CABI

ONE HEALTH CASES

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Urban Rats (*Rattus norvegicus*) through a One Health Lens: Social and Ecological Factors Promote Opportunities for Urban Leptospirosis in Rats, Dogs, and People

By studying rats and residents on the same blocks, we found that lower-income residents had more exposure to rat urine but rats were more likely to carry Leptospira interrogans in higher-income areas with higher rat abundance, highlighting social and ecological processes that increase leptospirosis risk for people and domestic animals.

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Abstract

Living in cities creates One Health challenges because urban environments can promote pathogen transmission in wildlife and human-wildlife interactions with commensal species such as rats. In this study, we examined social and ecological processes that lead to an elevated risk of leptospirosis, a fatal rat-associated disease transmitted through *Leptospira interrogans* bacteria in urine. We examined rat and human factors associated with (1) human exposure to rat urine in the home environment, (2) the presence of rats carrying *L. interrogans* on the block, and (3) environmental conditions associated with rat infection. We surveyed residents and trapped rats on the same 16 blocks in four neighbourhoods in Chicago. Survey respondents were more likely to observe rat urine in their homes if they had lower incomes. Blocks where rats were carrying *L. interrogans* had higher rat abundance and respondents with higher incomes, who reported dogs dying from leptospirosis, children playing in yards with rat waste, flooded yards, and gardens with rat burrows. Rats were more likely to be infected with *L. interrogans* if they were trapped on a block with more accessible garbage and if they were older. Our results highlight that rat presence alone does not determine the risk of close contact with rat-associated pathogens; socio-economics can affect an individual's ability to exclude animals from living spaces. In addition, improved waste management may help mitigate disease risks for humans, wildlife, and domestic animals. We also discuss opportunities for public education about rat-associated zoonoses and lessons learned about meaningful community engagement in One Health work.

What is the Incremental Value that Makes this a One Health Case?

The majority of people worldwide live in urban areas, where commensal rodents such as brown rats thrive. This case illustrates how an interdisciplinary approach that integrates data on human exposure to rats, rat pathogen surveillance, and environmental conditions on the same city blocks can provide insights into the importance of socio-economics, wildlife abundance, and sanitation for zoonotic pathogen transmission in urban landscapes. This approach enabled us to identify distinct social and ecological processes that increase the risk of leptospirosis exposure across an income gradient based on exposure to rat urine in the home or rats carrying *Leptospira interrogans*, the causative agent of leptospirosis. Further, our mixed-methods approach also included qualitative data on residents' health concerns about rats, revealing interactions likely to promote *L. interrogans* transmission to domestic dogs and children. We also highlight environmental conditions associated with rat infection that can be managed to reduce disease risk in rats, which in turn reduces risks for domestic animals and people. Interdisciplinary collaborations between ecologists, social scientists, mammologists, epidemiologists, community leaders, and pest management professionals were critical to the success of this project, as were partnerships with local elected officials. We also discuss the importance of broader community engagement in One Health work to support health equity.

Learning Outcomes

1. Recognise that zoonotic diseases are part of complex social-ecological systems that require information about human experiences and wildlife populations.
2. Understand the processes that promote zoonotic infection in wildlife or increase human exposure to infected wildlife require multifaceted data on individual people, structural factors, wildlife health, and environmental conditions, each of which can improve mitigation strategies.
3. Know that quantitative data can help identify risk factors based on the local presence of infected animals or exposure to animal waste while qualitative data can highlight the types of human-wildlife interactions likely to increase zoonotic disease risks.
4. Appreciate that meaningful community engagement takes time, trust, transparency, and effort but improves data quality, scientific inference, and relevance.

Background and Context

Living in cities creates One Health challenges for people, domestic and wild animals, and the urban ecosystems we share. These challenges arise in part due to human activities that promote relatively high densities of species that can use human-associated infrastructure and food sources (e.g. "urban exploiter" species, Rothenburger *et al*., 2017). These changes can promote more frequent human-wildlife interactions with wildlife that thrive in urban environments such as commensal rats (brown rats *Rattus norvegicus* and black rats *Rattus rattus*; Yahner, 2001). In addition to more frequent human-wildlife interactions, urban wildlife may experience poorer health in cities if urban environmental conditions promote pathogen transmission among animals (Murray *et al*., 2019). Thus, to protect the health of urban residents, their pets, and urban biodiversity, a One Health approach can help identify factors that promote human-wildlife interactions conducive to the transmission of zoonotic pathogens and the urban environmental conditions that can be modified to prevent zoonotic infections in wildlife.

One rat-associated zoonosis of global importance is leptospirosis, considered the most broadly distributed zoonotic disease on earth (Boey *et al*., 2019). If left untreated, leptospirosis can be fatal to humans and domestic animals such as dogs (Rissi and Brown, 2014; Costa *et al*., 2015a). Leptospirosis is caused by *L. interrogans* bacteria transmitted through the urine of infected hosts, which includes most mammals. Rats are thought to be an important reservoir for *L. interrogans* because once infected, rats typically remain persistent asymptomatic carriers (Sterling and Thiermann, 1981; Thiermann, 1981). Urine from infected rats contains leptospires, which can remain in soil and standing water for several weeks (Bierque *et al*., 2020). Because of the important role of water in transmission, leptospirosis is more common in tropical areas with high precipitation and flooding such as Brazilian slum favelas (e.g. Costa *et al*., 2015b). However, rates of leptospirosis in domestic dogs is increasing in the United States (White *et al*., 2017), suggesting that more research is needed on *Leptospira* sp. prevalence in urban wildlife and rats in particular. Understanding the environmental and social processes that lead to human or dog exposure to commensal rats and their urine can help managers design targeted interventions to prevent zoonotic diseases such as leptospirosis. However, because of the complexity of this system, understanding risk and identifying mitigation measures require interdisciplinary approaches that address both rat health and interactions with rats likely to promote pathogen transmission.

The risk of rat-associated diseases for urban residents depends on local conditions that can favour rat populations, pathogen prevalence in rats, and access to buildings. We previously found that rats are relatively more abundant in alleys with more accessible garbage (Murray *et al*., 2018) and that rats are more likely to carry *L. interrogans*, the bacteria that cause leptospirosis, in alleys with more municipal standing water complaints in higher-income neighbourhoods (Murray *et al*., 2020) and if they had been exposed to anticoagulant rodenticides (i.e. rat poisons; Murray and Sánchez, 2021). However, the risk of zoonotic disease transmission encompasses more than the presence of infected animals. Residents may also have more exposure to rats and their waste if they lack the resources to effectively exclude rats from their building or hire a pest control professional to exclude or control rats. While these associations can be useful for identifying high-risk areas, we can gain a more holistic One Health perspective by studying rat populations and resident interactions with rats in the same areas.

Identifying areas with higher a risk of health harms from rats is particularly important in Chicago, IL, USA, the city with the most rat complaints in America for the past 9 consecutive years (Orkin, 2023). In response to these rat issues, we started the Chicago Rat Project in 2018 in a partnership between Lincoln Park Zoo's Urban Wildlife Institute, Landmark Pest Management, Field Museum of Natural History, DePaul University, and scientists from The Vancouver Rat Project and Johns Hopkins University. This large interdisciplinary project focuses on the impacts of rats on human health and well-being, attitudes, and behaviours as well as the impacts of rodent control on rat populations and urban ecosystems. One of the primary goals of the Chicago Rat Project is to learn about factors that contribute to higher pathogen prevalence in rats and more frequent human-rat interactions.

In this study, we collected data on rat populations and human experiences with rats on the same city blocks to identify the processes that lead to human-rat interactions with elevated risk of pathogen transmission. Specifically, we examined rat and human factors associated with (1) exposure to rat urine in the home and (2) the presence of rats carrying *L. interrogans* bacteria on the block. We hypothesized that residents would be more likely to be exposed to rat urine in the home if they had inadequate resources to control or exclude rats and if there were more rats on their block. We also hypothesized that higher rat densities and standing water would promote the presence of rats carrying *L. interrogans* on a block. Because designing effective interventions requires a nuanced understanding of how and why people and domestic animals come in contact with rats, we also used residents' open-ended descriptions of their experiences to identify contexts likely to promote the transmission of *L. interrogans* from rats to people and pets. This systems-level approach allowed us to explore the nuances of human and animal exposure to rats and their pathogens (Fig. 1). In addition to preventing human-rat interactions likely to transmit *L. interrogans*, it is important to understand how we can modify urban environments to prevent *L. interrogans* infection in rats. To that end, we examined the extent to which environmental conditions controlled by people, namely accessible garbage, standing water, and exposure to anticoagulant rodenticides (i.e. rat poison), were associated with *L. interrogans* infection in rats. We hypothesized that more accessible garbage would promote opportunities for contact between rats, standing water would be a source of *L. interrogans* bacteria (i.e. leptospires) in the environment, and that anticoagulant rodenticides would impair rat immune function and promote infection, as it does in other species (e.g. Serieys *et al*., 2018).

Transdisciplinary Process

This study is part of a large interdisciplinary project designed to investigate human-rat interactions as a coupled human and natural system, in which we examined the impacts of rats on people (i.e. mental and physical health) and the impacts of people on rats (i.e. rodent control). This framework was collaboratively developed by an interdisciplinary team. Social scientists led the conceptual and methodological development of data collection to assess human exposures to rats or their waste, health outcomes (e.g. disease concerns, scales to assess depressive symptoms), engagement with rodent control (e.g. use of rat poison), and any potential confounding factors (e.g. demographics, environmental conditions). Disease ecologists, mammologists, and pest control professionals led the conceptual and methodological development of data collection on rat populations (e.g. relative abundance, population genetics), pathogen surveillance (*Leptospira*, enteric pathogens, respiratory viruses), and toxicology (i.e. exposure to anticoagulant rodenticides). Pest control professionals were also instrumental in developing protocols to assess resources available to rats (e.g. damaged garbage cans) and connecting scientists with community leaders. In this study, we focus on leptospirosis as the disease of interest because it is relevant to human and domestic animal health and transmitted through the environment.

We collected data on rat populations and human exposures to rats on 16 blocks in four wards (i.e. municipal districts with elected Alderpeople) in Chicago along an income gradient (Table 1). We identified our study areas through a multi-year process of community engagement. In 2021, we gave presentations about rats

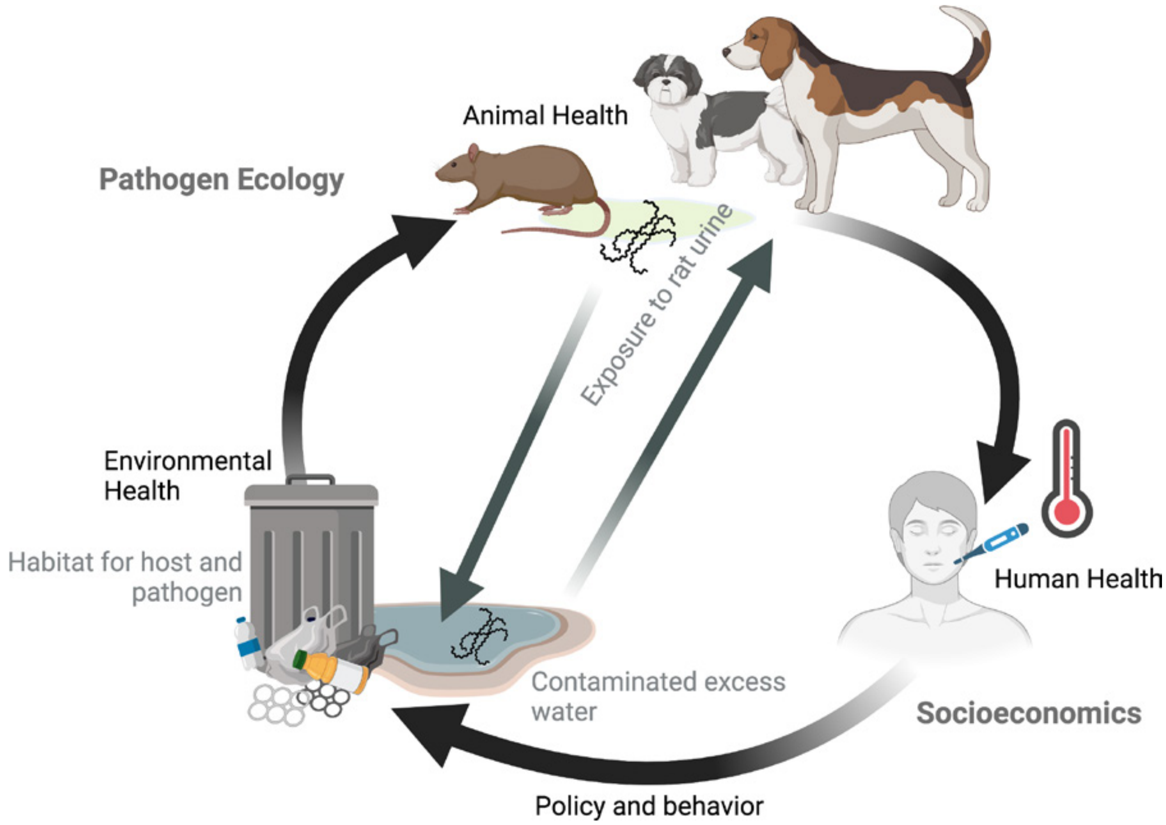

Fig. 1. Conceptual diagram showing how a One Health approach can help identify interactions among animal health, human health, and environmental health relevant to urban leptospirosis. Policies that limit the amount of garbage and standing water in alleys may reduce rat abundance and *L. interrogans* persistence in the environment, reducing opportunities for *L. interrogans* transmission between rats, dogs, and humans. Concurrently, socio-economic inequality based on income and renter status may impact the likelihood of experiencing rat infestations and exposure to rat urine in the home.

and our project to six community groups and four Ward Town Halls in 12 community areas across the city, ensuring that we presented to each study community area. These presentations, in addition to partnerships with a pest management company, facilitated relationship-building with several Aldermanic offices that shared their concerns about rats and identified areas where their constituents had reported frequent and severe issues with rats. Areas with relatively high rat complaints, as identified by four Ward Alderpeople, became our trapping sites in fall 2022 (Fig. 2).

In each of these four wards, we trapped rats in alleys on four adjacent blocks because rats have been shown to rarely move outside of one city block (Byers *et al*., 2019), enabling us to examine block-level variation in rat relative abundance, pathogen prevalence, and resident experiences with rats. We used snap traps (Big Snap-E Rat Trap, Kness Mfg. Co., Inc., USA) due to logistical constraints with live trapping and to build on our collaboration with pest control professionals. Our traps were active between August and November 2022 and were typically activated four nights per week. We recorded the number of active traps and trap nights in each block to compare trap success (i.e. the number of rats per trap per active trap night) as a measure of rat relative abundance. Traps were checked each morning of active trapping and any trapped rats were frozen at −20°C as soon as possible. Rats were necropsied at the Field Museum of Natural History, where we collected both kidneys for *L. interrogans* testing via PCR at the Wyoming State Veterinary lab following methods described in (Murray *et al*., 2020). We also collected liver tissue (≥2g) for analysis of 11 anticoagulant rodenticides at the Pennsylvania Animal Diagnostic Laboratory (PADLS) Toxicology Laboratory (Vudathala *et al*., 2010). We did not necropsy rats with visible signs of decomposition (e.g. fly eggs, skin sloughing), which we considered too degraded for reliable pathogen testing. All specimens were identified as *R. norvegicus* based on external measurements and cranial dental characteristics (Hoffmeister, 2002). During the trapping period, we also documented any garbage cans that needed to be replaced by the city of Chicago because they had damage (e.g. cracks, chewed holes) that permitted access by rodents.

Table 1. Summary of survey responses and rat trapping in four wards along an income gradient in Chicago. Median income data was sourced from the Chicago Metropolitan Agency for Planning community snapshots.

	Ward			
	A	**B**	**C**	**D**
Median income	\$22,228	\$30,961	\$41,536	\$58,283
Predominant race and ethnicity	Black or African American (75.5%)	White or Euro-American (58.5%)	White or Euro-American (78.9%)	White or Euro-American (86.3%)
Survey responses	4	11	48	31
Response rate (%)	1.8	9.4	42.5	32.3
Respondents observed rat urine in house	2/4 (50.0%)	4/10 (40.0%)	13/48 (27.1%)	6/30 (20.0%)
Rats trapped	2	26	98	26
Trapping success	4.16×10^{-3}	0.05	0.20	0.05
Trapping success by block (Mean ± St. Dev.)	$4.17 \times 10^{-3} \pm 5.89 \times 10^{-3}$	0.09 ± 0.06	0.13 ± 0.07	0.05 ± 0.04
Rats sampled	1	11	78	11
Leptospira interrogans positive rats (prevalence %)	0 (0%)	0 (0%)	6 (7.7%)	4 (36.4%)

Fig. 2. Signs of rats and rat habitat on our study blocks in Chicago, USA. We surveyed residents and trapped rats in 16 city blocks in four Wards (i.e. neighbourhoods) based on relatively high levels of rat complaints. In these alleys, we observed dead rats (a, d) and rat burrows (b). We also observed a high degree of accessible garbage and clutter that could serve as harbourage for rats (c). Photo credits: Jacqueline Y. Buckley (a, d) and Maureen H. Murray (b, c).

Following our trapping season, in January 2023, we mailed survey invitations, reminder cards, and hand-delivered reminder flyers to all households on the 16 trapping blocks (n = 441 households). We surveyed residents after trapping had concluded so that residents could think back about their experiences over the entire trapping period. The survey invitation and reminder postcards contained a URL to take the survey online, as well as a phone number if residents did not have internet access. The survey was available in English and Spanish and we provided participants with a $15 visa gift card after survey completion. In the survey, we asked about residents' observations of rats, droppings, and urine in the home on a 5-point rating scale from "Never" to "Daily or Almost Daily." We also asked about their perceptions about rats and rodent control; their knowledge and concerns about diseases from rats; and about environmental features on their block (e.g. standing water, sewer backups, trash in the alley).

To address our interdisciplinary goals, we used logistic regression models that combined variables from our rat trapping and survey datasets. To identify factors associated with exposure to rat urine in the home, we ran bivariate models (Table 2) with observing urine in the home at least once as the binary response variable and, as explanatory variables, rat relative abundance (i.e. trap success) on the block, income coded as above or below $50,000 to align with median household income, housing variables likely to affect the residents' ability to control rats themselves (renter vs. owner; house vs. apartment), and cat ownership, which has been found to have a protective effect for leptospirosis (Childs *et al*., 1992). We then created a final model with all variables $p \leq 0.10$ and significant confounding variables. We considered a variable to have a confounding effect if the coefficient for rat relative abundance or income changed by more than 10% (Corraini *et al*., 2017).

Table 2. Bivariate analysis for explanatory variables we hypothesized would be associated with the outcome "Noticed a strong smell or rats or rat urine" in the home at least once (n = 109).

Variable	n	Observed urine	Did not observe urine	OR (95% CI)	p
Rat relative abundance	152	0.05 ± 0.03 rats/trap/night	0.05 ± 0.04 rats/trap/night	1.00 (0.93, 1.06)	0.89
Income below $50,000	22	9/22 (40.9%)	12/22 (54.5%)	2.25 (0.78, 6.42)	0.10
Income above $50,000	61	15/61 (24.5%)	45/61 (73.8%)		
Renter	39	15/39 (38.4%)	24/39 (61.5%)	2.16 (0.89, 5.36)	0.09
Owner	60	13/60 (21.7%)	45/60 (75%)		
House	43	10/43 (23.3%)	31/43 (72.1%)	0.75 (0.30, 1.87)	0.55
Apartment	57	17/57 (29.8%)	40/57 (70.2%)		
Cat	24	5/24 (20.8%)	18/25 (75%)	0.74 (0.22, 2.10)	0.59
No cat	85	23/85 (27.1%)	61/85 (71.8%)		

To identify factors associated with the presence of rats carrying *L. interrogans* on the respondent's block, we ran bivariate logistic regression models (Table 3) with at least one rat testing positive on the block as the binary response variable and, as explanatory variables, rat relative abundance (trap success), income (binary), dog ownership because dogs can also carry *L. interrogans*, and whether or not the respondent considered standing water to be a "big problem" on their block. We then created a final model with all variables $p \leq 0.10$ and significant confounding variables. We used a binary variable for the presence of *L. interrogans* to avoid issues with calculating prevalence in alleys with only a few trapped rats (e.g. 1/1 rats testing positive), and also because *L. interrogans* is environmentally transmitted, and so one positive rat could contaminate local sources of standing water such as puddles.

Table 3. Bivariate analysis for explanatory variables we hypothesized would be associated with the outcome "Noticed a strong smell or rats or rat urine" in the home at least once (n = 109).

Variable	n	*L. interrogans* present	*L. interrogans* not present	OR (95% CI)	p
Rat relative abundance		0.06 ± 0.03 rats/trap/night	0.02 ± 0.03 rats/trap/night	1.23 (1.13, 1.37)	5.76×10^{-6}
Income below $50,000	22	3/22 (13.6%)	19/22 (86.4%)	0.19 (0.04, 0.76)	0.03
Income above $50,000	61	37/61 (60.7%)	14/61 (22.9%)		
Dog	47	21/47 (44.7%)	26/47 (55.3%)	0.75 (0.30, 1.87)	0.54
No dog	62	28/62 (45.2%)	33/62 (53.2%)		
Standing water big problem	16	11/16 (68.8%)	4/16 (25.0%)	1.81 (0.55, 7.10)	0.35
Standing water not a big problem	85	38/85 (44.7%)	25/85 (29.4%)		

To better understand the contexts likely to promote the transmission of *L. interrogans* or other health harms from rats, we also included an open-ended question to provide respondents the opportunity to describe their experiences in their own words. We asked respondents if they had ever had an experience that made them concerned about getting sick from a rat and, if so, to describe those experiences.

To identify environmental conditions associated with *L. interrogans* infection in rats, we ran bivariate logistic regression models (Table 4) with whether or not a rat tested positive for *L. interrogans* as the response variable. As explanatory variables, we included (1) the proportion of garbage cans we observed with cracks or holes that would be accessible to rats as a measure of garbage accessibility on the capture block, (2) whether or not residents on the capture block had made 311 reports to the city about standing water in the street during the study period (City of Chicago, 2023), and (3) whether or not the rat tested positive for at least one anticoagulant rodenticide. In this analysis, we used our own observations about garbage and municipal data about standing water to avoid bias associated with blocks with few survey respondents. We included the presence of standing water complaints as a binary variable because the trapping blocks either had ≥5 standing water reports or none. We also included rat reproductive status as an explanatory variable because older rats have been shown to have higher *Leptospira* prevalence (Minter *et al*., 2019; Murray *et al*., 2020). We then created a final model with all variables p ≤ 0.10 and significant confounding variables.

Table 4. Bivariate analysis for explanatory variables we hypothesized would be associated with *Leptospira interrogans* infection in rats (n = 102).

Variable	n	*L. interrogans* present	*L. interrogans* not present	OR (95% CI)	p
Reproductive status (reproductive)	35	9/35 (25.7%)	26/35 (74.3%)	22.8 (4.0, 43.2)	0.004
Reproductive status (non-reproductive)	67	1/67 (1.5%)	66/67 (98.5%)		
Proportion damaged garbage cans on block	102			3.1 (1.4, 9.5)	0.04
Standing water reports on block (yes)	39	6/39 (15.4%)	33/39 (84.6%)	2.6 (0.7, 10.9)	0.16
Standing water reports on block (no)	62	4/62 (6.5%)	58/62 (93.5%)		
Rodenticide (yes)	74	9/74 (12.0%)	66/74 (88%)	3.4 (0.6, 6.4)	0.26
Rodenticide (no)	26	1/26 (3.8%)	25/26 (96%)		

Project Impact

The overall response rate for our targeted survey was 24.7% (441 households, 109 responses), which is higher than other general household surveys (Sinclair *et al*., 2012) but this ranged from 1.8% to 42.5% among wards (median response rate = 20.9%; Table 1). We trapped a total of 152 rats, with trap success ranging from 0 to 26 rats or 0 to 0.11 rats/trap/night across blocks. There is often the general perception that rats are more abundant in lower-income neighbourhoods but we found no significant relationship between income and rat relative abundance across our study blocks along an income gradient (Table 1; Odds Ratio (OR) = 0.93 [95% CI: 0.75, 1.14]). Of the 152 rats we trapped, 102 did not have visible signs of decomposition and were in suitable condition to be necropsied and their kidneys were tested for *L. interrogans*.

Rat and human factors associated with rat urine in the home

Overall, 28% (28/109) of respondents had observed urine in their home at least once during the study period (Table 1). Our final model for observing rat urine in the home included respondent income, rat relative abundance, and renter status. The final model showed that respondents making less than $50,000 had 4.35 times the odds or 335% higher odds of being exposed to rat urine in the home relative to respondents making more than $50,000, even if they lived on the same block (Adjusted Odds Ratio [AOR] income under 50K = 4.35 [95% CI: 1.01, 9.39]; Fig. 3a). However, exposure to rat urine in the home was not significantly associated with rat relative abundance on the block (AOR trap success = 1.01 [95% CI: 0.94, 1.09]). Proportionately more renters had observed rat urine in the home (15/39, 38.5%) relative to owners (13/60, 21.7%) and this was a significant confounder but was not independently significant in the final model (AOR = 1.86 [0.56, 6.26]). These results suggest that local rat abundance alone is not a good predictor of who is exposed to rat urine in the home and that socio-economics is also important. Specifically, our results suggest that we might expect greater public exposure to rat urine, and therefore a higher risk for *L. interrogans* transmission from rats to people if rats are infected, for residents with lower incomes and renters.

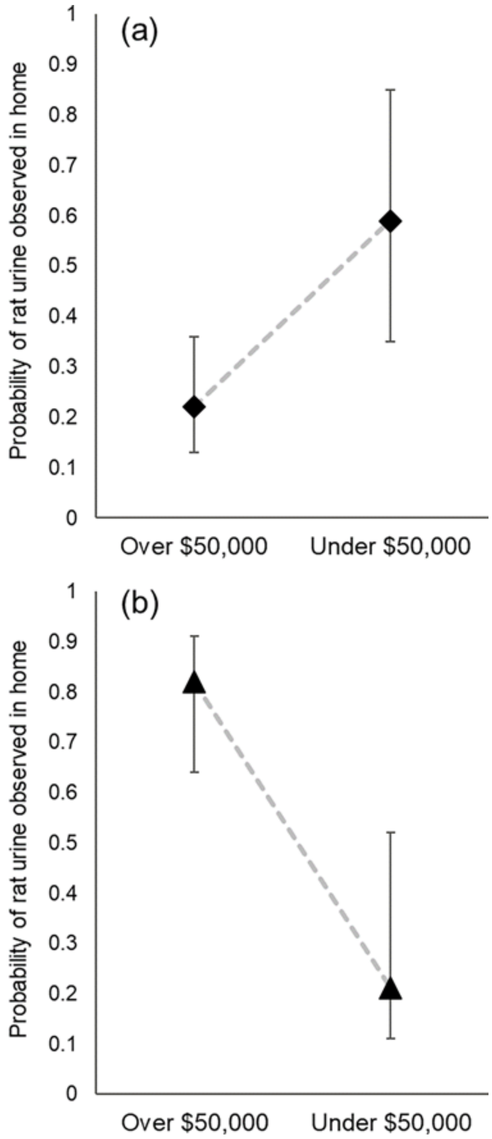

Fig. 3. Relationships between household income and the probability of (a) exposure to rat urine in the home and (b) living on a block with at least one rat carrying *L. interrogans*. These relationships derive from the outputs of two separate final models (n = 83 survey respondents for (a), n = 102 rats for (b)).

Rat and human factors associated with *L. interrogans* on the block

Overall, 9.8% (10/102) of trapped rats tested positive for *L. interrogans*, and this varied from 0% (0/11) to 36.4% (4/11) in different wards (Table 1). Our final model for the presence of at least one rat carrying *L. interrogans* on a block included respondent income, rat relative abundance/trapping success, and respondent perception of standing water issues. In this model, the odds of a respondent living on the same block as a rat carrying *L. interrogans* was 94% lower if they had an income under $50,000 (AOR under 50K = 0.06 [95% CI: 0.006, 0.43]; Fig. 3b). This small odds ratio had a large amount of error because only 10 respondents on the blocks with rat pathogen data had incomes under $50,000 and only 3 of those (33.3%) lived on a block with a rat carrying *L. interrogans* compared to 69.8% (37/53) of respondents making over $50,000. Our final model also showed that survey respondents had 1.34 times the odds or 34% higher odds of living on a block with at least one rat carrying *L. interrogans* if they lived on a block with higher rat relative abundance (AOR = 1.34 [1.18, 1.60]; Fig. 4). Proportionately more residents reported standing water being "a big problem" on blocks with *L. interrogans* positive rats (11/49, 22%) relative to blocks without *L. interrogans* positive rats (4/29, 13%) and this was a significant confounder but was not significant in the final model (AOR: 3.48 [95% CI: 0.49, 35.8]). These results follow the ecological expectation that disease transmission among rats is more likely with higher rat host density. Factors associated with higher incomes may be promoting *L. interrogans* carriage in rats, however, more data from lower-income residents would help strengthen this trend (see discussion on community engagement below). For both of our quantitative analyses (i.e. identifying factors associated with exposure to rat urine and the presence of rats carrying *Leptospira*), it is important to consider that small sample sizes may be masking significant relationships (Tables 2 and 3).

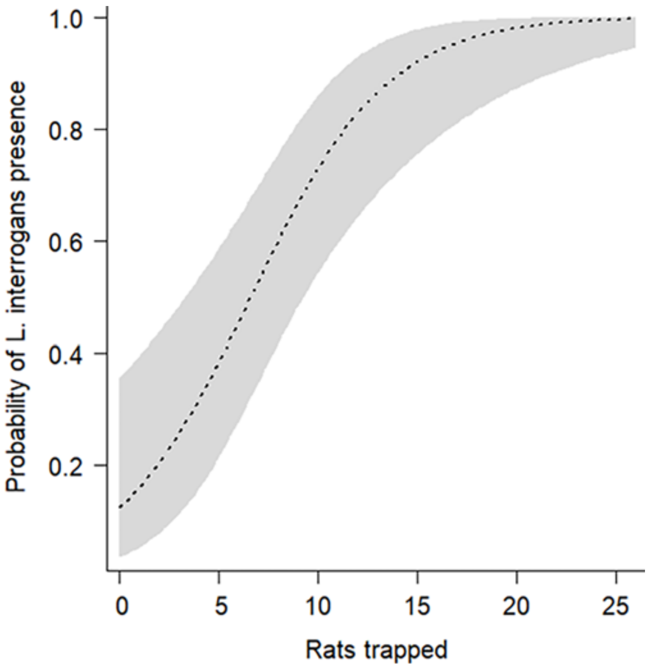

Fig. 4. Relationship between rat relative abundance (trap success) and the probability that at least one rat tested positive for *L. interrogans*. We trapped 152 rats on 16 blocks and sampled 102 for *L. interrogans* via PCR.

Human-rat interactions likely to increase risk of leptospirosis

We asked respondents to describe any experiences that made them concerned about getting sick from a rat and received 52 responses, including 17 from respondents on blocks with rats carrying *L. interrogans*.

In terms of health outcomes, several respondents on the blocks where we detected rats carrying *L. interrogans* mentioned their dogs' health. Two residents described their dogs dying from leptospirosis and mentioned rat urine as the source of infection.

> *"I had a fully vaccinated pet dog die from Lepto [sic] presumably from rat urine in the alley."*
>
> *"5 years ago my dog got leptospirosis likely from Rat Urine [sic]. Over a year ago there was a clearly sick rat in our yard. Often when it rains we have dead rats in the yard."*
>
> *"I'm afraid that my dogs are getting contaminated and ill from [rats]."*

Respondents on the blocks where we detected rats carrying *L. interrogans* also mentioned specific interactions that could increase the risk of *L. interrogans* transmission. Respondents mentioned dogs fighting with rats, dogs bringing rat waste inside on their paws, children playing in outdoor areas contaminated with rat waste, and rat urine in cars. Several respondents mentioned rat waste issues on their property that their landlord would not resolve.

> *"I have a dog and he often will try to approach rats/rat poop"*
>
> *"Concerned about rats attacking my dog."*
>
> *"I'm most worried about my dogs tracking feces into the house from their paws when I take them on walks and somehow getting into contact with it. I worry mostly about my pets safety because they have eaten rat feces before and probably will continue to unless I catch them in time."*
>
> *"[I am concerned about] seeing droppings around our property and knowing my kids play in our yard. How much contact are they having with rat droppings?"*

> *"there are rat droppings all over my parking area and they have gotten under the hood of my car and urinated everywhere. This concerns me for the health of my child (4 years old)"*

> *"I live in a building where the landlord does not care for the property and is a hoarder and there have been rat nests seen in our yard and basement, which are never cleaned and unhygienic."*

On the blocks where we did not detect rats carrying *L. interrogans*, none of the respondents mentioned concerns about leptospirosis. Instead, respondents mentioned impacts beyond infectious diseases such as fear and stress. Others mentioned rat waste in high-contact areas such as kitchen counters and beds.

> *"I'm always afraid. I live in a low income area and there are rats everywhere"*

> *"they jump out of my garbage can… it startles me and I'm a heart patient."*

Only 26% of all survey respondents were aware that leptospirosis could be carried by rats and transmitted through rat urine. This was reflected in the open-ended responses from residents, which revealed a wide range in the level of awareness of health risks from rats. On blocks where we detected rats carrying *Leptospira*, one respondent was aware that their dog likely contracted leptospirosis from rat urine in the alley whereas another respondent was reassured by their veterinarian that the biggest risk for dogs was rat fleas. Another respondent seemed unaware that soil can be contaminated with *L. interrogans* bacteria. Other respondents were concerned about rat waste but unsure what risks it poses.

> *"I see a lot of rats in my alley, on garbage cans, in my planters, in my CAR! I don't want to touch what they've touched because I don't know what diseases they carry. I wash my hands every time I take out the trash because I know they get on top of the trash cans."*

> *"Most concern is for my dog that kills them when he can. Was reassured by vet that fleas from rats can be the biggest problem"*

> *"Landlord doesn't remove raised garden beds that the rats have infested. They should be fine because they do nothing to the habitat"*

Respondents on blocks where we did not detect rats carrying *L. interrogans* also described a wide range in awareness of the risks associated with rats. Some respondents mentioned that they wash outdoor vegetables or use gloves to clean up rat waste. One respondent mentioned that they changed how they cleaned up rat waste because it could make them sick.

> *"tons of rat droppings at times near garbage cans that I and my family would sweep up. At first we did this without masks but heard that particles from cleaning them up could make you sick"*

The open-ended responses highlight fatal health risks from leptospirosis for domestic dogs that mirror our rat pathogen surveillance data. Interestingly, leptospirosis cases or concerns were not described on blocks where we did not detect rats carrying *L. interrogans*. The open-ended responses also characterized specific interactions such as contact with rat urine in cars, children playing in rat-infested yards, dog-rat interactions, and misconceptions about health risks from rats that may promote *L. interrogans* transmission between rats, dogs, and people.

Environmental conditions associated with *Leptospira interrogans* infection in rats

The 9.8% (10/102) of rats that tested positive for *L. interrogans* were captured on five of the 11 blocks where we caught rats (range = 1–3 positive rats per block). Our final model of factors associated with *L. interrogans* infection in rats included rat reproductive status, presence of standing water reports on the capture block, proportion of damaged garbage cans on the capture block, and rat exposure to anticoagulant rodenticides. In this model, a rat had 24.5 times higher odds of being infected with *L. interrogans* if they were reproductively active and thus older (AOR: 24.47 [3.91, 48.99]) and this relationship was statistically significant ($p = 0.004$). A rat also had 7.8 times higher odds of being infected if it was trapped on a block with a higher proportion of damaged garbage cans accessible to rats (AOR: 7.79 [0.84, 24.83]) and this relationship was nearly significant ($p = 0.09$). Proportionately more rats were infected on blocks with standing water reports (6/39, 15%) relative to blocks without standing water reports (4/62, 7%) and this was a significant confounder but was not significant in the final model (AOR: 2.83 [0.57, 11.88]). Proportionately more rats that had been exposed to anticoagulant rodenticides were infected (9/75, 12%) relative to rats that had not been exposed (1/26, 4%) and this was a significant confounder but was not significant in the final model (AOR: 5.46 [0.77, 11.32]).

Project Outlook

Our results highlight both social and ecological factors that may increase the risk of leptospirosis transmission between urban rats, residents, and their pets (Fig. 1). Notably, there appears to be opposing relationships between household income and the likelihood of encountering rat urine in the home vs. rats carrying *L. interrogans* on the block (Fig. 3). The ecological conditions that promote pathogen transmission (pathogen presence in local rats) were associated with higher incomes while social conditions that promote transmission (urine in the home) were associated with lower incomes. Residents with lower incomes and renters may have been more likely to observe rat urine in the home because they lack the resources or autonomy to make structural changes to exclude rats from their homes themselves or hire a pest management professional. An important limitation to survey data is bias in who is more likely to answer the questionnaire. In our study, is it possible that individuals with lower incomes were less likely to take the questionnaire (e.g. because they have other priorities) unless they had severe rat issues. Although we cannot determine such bias using our methods, we did find similar results from a larger survey respondent pool (n = 483) of randomly selected households in 2021. In that survey, 45% of respondents with incomes under $50,000 observed rat urine in the home compared to 31% of respondents who made over $50,000 ($\chi^2 = 9.24$, $p = 0.002$). Our results align with previous studies that have similarly found increased rat pressure for lower-income residents using inspection or report data rather than surveys (Childs *et al*., 1998; Easterbrook *et al*., 2004; Masi *et al*., 2010; Bachelder *et al*., 2016), suggesting that increased support and capacity-building is needed for lower-income residents. Specifically, this could include structural changes outside of the home to exclude rats and manage rat attractants (e.g. waste management policies) as well as action from people in positions of relative power such as landlords, who were mentioned in open-ended responses about health concerns from rats. As such, rat management can be thought of as one of many intersecting components of urban environments that contribute to health equity.

Conversely, residents with higher incomes were more likely to live on a block with at least one rat carrying *L. interrogans*. This aligns with our previous work showing a higher probability of rats carrying *L. interrogans* on blocks with more standing water complaints in higher-income neighbourhoods (Murray *et al*., 2020), but the current study avoids the issue of bias in who reports such complaints. However, the causal mechanism remains unclear because other factors that may be associated with income such as dog ownership did not appear to be important predictors of *Leptospira* presence in rats. Further, we found no significant relationship between rat relative abundance and income. To untangle causal relationships between income and *Leptospira* in rats, more research is needed into differences in rat populations, rodent control, and environmental conditions in higher vs. lower income areas. For example, we previously found that rats exposed to anticoagulant rodenticides (i.e. rat poisons) were significantly more likely to carry *L. interrogans* (Murray and Sánchez, 2021), and thus any differences in the use of rat poison associated with socio-economics may influence socio-spatial patterns in rat infection risk. Spatial patterns in rat infection may also be the result of the geospatial clustering of rat populations if there is genetic isolation between rats in different neighbourhoods (e.g. Combs *et al*., 2018). Regardless of the cause, these results emphasize the importance of studying One Health issues using multiple methods and a social-ecological lens across a wide range of socio-economic contexts. Another important consideration is that we did not confirm that leptospires were being shed in rat urine, which would require live-trapping rats. Given the positive reception we received from residents for kill-trapping their rats, live-trapping would require considerably more community messaging and convincing to maintain community buy-in.

Although quantitative approaches can help identify health risks based on the local presence of infected animals or exposure to animal waste, qualitative data can elucidate the nature of human-wildlife interactions likely to increase zoonotic disease risks. For example, our survey respondents described scenarios likely to promote *L. interrogans* transmission from the infected rats on their block such as dogs fighting with rats, dead rats in rainwater, rats urinating in cars, rats living in garden soil, and children playing in rat-inhabited yards. Public education materials could highlight the risks associated with these interactions so they may be mitigated, for example leashing dogs in alleys or taking safety precautions when gardening or disposing of dead rats. Respondents' open-ended descriptions also highlighted important gaps in knowledge, such as the risk of leptospirosis for pet dogs and in contaminated soil. Giving residents the opportunity to tell researchers about their experiences, concerns, and awareness in their own words provides powerful insights for mitigation strategies that are relevant to their daily lives.

Our results also highlight the interdisciplinary collaborations needed for One Health research. This project would not have been possible without insights from pest control professionals for rat trapping, disease ecologists and mammologists for pathogen testing, social scientists and epidemiologists to design the survey instrument, and research coordinators and interns to lead data collection. Outside of the research team, government officials (i.e. Alderpeople) helped us identify study areas with rat problems. This input was foundational to our study design and without it, months of community engagement would have been necessary to identify areas with high rat pressure. A crucial aspect to preventing pathogen transmission among people, wildlife, and domestic animals is understanding the environmental conditions conducive to wildlife infections so that they may be prevented. We found that accessible garbage was associated with *L. interrogans* infection in rats, likely because it promotes congregations of rats around damaged cans. In addition to identifying study areas, the Aldermanic offices replaced the garbage cans we identified as damaged, which helped put our management recommendations into practice. Government support is crucial for One Health research to inform policy. For example, the results of this study and others from the larger Chicago Rat Project were summarized in a report solicited by the City of Chicago's Office of the Inspector General to improve municipal rat management. In the future, strengthening collaborations with veterinarians could help us understand any trends in leptospirosis infections in Chicago dogs and what information pet owners receive about rat-associated zoonoses. For example, veterinary researchers have noted an increase in canine leptospirosis across the United States (White *et al*., 2017). Understanding the knowledge, attitudes, and practices of veterinarians and dog owners in areas where rats are carrying leptospirosis would help mitigate health risks for dogs and dog owners.

Although interdisciplinary collaborations have strengthened the Chicago Rat Project, increased community participatory engagement would have improved every part of our study. For example, the survey responses were biased toward relatively affluent wards (Table 1). We mainly engaged with our study neighbourhoods through their local Aldermanic offices because they are the primary intermediary for rat issues between residents and the city's Bureau of Rodent Control. However, by engaging with residents through government channels, we likely inadvertently excluded residents who are not aware of or do not feel comfortable engaging with the government for a variety of reasons. Trust in government continues to decline (Pew Research Center, 2023) and so working alongside community organizations would have likely improved participation in our study. We reached out to community organizations across the city via email, but successful engagement takes leg work over extended periods of time to develop trusting relationships. Greater community engagement would also help us better understand residents' motivations for taking the survey or not, because we observed a bias towards more responses in communities where we trapped more rats. We hope to apply these lessons learned in the next phase of the Chicago Rat Project, which is focused on community gardens (Fig. 2d). We now work extensively with Lincoln Park Zoo's Community Engagement team and are devoting the first 6–12 months of the project to relationship-building with study gardens. Putting in the effort to engage meaningfully with study communities will improve the quality, rigor, and insights of One Health data.

Conclusions

Our study shows that a One Health approach can help identify both social and ecological processes that may increase zoonotic disease risks from urban rats to make evidence-based management recommendations. Based on our data, mitigation strategies should focus on minimizing exposure to rat waste in the home environment for renters and lower-income residents. Conversely, strategies to minimize the likelihood of rat infection should focus on accessible garbage and standing water in areas with high rat densities, which may be in relatively affluent neighbourhoods. Based on ongoing conversations with pest control professionals and Aldermanic offices, removing barriers to engaging with free municipal rodent control such as awareness and trust may help reduce rat exposure for lower-income residents and renters. Similarly, increasing public awareness of free municipal programmes such as garbage can replacement can help reduce rat attractants and potentially the presence of rat-associated pathogens. More generally, public education should emphasize the risks associated with rat urine for human and dog health. These insights can be gained through interdisciplinary research teams and strengthened through thoughtful and meaningful community engagement.

Group Discussion Questions

1. What are some ways we could raise public awareness about rat-borne diseases in cities?
2. What are some limitations to surveys and snap-trapping rats? How could we address those limitations?
3. How would you design a community engagement plan for a similar project in your city, and how might that plan ensure the representation of underserved neighbourhoods?

4. What are some other examples of social (e.g. socio-economics, housing) and ecological (e.g. wildlife densities, habitat availability) processes that combine to increase One Health risks?
5. How can we make sure that One Health research projects influence policy?
6. What other collaborators or partners do One Health researchers need to consider when creating a robust team and how do we ensure they are included in research?

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Conflict of interest

The authors have no conflicts of interest to declare.

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