Inequality in exposure and knowledge drives vulnerability to rat-associated leptospirosis among Chicago communities

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Abstract

To predict and prevent public health risks from urban rats, studies often examine zoonotic pathogen prevalence in rats in different urban environments. However, human exposure to rats and their awareness of the associated risks are poorly understood. In this study, we aimed to identify factors associated with two aspects of vulnerability to leptospirosis as a model rat-associated disease: 1) exposure to rat urine in the home and 2) lack of awareness that rats carry leptospirosis. To collect data on residents' experiences and knowledge about rats, we mailed a survey to randomly-selected households along an income gradient in Chicago. Of 432 complete cases, 36% had observed rat urine in the home and 73% were unaware that rats carry leptospirosis. Using logistic regression, we found that non-white respondents had over three times higher odds of observing rat urine in the home than white respondents. Dog owners and respondents who sought out information about rats, regardless of source, were more likely to be aware that rats carry leptospirosis. When we examined both aspects of vulnerability simultaneously using multinomial regression, we found that residents most vulnerable to leptospirosis (who had been exposed to urine and were not aware that rats carry leptospirosis) were significantly less likely to be white and less likely to be dog owners. Our results suggest that more public education is needed about rat-associated diseases spread through feces and urine and that exposure to rats should be considered another environmental health burden that is disproportionately persistent in underserved communities of color.

Introduction

Increased urbanization has led to the re-emergence of rat-associated zoonoses across the globe [1]. To prevent public health risks from rat-associated zoonoses, it is important to understand which urban communities are most vulnerable to rats and their associated health harms in order to develop strategies to identify and predict potential at-risk areas for management. This requires information about zoonotic infection prevalence in rats [1, 2, 3] but also about which residents are more likely to come into contact with rats, which is poorly understood.

Of the pathogens carried by rats, the bacteria *Leptospira interrogans*, the causative agent of leptospirosis, is the most widely distributed. Leptospirosis symptoms in humans can range from mild flu-like symptoms to life threatening conditions such as renal failure, hepatic dysfunction, vascular damage, pulmonary hemorrhage, and muscle lesions [4]. Leptospirosis is the most widespread zoonosis in the world, with an estimated 1.03 million people infected each year [5]. The main mechanisms of leptospirosis transmission include exposure to leptospires in the urine of infected rodents, domestic dogs, livestock, as well as contaminated water and soil [6]. Rats excrete *Leptospira* in their urine [9], and the bacteria can persist for at least 16 days in soil and 28 days in standing water [1]. Historically, leptospirosis has been a concern in developing countries, with most studies being conducted in under-resourced "urban slum" environments, such as the favelas in Brazil [9]. However, *Leptospira* infection is becoming an increasingly important environmental health issue in developed and industrialized countries as well, especially during periods of seasonal rainfall and flooding [9]. For example, in the United States,

rates of leptospirosis in dogs have been increasing [10], which may indicate increased environmental contamination from rodents of public health concern.

While several studies have examined the prevalence of *Leptospira* sp. in urban rats, it is also important to understand which urban residents are more at risk if leptospirosis infection. Individuals with more contact with rats, for instance those with rat infestations in the home, have a higher likelihood of coming in contact with contaminated rat urine. Socioeconomics is also an important factor with respect to rat infestations. In the U.S., households in low-income neighborhoods report rat presence more frequently than households in high-income neighborhoods [11]. This pattern may arise because residents with lower incomes have fewer resources to hire professionals or manage opportunities for rat harborage, which includes ceiling and wall cracks, waste material, and overgrowth [12]. A study conducted in New Orleans demonstrated that rats were most abundant in areas with vacant buildings, unmaintained buildings and vegetation, and debris [13]. This is especially important in lower-income and historically marginalized communities where vacant and unmaintained homes are often disproportionately concentrated [14]. Although rats can be more abundant in lower-income neighborhoods, the rates at which urban residents encounter rats or rat waste in their homes is unknown but important for predicting exposure to leptospirosis.

Individuals may also be more vulnerable to leptospirosis from rats if they are not aware that rats carry leptospirosis. For example, individuals who are not aware that rats carry leptospirosis may be less likely to avoid or report standing water in their neighborhood, take precautions when cleaning up rat waste, vaccinate their dogs, or inform their healthcare provider of a rat infestation. Previous leptospirosis awareness studies have typically taken place after a large-scale outbreak [15], or targeted specific high-risk populations such as veterinarians [16], butchers [17], or dog owners [18], rather than the general population. Understanding factors associated with awareness in the general population can help identify unknown high-risk groups for targeted education programs.

In this study, we aimed to identify factors associated with two aspects of leptospirosis vulnerability in urban residents: exposure to rat urine in the home and lack of awareness that rats carry leptospirosis. We studied vulnerability to leptospirosis in Chicago, hailed the “rattiest city in America” for the eighth consecutive year in 2022 [19]. *Leptospira* sp. has been detected in Chicago’s rats [2] and has been increasing in dogs in the Midwest [10]. Based on previous patterns between rat infestations and socioeconomics, we hypothesized that individuals with lower incomes would be more likely to be exposed to rat urine in their home. We also hypothesized that individuals would be less likely to be aware that rats carry leptospirosis if they did not seek out information about rats or only from informal sources. Specifically, we hypothesized that individuals who sought information about rats from government websites and pest professionals would be more aware of leptospirosis in rats than those who got their information from other sources (e.g., social media, neighbors, other community members, etc.). Additionally, we hypothesized that dog ownership would be associated with greater awareness of rats as leptospirosis carriers due to veterinary care. Finally, we hypothesized that individuals with lower incomes who did not seek out information about rats would be both exposed to urine in the home and lacking

leptospirosis awareness, making them the most vulnerable group for possible leptospirosis exposure. Our results add to our understanding of how human behavior and socioeconomic inequality can affect exposure to and awareness of rat-associated diseases, an understudied topic of global public health importance.

Methods

To better understand urban residents' interactions with rats and their associated impacts on human health and well-being, we conducted a cross-sectional survey across Chicago in 2021. Survey invitations and reminder cards were mailed to randomly selected households in 12 community areas in Chicago selected along an income gradient (Fig. 1). The survey was available online, by phone, and on paper, as well in English, Spanish, and Mandarin Chinese to increase accessibility. A $10 incentive was offered for participation. We distributed the survey in June 2021 and the survey was open until mid-August, aligning with the time period when rat complaints reach their annual peak in Chicago [20]. The survey contained questions relating to respondents' experiences, knowledge, and perceptions of rats, use of rodent control, exposure to rat waste, and health outcomes. The survey was accompanied by an informed consent document summarizing the benefits and risks of the study with anonymous checkboxes. This study was approved by the Lincoln Park Zoo Institutional Review Board (IRB-21-001-EX).

Using a subset of questions from the parent survey, the goal of this analysis was to identify factors associated with two aspects of vulnerability to leptospirosis: 1) exposure to rat urine in the home and 2) awareness that rats carry leptospirosis. To assess exposure to rat urine, we asked respondents how frequently they smelled rat urine in or around their home in the last six months along a 5-point Likert frequency scale ranging from "Never" to "Daily or Almost daily". Respondents were considered to have been exposed to rat urine if they reported smelling rat urine in/around their home at least once in the past six months. To assess respondents' awareness that rats carry leptospirosis, we asked respondents if they thought the following four zoonotic diseases were carried by rats: leptospirosis and hantavirus (for which rats are known reservoirs) as well as rabies and West Nile Virus (for which rats are not known to be reservoirs). Respondents were considered to lack leptospirosis awareness if they responded "No" or "I don't know".

We included twelve explanatory variables in our analysis to test *a priori* hypotheses and account for respondent demographics. We first examined the relationship between information sources about rats and awareness that rats carry leptospirosis. To do so, we analyzed responses indicating where respondents had found information about rats in the past year. For the purposes of this analysis, we categorized information sources as either official sources (i.e., directly from governmental or professional organizations), unofficial sources, or not seeking information about rats. Official sources included pest professionals, City of Chicago posters, and the City of Chicago website. Unofficial sources included media such as television, radio, social media, other websites, as well as friends or family, neighbors, or other community members. We also tested the hypothesis that dog owners would be more aware that rats carry leptospirosis by comparing respondents who indicated whether or not they owned a dog.

We also adjusted for respondent characteristics that may influence the relationships described above. We asked about the frequency with which respondents saw rats in/around the home in the past six months, their housing type (houses with external doors such as single-family homes and townhouses vs. apartments), and whether the respondent rented or owned their home, as renters typically have less control over rat abatement in their home. We also asked about the respondents' age group and gender identity, which was presented as five categories; woman, man, non-binary, prefer not to say, and prefer to self-describe. Due to sample size (n = 8 non-binary or self-described), this analysis included only respondents who identified as a woman or man.

We included self-reported household income as well as race and ethnicity in our survey because exposure to rats in other studies has been associated with socioeconomic status, and socioeconomic indicators are historically correlated with income and race [21]. Racial or ethnic heritage was presented in nine categories that are consistent with the U.S. census [22]: Non-Hispanic White or Euro-American; Black, Afro-Caribbean, or African American; Latino or Hispanic American; East Asian or Asian American; South Asian or Indian American; Middle Eastern or Arab American; Native American or Alaskan Native; Prefer not say, and Prefer to self-describe. Most racial and ethnic groups were under-represented; for example, 29.2% of Chicago's population identifies as Black, Afro-Caribbean, or African American compared to only 6.7% of our survey respondents (Table A1). Further, several groups were too small (n < 10) to assess individually. For these reasons, we collapsed the responses into "white" and "non-white" categories in our analyses (e.g. [23]). We present our analyses including all racial and ethnic categories in the Supplemental Material (Table A2).

Because Chicago is highly segregated in terms of race, socioeconomic status, and environmental health [24, 25, 26], we associated respondents' demographics with other measures of environmental burdens through the Environmental Justice Index (EJI). The EJI is a national, place-based tool designed by the Centers of Disease Control and Prevention to measure the cumulative impact of environmental burden through the lens of human health and health equity [27]. To understand how exposures to rats are associated with other metrics of environmental health, we used respondents' self-reported location (i.e., closest major intersection) to identify their EJI score. EJI information is available at the census tract level, and ArcGIS Pro 3.0 was used to link respondent reported residences with EJI scores. To avoid assigning group level characteristics (e.g., census tract data) to individual respondents, we limited our analysis of EJI to only respondent demographics but did not include their experiences with rats.

Statistical Analysis

Statistical analysis was performed using RStudio v2022.02. A chi-square test was used to test the bivariate relationship between our variables of interest (Table 1). Multivariable binary logistic regression was used to evaluate the factors associated with rat urine exposure (exposed/not exposed) and lack of leptospirosis awareness (aware/not aware) separately. Multinomial logistic regression was used to evaluate a third model identifying factors associated with urine exposure and/or lack of leptospirosis awareness, with the group considered to be the most vulnerable being those exposed and not aware of

leptospirosis while the least vulnerable group being those not exposed to urine and aware of rats carrying leptospirosis. This model consisted of four nominal categories: respondents exposed to rat urine in the home and lacked leptospirosis awareness, respondents exposed to rat urine only, respondents that lacked leptospirosis awareness only, and respondents who reported neither. Variance Inflation Factor (VIF) was used to assess for multicollinearity between variables prior to model selection.

Table 1a Bivariate analysis of survey responses who were and were not exposed to rat urine in the home. Percentages and 95% confidence intervals are indicated in parentheses

	N	Urine in the Home (At least once)	Urine in the Home (Never)	Crude Odds Ratio	p-value
Total	432	157 (35.9)	280 (64.1)		
Income					
Under $50,000	133	62 (46.6)	71 (53.4)	1.90 (1.25, 2.90)	**0.003**
$50,000 +	299	94 (31.4)	205 (68.6)		
Non-White vs. White					
Non-White	145	81 (55.9)	64 (44.1)	3.58 (2.36, 5.47)	**<0.001**
White	287	75 (26.1)	212 (73.9)		
Housing Type					
Single-Family Home	216	68 (31.5)	148 (68.5)	0.67 (0.45, 0.99)	0.040
Apartment	216	88 (40.7)	128 (59.3)		
Housing Status					
Rent	148	58 (39.2)	90 (60.8)	1.22 (0.81, 1.84)	0.320
Own	284	98 (34.5)	186 (65.5)		
Gender					
Woman	263	95 (36.1)	168 (63.9)	1.00 (0.67, 1.50)	0.871
Man	169	61 (36.1)	108 (63.9)		
Age					
18-24	36	17 (47.2)	19 (52.8)	0.90 (0.51, 1.58)	0.742
25-34	110	30 (27.3)	80 (72.7)		

35-44	99	36 (36.4)	63 (63.6)		
45-54	72	32 (44.4)	40 (55.6)		
55-64	56	20 (35.7)	36 (64.3)		
65+	59	21 (35.6)	38 (64.4)		
Frequency of Rats in the Home					
Frequently	194	94 (48.5)	100 (51.5)	2.66 (1.79, 4.01)	**<0.001**
Rarely or Never	238	62 (26.1)	176 (73.9)		
Dog Ownership					
Yes	162	57 (35.2)	105 (64.8)	0.94 (0.62, 1.41)	0.836
No	270	99 (36.7)	171 (63.3)		
Information Source					
Official	296	107 (36.2)	189 (63.8)	1.22 (0.73, 2.06)	0.409
Unofficial	51	22 (43.1)	29 (56.9)	1.63 (0.79, 3.35)	
None	85	27 (31.8)	58 (68.2)		

Table 1b Bivariate analysis of respondents who were or were not aware that rats carry leptospirosis. Percentages and 95% confidence intervals are indicated in parentheses

	N	Lack of Leptospirosis Awareness	Aware of Leptospirosis	Crude Odds Ratio	p-value
Total	432	314 (72.7)	118 (27.3)		
Income					
Under $50,000	133	96 (72.2)	37 (27.8)	0.96 (0.61, 1.53)	0.968
$50,000 +	299	218 (72.9)	81 (27.1)		
White vs. Non-White					
Non-White	145	112 (77.2)	33 (22.8)	1.43 (0.90, 2.30)	0.132
White	287	202 (70.4)	85 (29.6)		
Housing Type					
Single-Family Home	216	159 (73.6)	57 (26.4)	1.09 (0.72, 1.68)	0.666
Apartment	216	155 (71.8)	61 (28.2)		
Housing Status					
Rent	148	108 (73.0)	40 (27.0)	1.02 (0.66, 1.61)	0.923
Own	284	206 (72.5)	78 (27.5)		
Gender					
Female	263	194 (73.8)	69 (26.2)	1.15 (0.74, 1.76)	0.53
Male	169	120 (71.0)	49 (29.0)		
Age					
18-24	36	30 (83.3)	6 (16.7)	Quadratic: 2.48 (1.28, 5.11)	**0.009**
25-34	110	83 (75.5)	27 (24.5)		
35-44	99	66 (66.7)	33 (33.3)		
45-54	72	53 (73.6)	19 (26.4)		

55-64	56	32 (57.1)	24 (42.9)		
65+	59	50 (84.8)	9 (15.2)		
Frequency of Rats in the Home					
Frequently	194	133 (68.6)	61 (31.4)	0.69 (0.45, 1.05)	0.083
Rarely or Never	238	181 (76.1)	57 (23.9)		
Dog Ownership					
Yes	162				
No	270				
Information Source					
Official	296	206 (69.6)	90 (30.4)	0.41 (0.21, 0.76)	**0.021**
Unofficial	51	36 (70.6)	15 (29.4)	0.43 (0.18, 1.00)	
None	85	72 (84.7)	13 (15.3)		

Table 1c Bivariate analysis of four nominal vulnerability categories: Most Vulnerable (exposed to urine in the home and unaware of leptospirosis in rats), Urine Exposed only, Lacking leptospirosis awareness only, and neither. Percentages and 95% confidence intervals are indicated in parentheses

	N	Most Vulnerable	Urine Exposed Only	Lack of Awareness Only	None	Chi-Square	p-value
Total	432	112 (25.9)	44 (10.2)	202 (46.8)	74 (17.1)		
Income							
Under $50,000	133	45 (33.8)	17 (12.8)	51 (38.3)	20 (15.0)	9.31	**0.025**
$50,000 +	299	67 (22.4)	27 (9.0)	151 (50.5)	54 (18.1)		
White vs. Non-White							
Non-White	145	63 (43.5)	18 (12.4)	49 (33.8)	15 (10.3)	40.63	**<0.001**
White	287	49 (17.07)	26 (9.06)	153 (53.31)	59 (20.56)		
Housing Type							
Single-Family Home	216	50 (23.1)	18 (8.3)	109 (50.5)	39 (18.1)	4.22	0.238
Apartment	216	62 (28.7)	26 (12.0)	93 (43.1)	35 (16.2)		
Housing Status							
Rent	148	42 (28.4)	16 (10.8)	66 (44.6)	24 (16.2)	1.03	0.794
Own	284	70 (24.7)	28 (9.9)	136 (47.9)	50 (17.6)		
Gender							
Female	263	66 (25.1)	29 (11.0)	128 (48.7)	40 (15.2)	0.94	0.815

Male	169	46 (27.2)	15 (8.9)	74 (43.8)	34 (20.1)		
Age							
18-24	36	14 (38.9)	3 (8.3)	16 (44.4)	3 (8.3)	27.05	0.028
25-34	110	20 (18.2)	10 (9.1)	63 (57.3)	17 (15.5)		
35-44	99	26 (26.3)	10 (10.1)	40 (40.4)	23 (23.2)		
45-54	72	22 (30.6)	10 (13.9)	31 (43.1)	9 (12.5)		
55-64	56	11 (19.6)	9 (16.1)	21 (37.5)	15 (26.8)		
65+	59	19 (32.2)	2 (3.4)	31 (52.5)	7 (11.9)		
Frequency of Rats in the Home							
Frequently	194	65 (33.5)	29 (15.0)	68 (35.0)	32 (16.5)	26.05	**<0.001**
Rarely or Never	238	47 (19.8)	15 (6.3)	134 (56.3)	42 (17.6)		
Dog Ownership							
Yes	162	38 (23.5)	19 (11.7)	68 (42.0)	37 (22.8)	7.42	0.060
No	270	74 (27.4)	25 (9.3)	134 (49.6)	37 (13.7)		
Information Source							
Official	296	73 (24.7)	34 (11.5)	133 (44.9)	56 (18.9)	9.60	0.142
Unofficial	51	16 (31.4)	6 (11.8)	20 (39.2)	9 (17.6)		
None	85	23 (27.1)	4 (4.7)	49 (57.6)	9 (10.6)		

We used an all-subsets approach to rank all combinations of explanatory variables – and their interactions – using Akaike Information Criterion (AIC) selection [28]. Models with delta-AIC < 2 were considered top models and averaged using Bayesian model averaging (Table 2) [29].

Table 2
Summary of competitive models (dAIC < 2) that were averaged to create final top models for exposure to rat urine, awareness of leptospirosis, and vulnerability (both exposure and awareness). The Rat Urine in the Home model and the Lack of Leptospirosis Awareness models are multivariate binary logistic regression models using Tjur's pseudo R squared. The Most Vulnerable model is a multinomial logistic regression model using McFadden's unadjusted and adjusted R squared

Response Variable	Model Ranking	Coefficients	Δ AIC	Model Weight	R-squared
Rat Urine in the Home	1	Race, Frequency of Rats in the Home	0.00	0.227	0.122
	2	Race, Frequency of Rats in the Home, Income	1.28	0.120	0.124
	3	Race, Frequency of Rats in the Home, Housing Type	1.78	0.039	0.123
	4	Race, Frequency of Rats in the Home, Gender	1.94	0.086	0.123
Lack of Leptospirosis Awareness	1	Age, Info Source, Dog Ownership	0.00	0.092	0.064
	2	Age, Info Source, Dog Ownership, Race	0.92	0.058	0.067
	3	Age, Info Source, Dog Ownership, Gender	1.10	0.053	0.067
	4	Age, Info Source, Dog Ownership, Frequency of Rats in the Home	1.51	0.043	0.065
	5	Age, Info Source, Dog Ownership, Income	1.52	0.043	0.065
	6	Age, Info Source, Dog Ownership, Race, Income	1.60	0.041	0.069
Most Vulnerable	1	Race, Dog Ownership, Frequency of Rats in the Home	0.00	0.362	0.060
	2	Race, Frequency of Rats in the Home	0.46	0.288	0.054

Results

In total, we received 665 at least partially completed surveys with an overall response rate of 14% (n = 4,750 surveys sent). Of respondents, 96% completed the survey online, and 96% of respondents chose to complete the survey in English. Our analysis group consisted of complete cases (i.e. missing none of the

variables in our analysis) from 432 respondents. Respondents who were excluded from our analysis due to missing data were more likely to be non-white (63%) and identify as men (57%) compared to the responses included in our complete case analysis (34% and 39% respectively).

Survey respondents in our analysis group were more likely to identify as women and as Non-Hispanic White or Euro-American relative to Chicago's population (Table A1). Overall, 61% of the respondents identified as women, which is higher than Chicago's 51.4%. Individuals identifying as Non-Hispanic White or Euro- American accounted for 56.5% of survey respondents, greater than Chicago's reported White population at 47.7%. Black, Afro-Caribbean, or African American individuals were largely underrepresented, accounting for 5.9% of survey responses but making up 29.2% of Chicago's population. Hispanic or Latino American respondents were also underrepresented, accounting for 14.9% of survey responses, but accounting for 28.6% of Chicago's population. Age statistics were generally representative of the local population (Table A1). However, respondents over 65 were slightly overrepresented. A disproportionate proportion of respondents were located in Chicago's North Side (Fig. 1), which is a historically predominantly white, higher income area. Among those who included geographic information, 70.9% of respondents were located in the North Side of Chicago, 11.0% in the South Side, and 16.9% in the West Side. In terms of demographic correlates with environmental health burdens, we found that non-white respondents were more likely to live in census tracts with more hazardous EJI rankings (GLM Z-score: 4.204, Standard Error: 0.1816, p-value: <0.001).

Exposure to rat urine

Out of 432 complete responses, 36% of respondents reported seeing urine in the home at least weekly (Table 1a). In the bivariate analysis, income, race, and frequency of rats in the home were significantly associated with urine exposure in the home. Our final top model for rat urine exposure in the home included the respondents' gender, white/non-white race, income, housing type and frequency of rat sightings in the home (Fig. 2). Respondents who identified as non-white had over three times higher odds of being exposed to urine in the home than those who identified as white (OR: 3.20 [2.06, 4.98]). Respondents who reported seeing rats in the home frequently had 2.4 times the odds of being exposed to urine in the home compared to those who reported seeing rats rarely or never (OR: 2.37 [1.56, 3.61]).

Lack of Leptospirosis Awareness

Out of 432 complete responses, 72% of respondents were unaware that rats carry leptospirosis (Table 1b). In the bivariate analysis, age (quadratic relationship) and information source were significantly associated with a lack of leptospirosis knowledge. Our final top model for awareness that rats carry leptospirosis included respondents' age, gender, white/non-white race, income, information sources, dog ownership, and frequency of rats in the home (Fig. 2). Respondents aged 18–24 and over 65 were significantly less likely to be aware that rats carry leptospirosis than intermediate age categories (i.e., quadratic relationship; OR: 2.42 [1.18, 5.00]). Respondents who sought out information about rats were more likely to be aware that rats carry leptospirosis than respondents who did not seek out

information about rats; however, contrary to our hypothesis, there was no significant difference between respondents who sought information from unofficial or official sources (OR Official sources: 0.39 [0.16, 0.93], Unofficial sources: 0.46 [0.24, 0.90]). Respondents who reported being dog owners were less likely to be unaware that rats carry leptospirosis than those who did not own a dog (OR: 0.57 [0.36, 0.89]).

Most Vulnerable Model:

We defined the “most vulnerable” group as those who were exposed to rat urine in the home and also lacked awareness of leptospirosis in rats. We designated the “least vulnerable” group as people who were not exposed to rat urine and who were aware of leptospirosis. Of our analysis subset, 26% of respondents were designated as most vulnerable (Table 1c). In the bivariate analysis, income, race, and frequency of rats in the home had a statistically significant association with being considered most vulnerable. Our final top model for factors associated with vulnerability to leptospirosis included white/non-white race, dog ownership, and frequency of rats in the home (Fig. 2). Compared to white respondents, respondents who identified as non-white had over four times the odds of being in the “most vulnerable” category than “least vulnerable” (OR: 4.81 [2.42, 9.10]). Dog owners had 50% decreased odds of being in the most vulnerable category compared to respondents who did not report owning a dog (OR: 0.49 [0.26, 0.91]).

Discussion

The goal of this study was to understand which urban populations are more vulnerable to rat-associated diseases by identifying factors associated with of two aspects of vulnerability to leptospirosis: 1) exposure to rat urine in the home and 2) lack of awareness that rats carry leptospirosis. We found that non-white respondents and those who see rats in the home at least weekly are more likely to observe rat urine in the home and that middle-aged respondents, dog owners, and those who seek out information about rats are more likely to be aware that rats carry leptospirosis. When we examined both aspects of vulnerability simultaneously, we found that residents most vulnerable to leptospirosis (who had been exposed to urine and were not aware that rats carry leptospirosis) were more likely to be non-white and less likely to be dog owners.

Non-white residents were more likely to observe rat urine in their homes and more likely to be designated “most vulnerable” to leptospirosis based on our multinomial models. There are limitations to grouping residents into white and non-white categories because we lose the experiences of specific groups of people. However, these broad disparities in exposure to rats add to environmental justice issues that have been at the forefront of public health issues in Chicago for many years due its history of segregation and redlining [30]. Even today, historic redlining has been shown to impact health outcomes for non-white Chicago residents. After the outbreak of COVID-19 in March of 2020, historically low-graded (i.e. red-lined) neighborhoods displayed a sharper increase in mortality borne by Black residents [30]. Although our data are correlational, non-white respondents may have been more likely to report rat waste in their homes because they were also more likely to live in census tracts with more hazardous EJI rankings, suggesting systemic issues with investment and infrastructure for communities of color. Indeed, exposure to rats may be considered another environmental health burden that should be considered when quantifying

environmental public health issues that are disproportionately persistent in non-white underserved communities similarly to other burdens such as air pollution and heat [27].

In addition to respondent demographics, we also found that dog ownership significantly increased the odds of survey respondents being aware that rats carry leptospirosis and being designated as “least vulnerable”. Studies show rates of leptospirosis are rising in dogs in Chicago [10]. However, a leptospirosis vaccine is commonly offered by veterinarians and highly recommended for dogs who frequently spend time outside [31]. It is possible that dog owners are getting information about leptospirosis through interactions with their veterinarian. The point of contact with a veterinary office is an opportunity to educate dog owners not only about leptospirosis in dogs, but also in rats and possible human exposures. An information packet given at the time of the appointment or immunization could be a helpful informational resource to spread awareness of leptospirosis risks and other rat-associated zoonoses for humans as well as pets.

Contrary to our predictions, we found no significant difference in awareness between respondents who sought information about rats from official and unofficial sources. Individuals who sought information from unofficial sources, such as television, social media, friends and family, or other community members, were over 30% more likely to be aware of leptospirosis in rats than those who sought information from official City of Chicago sources or pest professionals. This suggests that information shared through informal networks of community members may be helpful for reducing risk. Websites maintained by municipalities and university extension offices could do more to highlight a range of rat-associated health risks, including urine and feces. For example, the City of Chicago website highlights the risks associated with rat fleas, but does not mention the risks associated with rat feces and urine [32]. We suggest that official information sources add more detailed information about rat associated zoonoses and how residents can protect themselves from possible exposures. For example, the Centers of Disease Control offers infographics summarizing how to safely clean up rat waste [33]. However, it is important to consider that residents may seek out information about rats following exposure to rat urine, and so they may not be aware of the risks until after they have been exposed.

Despite an effort to capture a representative sample from across an income gradient in Chicago by mailing random households, there is some bias in our sample, which is a challenge faced by many surveys. While we offered the study in several languages, 96% of respondents completed the survey in English. As mentioned previously, our sample over-represented white residents and under-represented Black/African American and Latino residents, limiting our ability to understand the experiences of different communities of color. There also may have been a bias in those who chose to respond to the survey; people with rat problems or strong opinions about rats are likely more inclined to respond to a rat survey. However, even though this survey may have selected for respondents with previous rat issues, we still saw a large portion of respondents lacking awareness of leptospirosis in rats, demonstrating there is still a need for education even among those who show interest in learning more about rat-associated zoonoses. Our findings highlight the need for relationship building and community-engaged approaches in order to gather information about rat infestations from historically excluded groups that may mistrust

the medical and research community due to past injustices [34]. In addition, a multi-city study would allow for a more generalizable picture of leptospirosis vulnerability across different metropolitan layouts, cultures, and climates.

Conclusion

In this study, we aimed to identify factors associated with leptospirosis vulnerability in Chicago. We found that residents of color were most vulnerable, mainly based on exposure to urine in the home, while dog owners were least vulnerable, mainly based on awareness that rats carry leptospirosis. Exposure to rats is an environmental health issue that is often not quantified by traditional metrics, and a better understanding of who is vulnerable to rat-associated zoonoses is important in our rapidly urbanizing world.

Declarations

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Figures

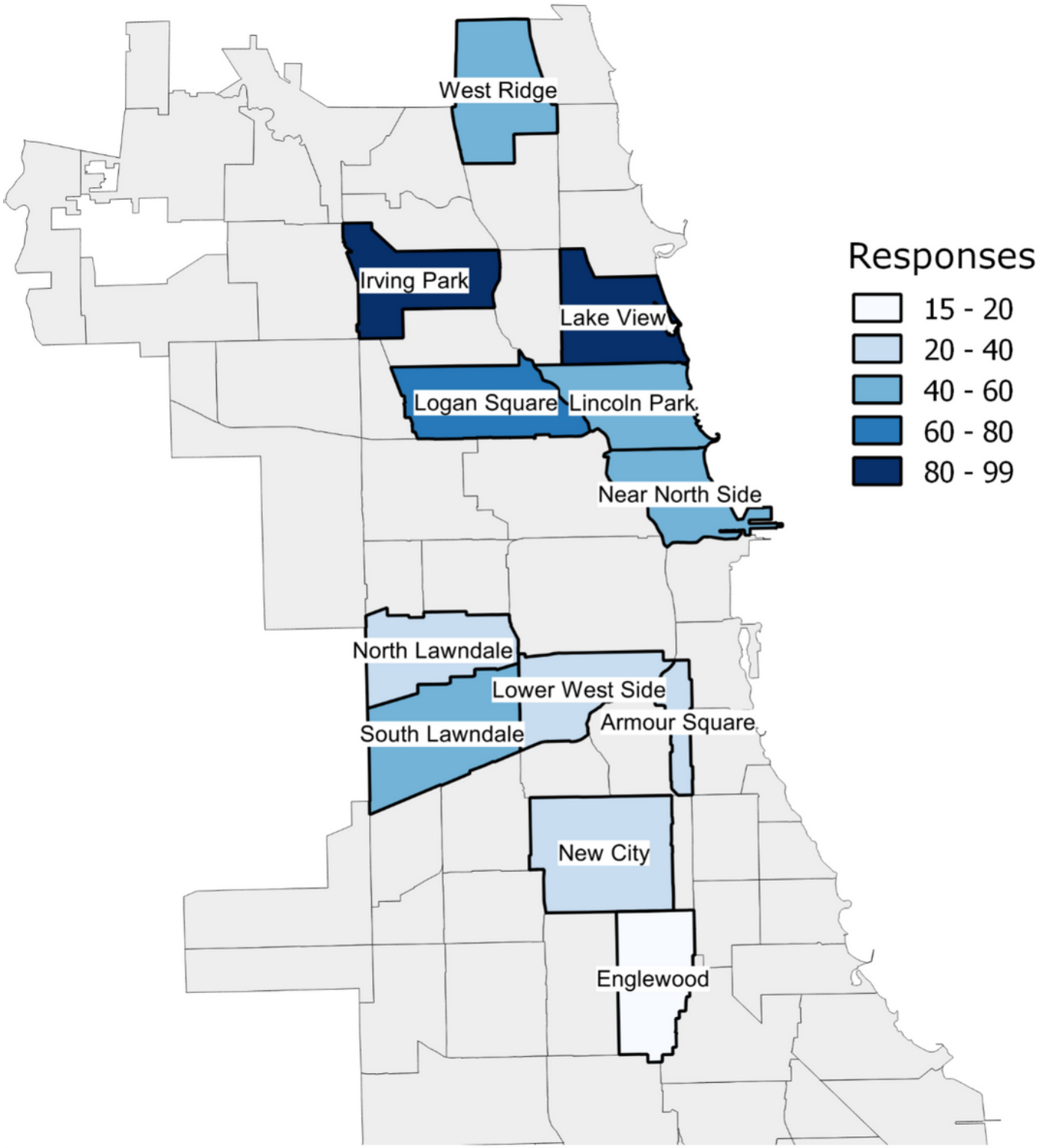

Figure 1

Map of survey responses by community area in Chicago. Shading indicates the number of survey responses

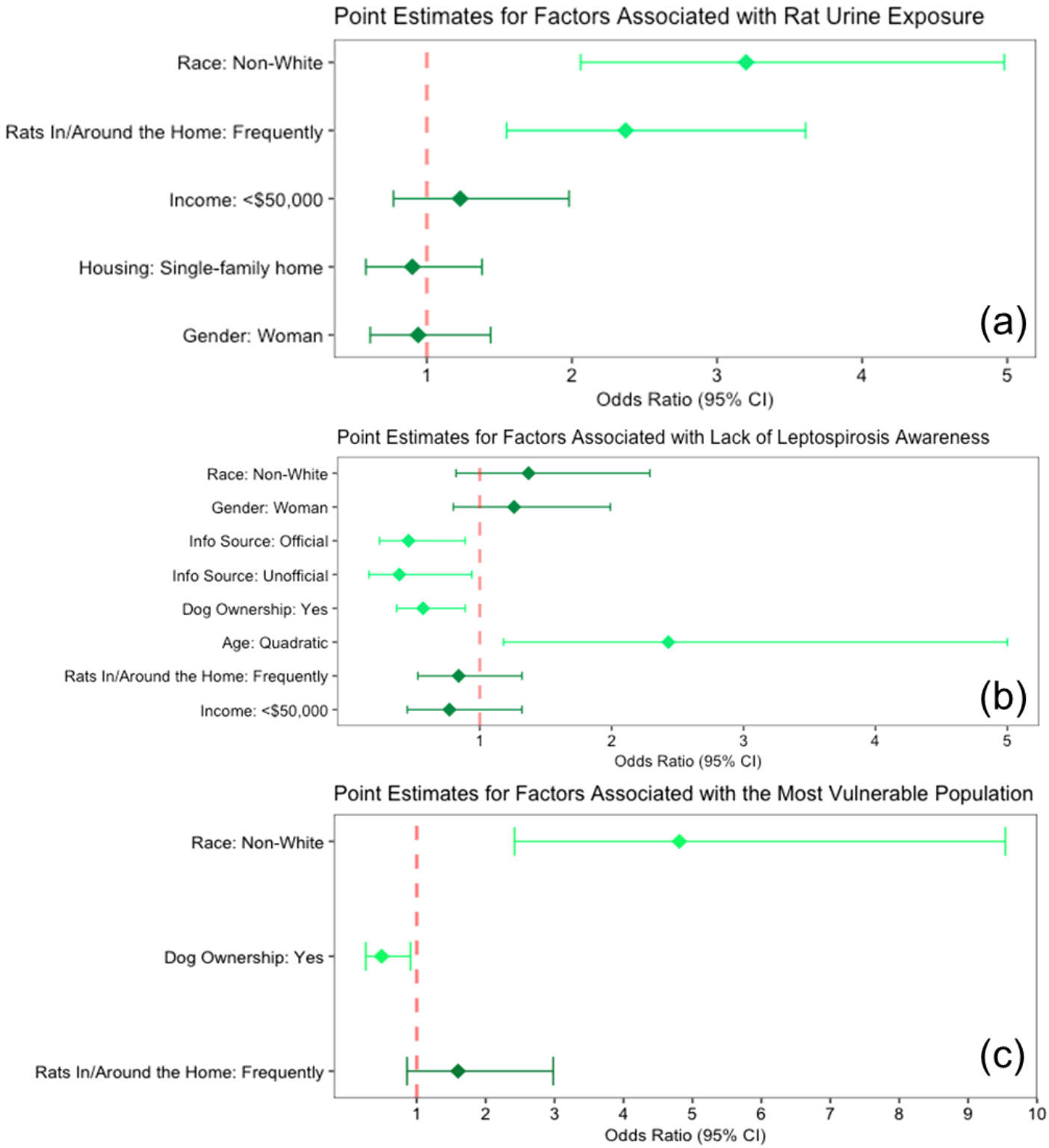

Figure 2

Forest plot of odds ratios and 95% confidence intervals from the final averaged top model from the binomial logistic regression for (a) rat urine exposure in the home, (b) lack of awareness of leptospirosis carriage by rats, and (c) multinomial logistic regression for the most vulnerable population (i.e. exposed to rat urine and not aware that rats carry leptospirosis). Light green coloring represents statistical significance

Supplementary Files

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