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Research Article

# Social and environmental correlates of rat complaints in Chicago

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## Abstract

Urban rats are widely distributed pests that have negative effects on public health and property. It is crucial to understand their distribution to inform control efforts and address drivers of rat presence. Analysing public rat complaints can help assess urban rat distribution and identify factors supporting rat populations. Both social and environmental factors could promote rat complaints and must be integrated to understand rat distributions. We analysed rat complaints made between 2011 and 2017 in Chicago, a city with growing rat problems and stark wealth inequality. We examined whether rat complaints at the census tract level are associated with factors that could influence rat abundance, rats' visibility to humans, and the likelihood of people making a complaint. Complaints were significantly positively correlated with anthropogenic factors hypothesized to promote rat abundance (restaurants, older buildings, garbage complaints, and dog waste complaints) or rat visibility (building construction/demolition activity), and factors hypothesized to increase the likelihood of complaining (human population density, more owner-occupied homes); we also found that complaints were highest in the summer. Our results suggest that conflicts between residents and rats are mainly driven by seasonal variation in rat abundance and human activity and could be mitigated with strategies such as securing food waste from residential and commercial sources. Accounting for social factors such as population density, construction and demolition activity, and home ownership versus rental can also help cities more accurately predict blocks at higher risk of rat conflicts.

Key words: human-wildlife interactions, public complaints, *Rattus*, socio-ecological system, spatial ecology

## Introduction

Urban brown rats (*Rattus norvegicus*) and black rats (*Rattus rattus*) are widely distributed pest species that have numerous negative effects on humans. Rats are vectors of bacterial (e.g. *Yersinia pestis*, *Leptospira* spp. and *Escherichia coli*) and viral (e.g. Seoul hantavirus) pathogens that can be transmitted to humans (Himsworth et al. 2013; Strand and Lundkvist 2019). Rats can also contribute to negative mental health outcomes such as symptoms of anxiety for residents facing rat infestations in their dwelling or neighbourhood (Zahner et al. 1985; Lam, Byers, and Himsworth 2018). Other harmful impacts of rats include rat bites (Childs et al. 1998; Hirschhorn and Hodge 1999), property damage (Pimentel et al. 2000; Martindale 2001; Battersby 2002)

and food spoilage (Pimentel et al. 2000). These impacts can be large for disadvantaged populations such as the homeless or drug users (German and Latkin, 2016; Leibler et al. 2016; Byers et al. 2019a). Although the damages from rat infestations are diverse, severe, and occur worldwide, urban rats are understudied, which limits evidence-based pest management in cities (Parsons et al. 2017; Desvars-Larrive et al. 2018). Municipal governments worldwide spend millions of dollars to control rat populations but are unsuccessful in eradicating rat populations. To maximize the efficacy of limited staff and funding to control rats, it is therefore important to understand the drivers of rat distributions to inform rat control efforts.

A better understanding of rat distributions in cities would help mitigate rat infestations by prioritizing rodent control where it is most needed. A growing literature has identified landscape variables associated with rats such as low incomes and vacant housing (Rael et al. 2016), older buildings (Langton, Cowan, and Meyer 2001; Walsh 2014), and poor sanitation (Langton, Cowan, and Meyer 2001; Himsworth et al. 2013; Murray et al. 2018). However, identifying areas with high rat densities by directly measuring rat populations is nearly impossible in large cities due to lack of resources for researchers, cryptic rat behavior, and inaccessibility of many rat habitats (e.g. under buildings, in sewers) (Desvars-Larrive et al. 2018). As an alternative to large-scale trapping or monitoring programs, many cities collect rat complaints via phone calls or online forms to prioritize areas most in need of rodent control (Margulis 1977). These complaints provide an indirect measure of where rats are present. In Chicago, rat complaints were positively correlated with rat relative abundance and rented housing units but negatively correlated with vacant land at the scale of community areas (Murray et al. 2018). At a finer scale, alleys with uncontained garbage were more likely to have more rats and more rat complaints (Murray et al. 2018). Similarly, in New York City, rat complaints were associated with subway lines and recreational public spaces, older buildings, vacant housing units, and low education, emphasizing the complex relationships between rat abundance and likelihood of complaints (Walsh 2014).

The relationships between rat complaints, environmental conditions, and socioeconomic status in previous work suggest that complaints could be used as a proxy for risk of rat infestations but are likely mediated by both biological factors (e.g. food availability) and social factors such as opportunities for residents to see rats or willingness to make a complaint. For example, rat complaints might be higher during times such as late summer when rats are more abundant (Feng and Himsworth 2014) and people are more active outside, or at locations with accessible food such as garbage. Rat complaints might also be higher in contexts in which residents are aware that rats are present. For example, building construction is anecdotally thought to promote rat problems in nearby areas by displacing rats above ground where they can be seen (Hu 2019). Demographic and socioeconomic factors might also mediate rat complaints because residents may be more likely to complain if they are aware that they can and should complain, and believe that complaining will lead to positive action (Margulis 1977). Control efforts might be more successful by viewing rat infestations as part of an urban social-ecological system in which conflicts with rats are promoted by rat abundance and human behavior.

Here, we tested whether rat complaints increased with both social and environmental factors we hypothesized would increase rat abundance, rats' visibility to humans, and the likelihood of people making a complaint. To do so, we analysed a multi-year dataset of rat complaints in Chicago, a city with growing rat concerns (Murray et al. 2018) and large racial wealth inequality (Racial Wealth Divide Initiative 2017), meaning rat impacts may also be unequally distributed across the city. We predicted that complaints would be higher in areas with rat attractants such as garbage, or harbourage such as older buildings. Rats must be observed by people in order for a complaint to be made, so we also predicted that complaints would be higher where there are more people to see rats or where rats are disturbed from construction. Lastly, we predicted that complaints would be higher where residents have higher levels of education or small children because these factors could contribute, respectively, to residents' knowledge and motivation to complain. Our results can be used to more accurately predict which communities are at higher risk of rat infestations to efficiently control rat populations and mitigate damage to public health and infrastructure.

## Methods

### Study area

We analysed rat complaints in Chicago, Illinois, USA, a large city with approximately 2.7 million residents (U. S. Census Bureau 2019a). Complaints about rats and other sanitation concerns can be made by contacting Chicago's 311 city services via phone, a website, or a mobile app. Chicago's Department of Streets & Sanitation investigates all rat complaints and places rodenticide in burrows if deemed appropriate (City of Chicago 2020a). Rats are a growing issue in Chicago and complaints increased by nearly 40% between 2008 and 2017 (Murray et al. 2018). We analysed rat complaints made from 2011 to 2017 to capture seasonal and annual variation and because complaints during these years were recorded consistently (see below).

### Dataset assembly and explanation of variables

#### *Complaint data, restaurant data and building permit data*

All statistical and spatial analyses were performed in the R computing environment v 3.6.1 (R Core Team 2019). A detailed description of all variables described below is provided in Table S1. We compiled spatial and temporal information about rats and humans from 311 city service data stored on the Chicago data portal (https://data.cityofchicago.org/). We accessed a rodent baiting/rat complaint dataset (City of Chicago 2019a) and extracted the date and geographic coordinates for each complaint. We restricted our analyses only to rat complaints for which the *Most Recent Action* was 'Inspected and baited,' as this indicates evidence of rats truly being present (in comparison to e.g. mice being mistaken for rats).

We included data related to garbage, dog faeces and restaurants in our dataset as we predicted these would provide food for rats, thereby increasing their abundance. Dog waste has been described as 'the No. 1 food source for rats' in Chicago (Spielman 2016, but see Murray et al. 2018) yet this relationship remains anecdotal. We accessed a sanitation complaint dataset (City of Chicago 2019b) and extracted the complaint date, coordinates, and type of sanitation violation reported. We condensed five sanitation violations into two categories: *garbage* (garbage in alley, garbage in yard, dumpsters not emptied,

overflowing carts) and *dog faeces* (dog faeces in yard). We did not include other sanitation violations (construction site cleanliness/fence, graffiti commercial vehicle, standing water, other), as we had no *a priori* expectation that these would influence rat presence. From a food establishment inspection dataset (City of Chicago 2019c), we extracted the inspection date, street address, and coordinates of establishments marked as *Restaurant*. We excluded inspections of out of business establishments and inspections where the business could not be located. We then removed any duplicate inspections of a restaurant within a given year, as our goal was to approximate the number of restaurants.

From a building permit dataset (City of Chicago 2019d), we extracted the permit issue date, coordinates, and permit type. We included two permit types we hypothesized would disturb rats (*new construction* and *wrecking/demolition*), thus increasing rat activity and visibility to humans. The building permit dataset did not include the start date or duration of construction/demolition activity. However, a permit must be reinstated if construction has not begun within 6 months of permit approval (City of Chicago 2020b); therefore we believe permit issue date is a reasonable proxy for construction/demolition activity.

Chicago's 311 services switched to a new system in December 2018, and rat complaints from 2011 up to that point were stored in a historical database. We therefore chose to restrict our analysis to the period of 1 January 2011 to 31 December 2017. We assigned record dates to one of four yearly quarters (Quarter 1: January–March; Quarter 2: April–June; Quarter 3: July–September; Quarter 4: October–December). We predicted that rat complaints would be highest in the late summer when rat population density is highest (Feng and Himsworth 2014). Previous studies have examined correlates of rat complaints at the scale of neighbourhood or community area (Murray et al. 2018). Rats typically have home ranges of approximately 150 m or one city block (Byers et al. 2019b), making it crucial to examine correlates of rat complaints at a finer scale, such as the census tract level (Walsh 2014). We downloaded a shapefile of Chicago census tract boundaries (City of Chicago 2013) for the year 2010 and used the 'sp' package (Pebesma and Bivand 2005; Bivand, Pebesma, and Gomez-Rubio, 2013) to determine the corresponding census tract for each rat complaint, sanitation complaint, building permit, and restaurant. We then calculated the number of rat complaints, sanitation complaints, and building permits issued in each census tract for every quarter from 2011 to 2017 (28 quarters total), and the number of restaurants in each census tract for every year.

#### *Socioeconomic and demographic data*

We extracted socioeconomic and demographic data at the census tract level for the years 2011–2017 from the American Community Survey (2018: ACS 5-Year Estimates Data Profiles; https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/). The data profiles contain commonly requested social, economic, housing and demographic data. Only 5-year estimates were available at the census tract level; although 1-year estimates are better able to reflect yearly changes in data, 5-year estimates have smaller margins of error than 1-year estimates. From a social characteristics data profile (U. S. Census Bureau 2019b), we extracted percent of residents with a graduate degree, because rat sightings have been associated with low education levels (Walsh 2014). From an economic characteristics data profile (U. S. Census Bureau 2019c), we extracted median household income. We adjusted all median household income values for inflation (to 2017 dollars) using inflation adjustment factors derived from the Consumer Price Index (All Items R-CPI-U-RS annual averages; U. S. Census Bureau; U. S. Bureau of Labor Statistics 2020). We included household income as a variable because we hypothesized that lower-income areas might support higher rat abundances, likely because there are fewer resources for building maintenance and rodent control (Vadell, Cavia, and Suárez 2010; Rael et al. 2016). Conversely, residents in higher income areas might be more likely to make a 311 complaint if they saw rats. From a housing characteristics data profile (U. S. Census Bureau 2019d), we extracted percent vacant housing units, percent structures built pre-1950, percent owner-occupied housing units, and percent overcrowded housing units ($\geq$ 1.51 occupants per room). Vacant housing can promote rats (Rael et al. 2016) and we hypothesized that older buildings could provide rat harbourage and that property owners would be more motivated to complain about rats than renters. We also hypothesized that crowded housing might promote conditions beneficial to rats (e.g. more garbage) and increase the number of people available to observe rats. From a demographic and housing estimates data profile (U. S. Census Bureau 2019e), we extracted total population and percent under 5 years. Previous work found that children under the age of 5 are more likely to be bitten by rats than other age groups (Coombe and Marr 1980; Hirschhorn and Hodge 1999) and so we hypothesized that families with young children would be more motivated to complain about rats. We calculated the area of each census tract in square kilometres using the 'raster' package (Hijmans 2019), and calculated census tract population density by dividing total population by area; population density values were log-transformed for all analyses described below.

### Statistical analyses

Our response variable was the number of rat complaints in a given census tract, quarter, and year. In data exploration, we found a large number of zeros in this response variable, which we hypothesized were a mixture of true zeros (i.e. no rat complaints made because no rats are present) and false zeros (no rat complaints made because e.g. rats are present but not observed; rats are observed but not reported). We therefore chose to model rat complaints with zero-inflated generalized linear mixed models (GLMMs) using the 'glmmTMB' package (Brooks et al. 2017). Zero-inflated models or 'mixture' models assume that true zeros and non-zero counts are generated via a count process (modelled with a Poisson or negative binomial model and log link) and that false zeros are generated via a separate process (modelled with a binomial model and logit link) (Zuur et al. 2009). However, it is not necessary to identify true and false zeros, or to split the data into true and false zeros, in order to perform the analysis.

Rat complaints were over-dispersed, indicating that a Poisson distribution was not appropriate. We therefore first fit two global zero-inflated models (i.e. all explanatory variables in conditional component, no interactions): one where the count process was modelled with a quasi-Poisson distribution (variance is a linear function of the mean rather than equal to the mean) and one where the count process was modelled with a negative binomial distribution (variance increases quadratically with the mean) (Brooks et al. 2017). All explanatory variables were mean-centered and scaled by their standard deviation to facilitate comparison of variable importance. We checked for collinearity using the 'performance' package (Lüdecke, Makowski, and Waggoner 2020); all variables had variance inflation factors $< 4$ (Zuur, Ieno, and Elphick 2010). Year and census

**Table 1:** Comparison of 10 candidate ZINBs used to predict rat complaints as a function of multiple social and environmental variables

| Candidate model | Variables | ΔAIC |
|---|---|---|
| Global | % structures built pre-1950 + % vacant housing units + dog faeces complaints + garbage complaints + restaurants + construction/demolition permits issued + quarter + median household income + % graduate degree + % owner-occupied units + % under 5 years +log (population density) + % overcrowded rooms | 0.0 |
| All environmental variables | % structures built pre-1950 + % vacant housing units + dog faeces complaints + garbage complaints + restaurants + construction/demolition permits issued + quarter | 24.7 |
| Season | Quarter | 356.3 |
| Attractants | Dog faeces complaints + garbage complaints + restaurants | 4696.4 |
| Disturbance | Construction/demolition permits issued | 5091.4 |
| Harbourage | % structures built pre-1950 + % vacant housing units | 5133.3 |
| All social variables | Median household income + % graduate degree + % owner-occupied units + % under 5 years + log (population density) + % overcrowded rooms | 5172.2 |
| Human density | Log (population density) + % overcrowded rooms | 5174.8 |
| Demographics | % owner-occupied units + % under 5 years | 5212.6 |
| Socioeconomics | Median household income + % graduate degree | 5213.7 |

Median household income values were adjusted for inflation (to 2017 dollars). All models included year and census tract as random effects in the conditional portion of the model.

tract were also included in the conditional portion of each model as random effects. The zero-inflated portion of the model was held at 1 at this stage in the modelling process. We compared the two global models with Akaike's information criteria (AIC) using the 'bbmle' package (Bolker 2017) and found that the model with a negative binomial distribution was best supported (ΔAIC of quasi-Poisson model = 823.8). We therefore used this distribution for all further models.

We next compared the global zero-inflated negative binomial (ZINB) model against a set of nine ZINB models representing different hypotheses about how rat complaints could vary across Chicago (Table 1). With these models, we tested whether the number of rat complaints varied as a function of (1) harbourage (% structures built pre-1950, % vacant housing units), (2) attractants (dog faeces complaints, garbage complaints and restaurants), (3) disturbance (construction/demolition permits), (4) human density (population density, % overcrowded rooms), (5) socioeconomic factors (median household income, % graduate degree), (6) demographic factors (% owner-occupied units, % under 5 years) or (7) season (quarter). We also considered a model (8) with all environmental variables (% structures built pre-1950, % vacant housing units, dog faeces complaints, garbage complaints, restaurants, construction/demolition permits and quarter) and a model (9) with all social variables (median household income, % graduate degree, % owner-occupied units, % under 5 years, population density and % overcrowded rooms) (Table 1). Year and census tract were again included as random effects in the conditional portion of the model, and the zero-inflated portion of the model was still held at 1. We again used AIC to compare models, and considered models with ΔAIC of 0–2 to have substantial support (Burnham and Anderson 2002). Finally, we re-ran the best-supported model, but this time all explanatory variables were included in the zero-inflated portion of the model. We chose this approach given that we had no *a priori* hypotheses about which variables might be most important, and wanted to generate hypotheses about processes that drive false zeros to guide future research. No random effects were included in the zero-inflated portion of the model as this led to unreliable parameter estimates.

## Results

We analysed social and environmental correlates of 211 028 confirmed rat complaints made from 1 January 2011 to 31 December 2017. The median number of rat complaints in a census tract during a year and quarter was 6 (range 0–136, interquartile range: 2–13). During the study period, 61 366 garbage complaints and 6 631 dog faeces complaints were made, and 19 625 construction/demolition permits were issued. Rat complaints, garbage complaints, and issuance of construction/demolition permits exhibited hump-shaped relationships with time, with a peak in Quarter 3 (July–September), while dog faeces complaints generally decreased over the course of a year (Fig. 1).

The global model (i.e. all explanatory variables) was best supported in our model comparison (Table 1). Nine explanatory variables in the conditional portion of the global model were significantly correlated with the number of rat complaints (Table 2). Compared to Quarter 1 (January–March), rat complaints were significantly higher in all other quarters (Q3 > Q2 > Q4 > Q1), and highest in Quarter 3 (July–September; incident rate ratio (IRR) = 2.56, $P < 2$ e-16). In addition, more rat complaints were associated with higher human population density (IRR = 1.16, $P = 2.0$ e-7), a larger percent of structures built before 1950 (IRR = 1.16, $P = 1.3$ e-15), more restaurants (IRR = 1.13, $P = 4.4$ e-9), and more garbage complaints (IRR = 1.07, $P < 2$ e-16); these relationships are visualized with marginal effects plots (Fig. 2). Rat complaints were also correlated with a larger percent of owner-occupied units (IRR = 1.06, $P = 0.01$), more dog faeces complaints (IRR = 1.02, $P = 4.8$ e-7), more construction/demolition permits issued (IRR = 1.02, $P = 6.5$ e-5), and a smaller percent of residents under the age of 5 (IRR = 0.98, $P = 0.01$). We did not find a significant effect of four explanatory variables: % with a graduate degree, % overcrowded rooms, % vacant housing units and median household income (Table 2). Using the global model, we predicted rat complaints in Quarter 3 for all census tracts; complaints were generally predicted to be higher in the northern parts of the city (Fig. 3).

Of the variables included in the zero-inflated portion of the model, five were significantly correlated with the probability of

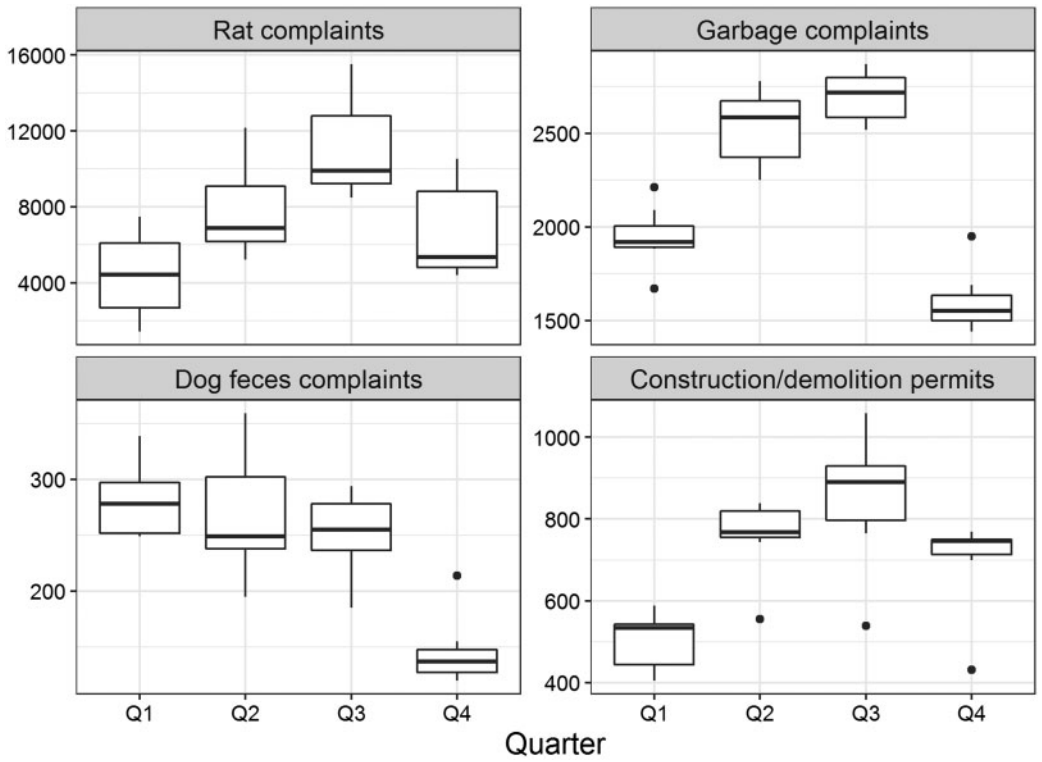


**Figure 1:** Rat complaints, garbage complaints, dog faeces complaints, and construction/demolition permits issued by year and quarter (Q1: January–March, Q2: April–June, Q3: July–September, Q4: October–December), from 2011 to 2017 in Chicago, Illinois. Data are from the Chicago 311 city services, accessed via the Chicago Data Portal. Note the different scales on the y-axis of each sub-plot.

a false zero (no rat complaints made because e.g. rats are present but not observed; rats are observed but not reported) (Table 2). Specifically, a higher probability of a false zero was associated with fewer garbage complaints (odds ratio (OR) = 0.07, $P = 4.6$ e-3), a smaller percent of structures built before 1950 (OR = 0.30, $P = 1.2$ e-3), lower population density (OR = 0.68, $P = 3.4$ e-3) and a larger percent with a graduate degree (OR = 2.53, $P = 0.01$). Compared to Quarter 1, the probability of a false zero was not significantly different in Quarter 2, but was significantly less in Quarter 3 (OR = 0.29, $P = 0.02$) and Quarter 4 (OR = 0.28, $P = 0.02$).

We visualized census tracts that had greater or fewer rat complaints than expected, controlling for the variables in the global model (Fig. S1). Areas in the south, along the lakefront, and in the northwest had fewer rat complaints than expected by the fixed effects of the global model, while areas in north and mid-Chicago had more complaints than expected (Fig. S1).

## Discussion

We found that it is important to consider both social and environmental variables to understand the distribution of rat complaints, and in turn, rats themselves (Fig. 4). We found positive correlations between rat complaints in Chicago and environmental factors that could promote rat abundance (restaurants, garbage, dog faeces, older buildings and season), as well as social factors that could increase rat visibility (human population density and disturbance) and willingness to make a complaint (owner-occupied units). Our results emphasize the complex, socio-ecological nature of rat-human interactions, and can be used to inform rat mitigation strategies.

### Factors promoting rat abundance

Attractants associated with human food, including the number of restaurants and the number of garbage complaints, were important correlates of rat complaints; garbage complaints were also negatively correlated with the probability of a false zero. Previous work at a larger spatial scale (community area) in Chicago also found that uncontained garbage was strongly associated with rat abundance and complaints (Murray et al. 2018), while in New York City, locations of rat sightings were positively correlated with the density of food service establishments (Parsons et al. 2020). Food waste produced by restaurants, as well as other waste generated by residents, likely serves as an abundant, predictable resource that attracts rats and allows their populations to grow. Indeed, during the COVID-19 pandemic, when many restaurants closed or offered reduced service, the US Centers for Disease Control and Prevention issued a statement warning of possible increases in rodent activity as rats search for new food sources (Centers for Disease Control and Prevention. 2020). Reducing available food and garbage could be jointly addressed by residents (e.g. securing garbage in heavy-duty 'super carts' supplied by the city) and commercial businesses (e.g. more frequent trash collection in areas with greater numbers of restaurants).

Dog faeces complaints were also positively correlated with rat complaints, though the effect size was smaller compared to the number of restaurants and garbage complaints. Street signs in Chicago encourage dog owners to pick up after their dogs ('Dog waste attracts and feeds rats'), but our findings indicate dog faeces might be relatively less important as a rat food source than garbage. Alternatively, the smaller effect size for

**Table 2:** Model coefficients for the best-supported model (i.e. global model)

| Parameter | Estimate | SE | IRR/OR | 95% CI | z | P |
|---|---|---|---|---|---|---|
| **Conditional model** | | | | | | |
| Quarter 1 | — | — | — | — | — | — |
| Quarter 2 | 0.57 | 0.02 | 1.77 | 1.72–1.82 | 36.80 | **<2 e-16** |
| Quarter 3 | 0.94 | 0.02 | 2.56 | 2.49–2.64 | 60.78 | **<2 e-16** |
| Quarter 4 | 0.49 | 0.02 | 1.63 | 1.58–1.68 | 31.66 | **<2 e-16** |
| Construction/demolition permits | 0.02 | 0.01 | 1.02 | 1.01–1.03 | 3.99 | **6.51 e-5** |
| Dog faeces complaints | 0.02 | 0.00 | 1.02 | 1.01–1.03 | 5.03 | **4.83 e-7** |
| Garbage complaints | 0.07 | 0.01 | 1.07 | 1.06–1.09 | 12.42 | **<2 e-16** |
| Restaurants | 0.12 | 0.02 | 1.13 | 1.09–1.18 | 5.87 | **4.36 e-9** |
| % with graduate degree | −0.01 | 0.02 | 0.99 | 0.94–1.03 | −0.57 | 0.57 |
| Median household income | −0.03 | 0.02 | 0.97 | 0.93–1.02 | −1.28 | 0.20 |
| % vacant housing units | −0.03 | 0.01 | 0.97 | 0.95–1.00 | −1.93 | 0.05 |
| % owner-occupied units | 0.06 | 0.02 | 1.06 | 1.02–1.11 | 2.75 | **0.01** |
| % units built pre-1950 | 0.15 | 0.02 | 1.16 | 1.12–1.20 | 8.00 | **1.27 e-15** |
| % overcrowded rooms | −0.00 | 0.01 | 1.00 | 0.98–1.02 | −0.09 | 0.93 |
| % residents under 5 years | −0.02 | 0.01 | 0.98 | 0.96–1.00 | −2.48 | **0.01** |
| Log (population density) | 0.15 | 0.03 | 1.16 | 1.10–1.23 | 5.20 | **2.04 e-7** |
| **Zero-inflated model** | | | | | | |
| Quarter 1 | — | — | — | — | — | — |
| Quarter 2 | −0.46 | 0.58 | 0.63 | 0.20–1.98 | −0.79 | 0.43 |
| Quarter 3 | −1.24 | 0.55 | 0.29 | 0.10–0.85 | −2.26 | **0.02** |
| Quarter 4 | −1.27 | 0.52 | 0.28 | 0.10–0.78 | −2.43 | **0.02** |
| Construction/demolition permits | 0.02 | 0.08 | 1.02 | 0.87–1.20 | 0.29 | 0.77 |
| Dog faeces complaints | −0.37 | 0.79 | 0.69 | 0.15–3.21 | −0.48 | 0.63 |
| Garbage complaints | −2.67 | 0.94 | 0.07 | 0.01–0.44 | −2.83 | **4.64 e-3** |
| Restaurants | −0.73 | 0.42 | 0.48 | 0.21–1.10 | −1.74 | 0.08 |
| % with graduate degree | 0.93 | 0.37 | 2.53 | 1.21–5.25 | 2.48 | **0.01** |
| Median household income | −0.31 | 0.29 | 0.74 | 0.42–1.30 | −1.06 | 0.29 |
| % vacant housing units | 0.33 | 0.30 | 1.38 | 0.78–2.47 | 1.10 | 0.27 |
| % owner-occupied units | −0.38 | 0.65 | 0.68 | 0.19–2.43 | −0.59 | 0.55 |
| % units built pre-1950 | −1.19 | 0.37 | 0.30 | 0.15–0.63 | −3.24 | **1.22 e-3** |
| % overcrowded rooms | 0.10 | 0.10 | 1.11 | 0.92–1.34 | 1.07 | 0.28 |
| % residents under 5 years | −0.16 | 0.17 | 0.86 | 0.62–1.19 | −0.93 | 0.35 |
| Log (population density) | −0.38 | 0.13 | 0.68 | 0.53–0.88 | −2.93 | **3.35 e-3** |

All explanatory variables were centered and scaled by their standard deviation. *P*-values less than 0.05 are bolded. SE, standard error; IRR, incident rate ratio; CI, confidence interval; OR, odds ratio.

dog faeces might reflect the lower number of dogs faeces complaints made compared to garbage complaints (6 632 dogs faeces complaints vs. 61 397 garbage complaints in this dataset). Although the relationship between dog faeces complaints and rat complaints was relatively weak, areas with high overlap between rats and domestic dogs may promote the transmission of pathogens from rats to humans. For example, rats are reservoir hosts for the zoonotic pathogen *Leptospira interrogans*, the bacterium that causes leptospirosis in humans and dogs (Bharti et al. 2003). Although rare in humans in the United States, the incidence of leptospirosis infections in domestic dogs has increased steadily over the past 20 years in the Chicago area (White et al. 2017), highlighting the need to understand rat abundance and distribution in urban centres. Future work could explore the underlying motivations of residents in making rat complaints versus garbage or dog faeces complaints to accurately assess health risks from urban rats across the city.

Aside from food sources, we found that the percent of older buildings was positively associated with rat complaints and negatively associated with the probability of a false zero, potentially because older structures provide shelter or harbourage for rats. Older buildings may be more permeable to rats due to cracks in foundations, weathered seals around doors and windows, or degraded building material that is easier for rats to breach. In England, older buildings were suggested to be more attractive to rats due to more mature gardens providing harbourage for rats (Langton, Cowan, and Meyer 2001). It is also possible that residents of historic homes may be more motivated to make rat complaints. Owners with older homes or in low-income areas where buildings are degraded could need additional support mitigating rat infestations and must be especially diligent about cleaning food attractants.

As predicted, time of year was an important correlate of rat complaints; it was also a predictor of the probability of false zeros. Our finding echoes previous work showing that rat complaints in Chicago from 2008 to 2018 were lowest in February, increased to a maximum in August, and then decreased again (Murray et al. 2018). The pattern in rat complaints likely reflects seasonal patterns in rat abundance observed in temperate areas (Feng and Himsworth 2014), and could also reflect increased outdoor activity of humans during the summer months.

## Factors promoting rat visibility

Human population density was positively correlated with the number of rat complaints, and negatively correlated with the probability of a false zero. It is reasonable that in densely populated areas, rats are less likely to go unnoticed and/or

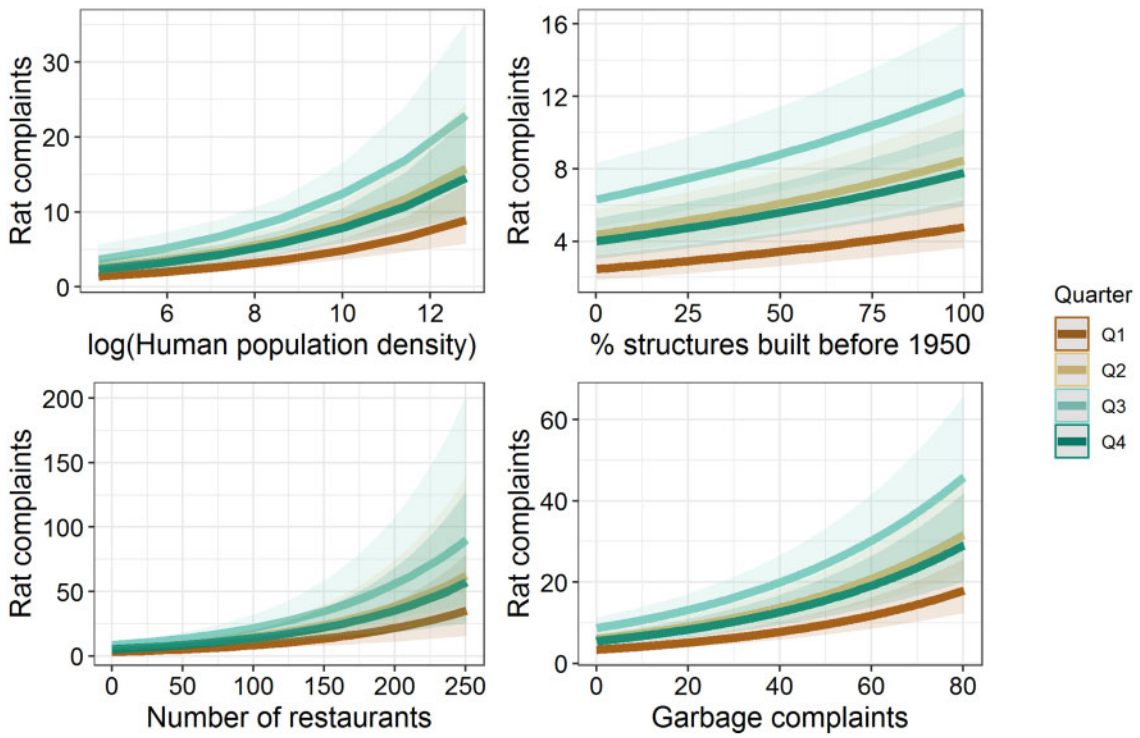


**Figure 2:** Marginal effects plots showing relationship between rat complaints and human population density (log-transformed), % structures built pre-1950, number of restaurants, and garbage complaints. Relationships for each quarter (Q1: January–March, Q2: April–June, Q3: July–September, Q4: October–December) are depicted by line colour. All explanatory variables were mean-centered and scaled by their standard deviation for the analysis, but are back-transformed to their original scale here (human population density remains log-transformed).

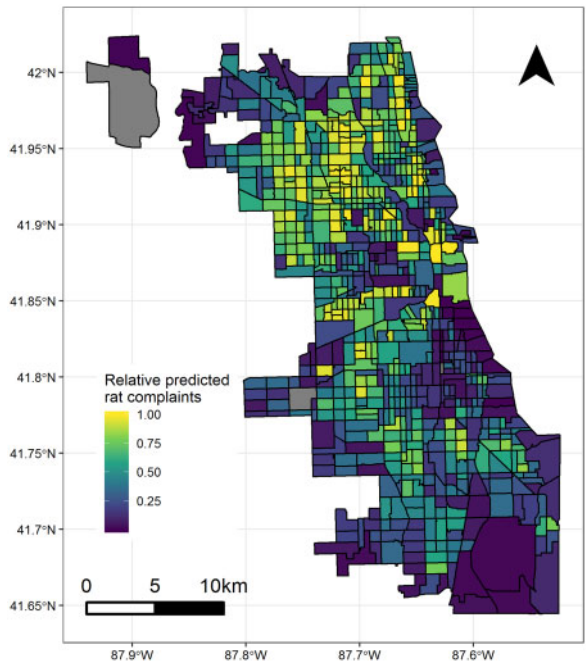


**Figure 3:** Predicted rat complaints for Quarter 3 (July–September) for census tracts in Chicago, Illinois as a function of the fixed effects of the best-fit model. Predictions are plotted as percentiles, providing a relative measure of predicted complaints. Predictions are shown only for Quarter 3 as this quarter had the highest rat complaints. Gray areas have no residential properties.

unreported. This result has management implications; specifically, in less populated areas, residents might need to be especially diligent about making complaints because rat sightings occur less frequently. Conversely, cities that prioritize rodent control based on the number of 311 rat complaints should not disregard areas with lower population densities as these areas could have disproportionately fewer complaints even if rats are present.

Disturbance, as measured by the number of construction and demolition permits issued, had a small but positive correlation with rat complaints. The small effect size observed could be due to the uncertain association between permit issuance and timing of actual building activity. In addition, Chicago ordinances require that a rodent inspection be performed prior to applying for a demolition permit; if rodents or signs of rodent activity are found, abatement measures must be performed (City of Chicago 2020c). Therefore, the small effect size might reflect that abatement before demolition is an effective strategy to reduce rat presence.

## Factors influencing willingness to make a rat complaint

We found that a greater percent of owner-occupied homes was associated with more rat complaints, while previous work found that rat relative abundance was positively correlated with the percent of rented housing units (Murray et al. 2018). This discrepancy could be driven by property owners being more motivated to make rat complaints than renters, or differences in the entities to which owners and renters make complaints. For instance, renters might complain about rats to their landlords or to private pest control businesses rather than to the city. Surveys of owners' versus renters' motivations in reporting rat complaints, and whether they prefer to report

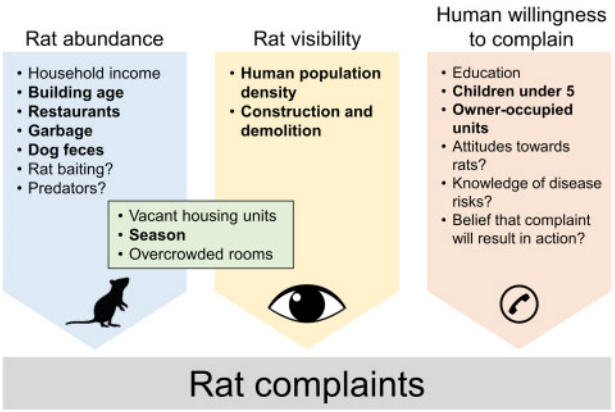


**Figure 4:** Conceptual figure showing different biological and social factors that could influence rat complaints via changes in rat abundance, rat visibility, and human willingness to make a rat complaint. Factors in the green box could influence both rat abundance and visibility. Bold font indicates factors found to be statistically significant in this study, non-bold indicates non-significant factors, and question marks indicate factors that were not addressed here but might also influence rat complaints.

complaints to 311 or private companies, would be useful to clarify this issue.

In contrast to our expectations, the percent of residents under 5 years had a small, negative correlation with rat complaints. Adults with young children could still have the desire to protect their children from rats, but might not have the available time to make rat complaints. Though the percent of people with a graduate degree was not associated with rat complaints, it was positively correlated with the probability of a false zero. This result might indicate that more highly educated residents fail to report rats to 311 when they are seen; future research could examine underlying reasons for this behavior (e.g. deciding to contact pest management companies directly rather than going through the city).

### Future directions

Here, we contribute to the growing body of work to understand rat distributions within cities and mitigate risks associated with rat infestations. We found that both social and environmental factors are associated with rat distributions; thus, our results highlight the importance of integrating social and environmental data to develop accurate estimates of rat populations and predict which communities are most vulnerable to rat infestations. Although analysing 311 complaint data is an accessible method to estimate rat activity, 311 complaints likely represent a subset of all rodent sightings and there are inherent and systematic biases in the contexts in which residents are able to observe rats that are present and have the knowledge, ability, and motivation to lodge a complaint (McLafferty, Schneider, and Abelt 2020).

Residents might be more likely to complain about rats if they hold highly negative attitudes about rats or perceive rats to be scary or dangerous (Fig. 4). Similarly, residents who are more knowledgeable about the risks of rat-associated disease and property damage may be more motivated to complain. Motivation to complain could also be influenced by the context in which people observe rats (e.g. in their dwelling, outside on their property, on neighbours' property, in alleys). In the future, studies that integrate multiple types of data could help characterize these complexities. Surveys and interviews could help identify motivations and barriers to making rat complaints that are difficult to capture in a large-scale spatial analysis. For example, individuals experiencing homelessness can frequently encounter rats because they typically spend a large amount of time outdoors in urban areas where rats are active (Byers et al. 2019a). However, unhoused individuals are unlikely to report a rat sighting for myriad reasons, including the lack of a street address, and so a lack of information on homelessness is a limitation of our study. In addition, communities may be more likely to complain about rats if they believe that the city will respond to their complaints. While it is difficult to measure public trust using census data, surveys and interviews can capture socioeconomic and cultural factors (e.g. race) associated with trust in government due to current experiences or historical legacies. Future studies can also refine rat population estimates in urban neighbourhoods using genetic analyses (Byers et al. 2021; Combs et al. 2018). Collaborations with pest management professionals will be valuable because pest professionals can verify the presence of rats, while large-scale building inspection programs can provide relatively unbiased estimates of rat infestations in different communities (Sutherland, Greenlee, and Schneider 2020).

In addition, other factors beyond those explored here could influence rat populations (Fig. 4). Rodenticide baiting and predation by native and introduced predators likely reduce rat abundance, yet their effects are not well known. Many cities in the United States, including Chicago, have programs that use feral cat colonies (e.g. trap-neuter-release programs) to control rodent populations (Cook County 2020). Future work exploring the influence of rat baiting and predators would help to understand their impacts on rats.

### Management applications

We found that rat complaints in Chicago were associated with factors that promote rat abundance and increase the likelihood that rats will be observed by people. These results suggest that rat management programs should target areas with available food waste and harbourage such as older homes. Rather than targeting dog waste as a rat attractant, signs emphasizing the importance of storing garbage securely could be more effective. Our results also suggest that rat complaints may be artificially low in areas with low human densities. Thus, regular inspections in lower density areas could be helpful in proactively managing rats that are present but not reported. Lastly, there appears to be a complex relationship between complaints and property ownership versus renting. Information campaigns targeted to renters may help provide more consistent rat control if landlords vary in their diligence towards pest management.

## Supplementary data

Supplementary data are available at *JUECOL* online.

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## Data availability

All data used in the study are publicly accessible: see References for links. The code to perform analyses and generate figures is available at https://zenodo.org/record/4543981#.YCxO_BZOlEZ.

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