth infections in people and wild nonhuman primates sharing habitats are needed to more accurately characterize the risk of zoonotic transmission.

Age was a significant risk factor for parasitism in both people and macaques. Among macaques, infants and juveniles experienced higher overall parasitism, as well as higher prevalence of *Trichuris* sp. and hookworms. A previous survey in the region reported no relationship between parasitism and host age or sex; however, we were unable to compare how our methods of age classification differed.[16] Our observation of human parasitism in adults but not children was supported by two other Thai studies reporting positive relationships between age and infection.[15,23] These findings suggest that government helminth prevention programs targeted toward children and youth over the last decade[14] have been successful.

Forest parks with free-ranging macaques accommodate a wide range of interactions with human tourists or locals and are a popular attraction in many Southeast Asian countries.[24–26] Kosumpee Forest Park attracts 50,000–80,000 visitors per year (predominately Thai tourists and local residents; estimates based on our observations) and provides little structure for ensuring safe interactions between visitors and macaques. Our survey respondents reported that tourists did not exercise proper precautions in avoiding aggression or minimizing disease transmission, and this was confirmed by our observations in the field. Other human–animal conflicts were also apparent. Respondents residing in close proximity to the park expressed frustration that macaques took food from human dwellings, damaged property, and defecated close to houses. Although our study did not explore specific interventions to decrease human–macaque conflict, our questionnaire confirmed a low level of awareness regarding disease transmission between people and animals. This suggests that education might play a key role in helping the public to minimize conflict. Infrastructure changes such as installing screens on windows to block entry into homes, and burying power cables to prevent macaques using them for easy transit through communities could limit macaque access to human dwellings. Our finding that occupational contact with animals was associated with protection against gastrointestinal parasitism could be explained by increased awareness of pathogen transmission and improved personal hygiene measures to protect against infection.

Despite our best attempts to maximize opportunities for equal participation, there was a female bias in our dataset, likely due to gender difference in labor participation that impacted availability during the day. Our investigation of environmental factors related to human and macaque coexistence was limited to the infrastructure data collected through the household questionnaire. This could be addressed in a future study by assessing parasite ova in soil and water, quantifying the natural carrying capacity (e.g., forage availability) of Kosumpee Forest Park, conducting spatial analyses of parasite-positive macaque and human stool, and identifying effective barriers to macaques entering homes. Our estimates of gastrointestinal parasitism were limited by the single stool sample obtained per host, by the use of eggs per gram as a proxy for infection intensity, and by our identification of some helminths to the genus rather than species level. Future studies that include multiple stool samples per individual would have a higher likelihood of parasite detection.

Animals can be sentinels for adverse health events in people, and vice versa.[27,28] Our observations of parasitism in people and macaques indicated that despite huge gains in parasite control among people, parasites of medical and veterinary importance remain present in the area. Ongoing surveillance of key parasites, such as *Strongyloides* spp., is warranted to prevent reemergence in people and increased prevalence among macaques. The presence of *Taenia* and *O. viverrini* in human stool indicates that some residents continue to consume raw/undercooked fish or meat, which is also supported by our questionnaire data. In addition, our team observed local residents feeding offal and other unwanted food products to macaques, thereby increasing the risk of parasite prevalence in the social groups. Parasite control among people could be aided by efforts to promote parasite screening, regular prophylaxis, snail control, and high-quality wastewater infrastructure. The presence of gastrointestinal parasitism in almost half of macaque samples signified not only a potential health concern in a population that is already struggling to adapt to food and space constraints but also that macaques act as reservoirs of parasites in this shared environment. Targeted strategies to improve the health of macaques in Kosumpee Forest Park might include managing population size/density to match natural forage availability and limiting macaque contact with offal, household garbage, and human waste.[1]

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