Dynamics Between Residential Composting and Rodent Sightings in Boston

Dynamics Between Residential Composting and Rodent Sightings in Boston

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Abstract

Commensal *Rattus* species rank among the most widespread urban pests thriving on human-generated resources and posing significant challenges to public health and infrastructure (Lee et al., 2021). Despite their prevalence, there remains a gap in understanding their urban ecology and effective prevention strategies (Lee et al., 2021; Lee et al., 2022a; Lee et al., 2022b). City officials have increasingly turned to composting initiatives as rodent management tools, recognizing the relationship between poorly managed food waste as an attractant for high rodent activity (Lee et al., 2022a; Sánchez et al., 2021; Tamayo-Uria et al., 2014). However, it remains unclear how effectively residential composting contributes to rodent control, particularly across different urban environments and socioeconomic contexts (Lee et al., 2021; Lee et al., 2022a). The "War on Rats" is complex, and assessing the effectiveness of food waste control strategies requires a nuanced understanding of rodent and human behavior (Lee et al., 2022b).

The main objective of my thesis was to investigate the impact of food waste control strategies on rodent complaint levels in Boston from 2022-2024. I focused on how Boston's voluntary residential composting program and community compost bins impacted 311 rodent sightings reported across neighborhoods. I hypothesized that increased residential composting would decrease rodent sightings, with varying effects across different urban densities. I evaluated these relationships using time series analysis, spatial clustering, buffer analysis, and lagged correlation. Results showed that despite composting participation increasing by 54% (from 17,134 to 26,426 households) and

food waste diversion rising by 228% (510.44 to 1,675.13 tons), rodent sightings rose by 0.4% (5,944 to 5,965). Additional analysis of 14 Project Oscar community compost bins revealed rodent activity increases of 180% in Allston and 29% in South End.

K-means clustering revealed four distinct neighborhood patterns based on composting participation and 311 service requests about rodents: low-activity areas with minimal engagement in composting and rodent sightings, moderate zones with balanced participation in both variables, high-rodent sightings (150-350 sightings) with moderate composting adoption, and high-composting neighborhoods (300-900 sign-ups) with few rodent sightings (50-150 sightings).

Additionally, I investigated how composting participation varied across neighborhood characteristics. I hypothesized higher human density areas would show weaker reductions in rodent activity. The data partially confirmed this, with lower-density areas achieving higher composting participation and demonstrating slightly stronger negative correlation coefficients (reaching approximately -.6 by week 20) between household composting and rodent sightings compared to higher-density areas (-.5), consistent across multiple density metrics.

This research establishes a framework for evaluating urban waste management strategies while acknowledging the limitations of using 311 requests as proxies for rodent activity. These preliminary findings can guide municipalities toward improved collection methods and more targeted approaches for measuring integrated pest management effectiveness across diverse urban neighborhoods. The identified patterns suggest that policy makers should implement neighborhood-specific waste management strategies rather than one-size-fits-all approaches across varied urban environments.

Dedication

To my partner Marc, whose support has been my anchor through this journey. Your encouragement has allowed me to push beyond my self-perceived limits.

To my parents, Sangita and Shri, who nurtured my curiosity from the beginning and showed me that education is not just a path but a lifetime journey.

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Definition of Terms

Commensal rodents: Commensal rodents are species that live in close association with humans and benefit from this relationship without causing harm. Of the 61 known Rattus species, only five are true commensals that regularly live near humans. These species thrive in urban environments by exploiting human-provided resources such as food and shelter (Feng & Himsworth, 2014).

Environmental justice (EJ) populations: Communities identified through criteria established by the Massachusetts Executive Office of Energy and Environmental Affairs, including minority status (≥40%), income level (≤65% of statewide median), and language isolation (≥25% speak English less than “very well”).

Food, water, harborage, and fertile mates (FWAHFM): FWAHFM are the essential resources that sustain urban rodent populations (Lee et al., 2021).

GEOID: Geographic units used by the U.S. Census Bureau, typically containing around 4,000 residents, designed to be relatively permanent to enable statistical comparisons over time.

Housing density: The number of housing units per square mile within a GEOID, used to measure the concentration of residential development.

Integrated Pest Management (IPM): A comprehensive approach that combines various methods of control, all working together as a system to limit rodent's access to FWAHFM (Lee et al., 2021).

Municipal solid waste management (MSWM): Comprised of regulatory, administrative, market, technology, and social subcomponents relating to waste (Louis, 2004).

Population density: The number of people per square mile within a GEOID used to measure the concentration of human inhabitants.

311 service requests: Non-emergency service reports from residents to their cities covering issues related to local government services and quality-of-life concerns, such as rodent sightings. These requests are geotagged, allowing for spatial analysis of urban issues.

Urban density: A measure of the intensity of land use in cities, encompassing population density and building density, which influences the distribution of resources and infrastructure within urban environments.

Chapter I

Introduction

Within an urban ecosystem, commensal rodents have emerged as master adaptors, threading themselves into the fabric of city life through their remarkable ability to exploit the essential resources of food, water, and harborage, fostering fertile mates (FWAHFM). These persistent species don't merely exist alongside human communities; they actively integrate into our urban infrastructure, creating challenges that ripple through public health, infrastructure, and community well-being (Lee, Byers, Cox, Stephen, Patrick, & Himsworth, 2021). Their presence serves as a living reminder that in urban environments, no system—whether waste management, public health, or pest control—exists in isolation.

Growing human populations in cities and the effects of climate change are already creating conditions that favor rat population growth, posing greater challenges for existing sustained control efforts and increasing risks if not addressed properly. The challenge of managing urban rat populations is exacerbated in densely packed cities, especially subterranean cityscapes where rats find refuge and breeding grounds, thriving on food from garbage improperly managed by humans (Lee et al., 2022a). Integrated Pest Management (IPM) approaches combine various methods of control and have emerged as central to efforts aimed at limiting rodents' access to FWAHFM. This requires coordination across municipal departments and stakeholders to enforce policies and programs (Lee et al., 2021). Commensal rodents are often viewed as pests requiring control, but their presence in urban ecosystems is far more complex. Studies underscore the importance of addressing the root causes sustaining rodent populations through strategic urban planning and community involvement (Lee et al., 2022b).

Cities have implemented strategies like composting programs, organic waste bans, and waste management regulations to better manage municipal food waste, as food attractants are positively correlated with areas of peak rodent activity (City of Boston, 2023; U.S. EPA, 2022). Efforts to divert organic waste from landfills also can contribute to broader environmental objectives by reducing methane, a potent greenhouse gas, and promoting regenerative resource management (Sandson & Leib, 2019).

Municipal composting programs have been complemented by public education campaigns, enforcement of municipal codes, and the exploration of new rodent management technologies, signaling a shift towards more holistic and sustainable urban pest management practices (*Ordinance Establishing the Office of Pest Control*, 2024). Yet, despite these concerted efforts, accurately assessing the effectiveness in reducing rodents remains a challenge due to inconsistencies in monitoring and evaluation metrics (Lee et al., 2022a). Studies have identified limitations on using 311 service requests as an indicator of rodent activity, but there is limited guidance on how to proceed with existing data. Continuing to refine and adapt approaches based on scientific evidence, technological advancements, and community feedback is crucial for city officials and pest management professionals alike (Lee et al., 2022b).

Research Significance and Objectives

Through analysis of Boston's 311 service requests, residential composting participation data, community compost bin participation, and demographic information, I investigated the interconnections between rodent activity, food waste management practices, urban density, and socioeconomic patterns. This research aimed to transcend traditional pest control narratives by examining rodents as components of urban ecological systems, adapting, and responding to human-driven changes in waste management and city development.

By investigating how changes in food waste management through residential composting influence resource availability for commensal rodents, the research provided valuable insights for policymakers and urban planners working to balance environmental goals with public health concerns. The results of this research could also guide future research within IPM and align ecological sustainability objectives with the development of more livable urban spaces, regardless of socioeconomic status.

My research objectives were therefore to:

- Analyze the relationship between residential composting participation (including opt-in programs and community compost bins) and 311 service requests across Boston, evaluating composting's potential for commensal rodent suppression.
- Investigate how the impact of composting participation on rodent activity varies based on population and housing density within 2020 U.S. Census GEOIDs.
- Quantify whether increased composting participation in Boston reduces rodent sightings across various timeframes and spatial scales, providing actionable insights for urban policymakers and planners.
- Identify ecological and behavioral factors in urban rodent-waste management dynamics that warrant further investigation, helping city planners develop more nuanced and effective IPM strategies.

Background

Commensal rodents excel in urban environments by adeptly exploiting human resources and thriving in complex, fragmented habitats of urban environments (Feng & Himsworth, 2014). This has created challenges for cities to control growing populations, requiring strategies to prevent, eliminate, and monitor populations (Lee et al., 2022b). This has enforced the need for regulation and resources to implement a solution that spans across departments and engage citizen awareness. Consequently, while municipalities have orchestrated tools and organized programs in siloed attempts to mitigate rodent infestations, it has been made evident that a coordinated multi-faceted approach is vital (Lee et al., 2021), IPM combines various methods of control, all working together as a system to limit commensal rodent's access to FWAHFM (Lee et al., 2021). As a result, different government agencies have begun collaborating and coordinating their efforts to develop a comprehensive strategy to address commensal rodent challenges effectively (City of Boston City Council, 2024).

Commensal *Rattus*

While there are 70 known *Rattus* species, only five are considered true commensals that regularly live near humans (Feng & Himsworth, 2014; Richardson, 2024). The Norway rat (*Rattus norvegicus*) and the black rat (*Rattus rattus*) are the most common commensal rodents globally, with origins in northern China and southern Asia respectively (Feng & Himsworth, 2014; Lee et al., 2022b). Over approximately 500 rat generations, from the late 19th into the 20th century, urban environments have dramatically shaped rat populations, resulting in the genetic adaptations to city living (Harpak et al., 2021).

Analysis of whole-genome sequences of Norway rats from New York City revealed genetic signatures of adaptation for genes associated with metabolism, diet, nervous system function, and locomotory behavior (Harpak et al., 2021). These genetic changes appear to have emerged after the rats split from their ancestral population in northeast China, suggesting recent evolution in response to urban environments (Harpak et al., 2021). Norway and black rats have become so well-adjusted to urban environments that they are rarely found in truly wild settings, leading some researchers to suggest they may be obligate human commensals (Feng & Himsworth, 2014). These species are classic urban exploiters, thriving around human settlements and rapidly multiplying due to their adaptability to urban environments (Richardson, 2024).

The global distribution of commensal *Rattus* species reflect their habitat preferences, as Norway rats and black rats have successfully colonized every continent except Antarctica (Feng & Himsworth, 2014). Norway rats have become particularly successful in temperate urban areas, where they typically inhabit lower elevations and underground spaces, while black rats tend to dominate in coastal regions and tropical climates, often occupying higher elevations within structures (Feng & Himsworth, 2014). Both species reached their worldwide distribution primarily through human maritime activities, demonstrating remarkable success in colonizing new environments alongside human settlement patterns (Jenkins, 2001).

Over decades, the exponential rise of commensal rodent populations can be attributed to the species' unique characteristics. They chew through tough materials, squeeze in tiny openings, can jump up to three feet, and climb wires and pipes (Jenkins, 2001). Rodents maintain their perpetually growing teeth by constantly chewing and grinding various objects, which prevents their incisors from overgrowing (Jenkins, 2001).

Although commensal rodents have a short lifespan, with studies showing a 90-95% mortality within their first year, their reproductive behaviors are remarkably efficient and adaptable (Feng & Himsworth, 2014; Lee et al., 2022a). With a brief gestation period of approximately three weeks, rats can produce up to five liters annually with four to eight pups per litter when conditions are favorable (Feng & Himsworth, 2014). A fascinating aspect of their reproduction is the establishment of estrous synchronization among group-living females, resulting in coordinated population booms and significantly higher pup survival rates of 80% compared to 28% in asynchronous breeding groups (Feng & Himsworth, 2014).

Pups develop rapidly, consuming solid food by three weeks and reaching weaning age at one month, with sexual maturity possible as early as three months (Feng & Himsworth, 2014). In urban environments, rats grow faster and reach sexual maturity earlier compared to their rural counterparts, likely due to greater resource availability (Feng & Himsworth, 2014). While reproduction can occur year-round in urban settings, it is typically seasonal in temperate climates, with breeding activity peaking in spring and fall, leading to population density peaks in late summer and early fall (Feng & Himsworth, 2014). This forms a distinct bimodal distribution, with populations rising in spring and early summer, experiencing a summer dip, and then peaking again in fall (Richardson, 2024). This seasonality primarily affects females, as males maintain consistent reproductive capability throughout the year (Feng & Himsworth, 2014).

Additionally, extreme weather events and changes in precipitation patterns can affect rat behavior and survival, particularly in urban areas where underground infrastructure provides shelter (Andreassen et al., 2022). Climate warming may extend the active periods of rats, allowing them to reproduce more frequently and potentially increasing their populations. Cities with faster warming trends have shown corresponding increases in rat populations (Richardson, 2022). These environmental changes may alter traditional patterns of rat population dynamics, potentially leading to more frequent or severe localized outbreaks in some urban areas (Andreassen et al., 2022). The combination of increasing human population densities in cities and climate change creates more favorable conditions for rat population growth, making long-term control efforts increasingly challenging (Richardson, 2024).

Management of Urban Rat Populations

The interaction between seasonal changes, urban infrastructure, food availability, and human activities creates a complex network of factors influencing rodent population dynamics. Understanding these interactions is crucial for developing effective urban pest management strategies. Recent studies of rat populations in 16 major U.S. cities have shown significant increases in 11 cities, highlighting their continued success in urban environments (Richardson, 2024). The challenge lies in developing comprehensive monitoring systems that can accurately assess population trends and the effectiveness of management interventions across different urban environments and temporal scales (Andreassen et al., 2022).

Stakeholder Research and Systematic Reviews

Building on spatial analyses of commensal rodent populations, researchers began examining how management strategies translate into practice. The School of Population of Public Health at the University of British Columbia conducted an extensive stakeholder analysis across seven U.S. cities, interviewing forty IPM professionals to understand implementation challenges (Lee et al., 2021). Their qualitative analysis revealed systemic barriers to effective municipal rat management and highlighted the need for evidence-based approaches in developing and refining IPM. Beyond limited resources, stakeholders identified several key obstacles: insufficient political and public interest, challenges in coordinating across urban landscapes, and the tendency to prioritize other municipal issues over rat management.

This initial stakeholder research highlighted the need for more systematic examination of urban rodent management approaches. As cities struggled to implement effective control measures, researchers began exploring comprehensive reviews and detailed city-specific analyses to better understand successful strategies. The UBC team subsequently conducted a systematic review of 120 studies, including textbook chapters, primary research, program evaluations, and expert commentaries on municipal rat management (Lee et al., 2022b). Their analysis proposed a new paradigm integrating pest management with urban planning, reconceptualized rat management as a public health component, and emphasized community engagement through a systems-thinking approach.

The systematic review also revealed critical gaps in evaluation methodology. The absence of consistent, objective metrics made it difficult to assess program effectiveness and justify resource allocation. This challenge extended beyond identifying and eliminating environmental factors conducive to rats, highlighting the need for behavioral change strategies at the municipal level that had yet to be thoroughly explored.

City-Level Analyses

While these broad studies provided valuable frameworks for understanding urban rodent management, detailed analyses of individual cities offered crucial insights into specific environmental and social factors affecting rat populations. Two notable studies - one in Madrid and one in Chicago - demonstrated how local conditions influence rodent activity and control effectiveness.

Internationally, research has delved into these multifaceted causes of urban rat infestations and their implications for public health, environmental integrity, and the economy. Building on earlier work linking urban infrastructure to rat populations (Langton et al., 2001), Tamayo-Uria et al. (2014) employed GIS to investigate correlations between rat infestations and environmental factors in Madrid. Their study examined 10,956 validated rat sightings reported to Madrid's Technical Unit for Vector Control (TUVC) between 2002-2008, analyzing relationships with housing age and density, distance to vegetated areas, markets, water sources, cat feeding stations, and human population density.

The analysis revealed several significant environmental correlations (Tamayo-Uria et al. (2014). Older buildings showed higher infestation risks than newer construction, likely due to maintenance issues and less rat-proof design features (Tamayo-Uria et al., 2014). Areas with higher human population density experienced more rat problems, possibly due to increased garbage and shorter dispersal distances needed for rats to colonize nearby dwellings (Tamayo-Uria et al., 2014). This relationship was particularly pronounced in areas with both high population density and aging infrastructure (Tamayo-Uria et al., 2014). Proximity to markets and unkempt vegetated areas were also significant risk factors, while well-maintained public parks showed a negative correlation with rat activity, emphasizing how proper urban space management influences rat populations (Tamayo-Uria et al., 2014).

Interestingly, proximity to water sources such as fountains, ponds, streams, and rivers lowered the risk of sighting a rat, contrary to common assumptions. Tamayo-Uria et al. (2014). The researchers hypothesized this might relate to better maintenance of sewer systems near water infrastructure. They also found that cat feeding stations, rather than deterring rats through predation pressure, were positively associated with rat presence, likely due to the food resources these stations provided (Tamayo-Uria et al., 2014). These findings aligned with Baker et al.'s (2005) research showing limited effectiveness of cats as urban rat predators (Tamayo-Uria et al., 2014).

The study's Generalized Additive Models (GAMs) performed particularly well at the district level, explaining 94.2% of variance, compared to the city-wide scale at 55.5%. All environmental factors studied were significantly associated with rat infestations ($p<0.05$), except distance to vegetated areas in one district model. This scale-dependent effectiveness indicates the importance of considering neighborhood-level characteristics in pest management planning.

This type of spatial analysis and environmental risk assessment represents an important shift toward more strategic urban rat management. Rather than simply reacting to infestations, understanding the environmental factors that create favorable conditions for rats allows municipal authorities and pest management professionals to take preventive measures and allocate resources more efficiently. The identification of recurring areas of high rodent activity and their associated risk factors provides valuable information for developing targeted, long-term control strategies that address root causes rather than just symptoms.

Building on foundational research linking urban infrastructure to rat populations (Langton et al., 2001), Sánchez et al., (2021) analyzed 311 service requests of rodent sightings in Chicago. Their study examined 211,028 sightings from 2011-2017, analyzing correlations with four key variables: attractants (factors providing resources for rats, such as garbage, dog feces, and restaurants), disturbances (factors increasing rat visibility, like construction/demolition), harborages (shelter opportunities, such as older buildings), and socio-economic factors (including population density and housing characteristics). The researchers gathered data through multiple public records: 311 service requests, food establishment inspections, building permits, the American Community Survey, and economic profiles from the U.S. Census Bureau. They employed zero-inflated generalized linear mixed models in R (GLMMs) to analyze rodent sightings in Chicago's census tracts, accounting for both actual absences and unreported presence of rats.

Sánchez et al.'s (2021) analysis revealed significant positive correlations between rodent sightings and various factors, measured using incident rate ratios (IRR). An IRR above 1 indicates a higher rate of occurrence, below 1 indicates a lower rate, and equal to 1 suggests no difference between groups. For example, increases in restaurants (IRR $\approx$ 1.13), garbage complaints (IRR $\approx$ 1.07), and pre-1950 structures (IRR $\approx$ 1.16) all correlated with increased rodent sightings (Sánchez et al., 2021). The study also found temporal patterns consistent with established seasonal patterns in urban rat populations, with complaints peaking during summer months (Feng & Himsworth, 2014; Sánchez et al., 2021).

These findings supported earlier research on the relationship between urban infrastructure and rat populations (Himsworth et al., 2013), though the researchers acknowledged several important limitations. While restaurant presence strongly correlated with rodent sightings, they couldn't fully differentiate between actual increases in rat populations versus increased human encounters due to higher foot traffic. Similarly, the correlation with pre-1950 buildings could stem from multiple factors, including deteriorating infrastructure, mature landscaping, or varying maintenance practices.

These methodological challenges highlight the importance of integrating multiple data sources - including direct observations, pest management records, and building inspections - to develop more accurate estimates of urban rat populations and better predict vulnerable communities.

An analysis by Fochios (2024) of New York City Housing Authority (NYCHA) developments highlighted how institutional structures influence rodent control effectiveness. Examining data from 2010-2016, they found nearly 15,000 rodent-related complaints in public housing properties, with concentrations in developments with aging infrastructure. The study analyzed multiple variables including building maintenance records, 311 service requests, and compliance with federal Housing Quality Standards (HQS), revealing how overlapping jurisdictions and regulatory requirements shaped pest management outcomes.

Fochios (2024) identified several key barriers to effective rodent control in public housing settings. Despite mandatory IPM requirements, implementation was often hampered by budget constraints and coordination challenges across agencies. These findings emphasize how institutional frameworks and resource allocation significantly influence urban rodent management strategies, complementing the environmental and spatial analyses from Chicago and Madrid.

Overall, studies across multiple cities have identified consistent environmental factors contributing to rat infestations. Research in Madrid, Chicago, and New York revealed significant correlations between rat presence and several key factors: building age, population density, and proximity to food sources. These patterns were particularly evident in NYC public housing, where aging infrastructure and high population density created favorable conditions for rat infestations, leading to 51% of NYCHA residents reporting unsafe living conditions (Fochios, 2024). Across all three cities, 311 service requests provided crucial data for understanding urban rodent distributions, though institutional frameworks and resource allocation significantly influenced management outcomes.

311 Service Request Exploration

The implementation of 311 systems marked a significant evolution in urban governance, originally emerging in Baltimore in 1996 as a solution to overwhelmed emergency response systems (O'Brien, as cited in DaPonte, 2024). While initially conceived to divert non-emergency calls from 911, these systems evolved into comprehensive tools for urban management and civic engagement. However, research across major U.S. cities has revealed consistent reporting biases. Murray et al. (2018)

found that while actual rat populations were higher in areas with rental units in Chicago, complaint patterns didn't reflect this reality. This pattern was confirmed by Sánchez et al. (2021) when more owner-occupied homes reflected higher complaint rates, despite evidence suggesting higher rat abundance in rental units.

These discrepancies likely reflect differences in residents' knowledge of reporting systems and their perceived ability to effect change through official channels (Himsworth et al., 2013). Cities have attempted to address these barriers through technological innovation and accessibility measures. For instance, many municipalities now offer multi-language support and multiple reporting channels, including mobile applications, social media, and traditional phone lines (DaPonte, 2024). Recent policy initiatives, such as NYC's Local Law 127-2021, have begun addressing such disparities by expanding access to NYC's 311 system for public housing residents (Fochios, 2024).

Temporal variations further complicate analysis. While relationships between neighborhood characteristics and 311 service request patterns vary over time (White & Trump, 2018), rodent-related complaints show consistent seasonal patterns tied to both rat population dynamics and human activity levels (Feng & Himsworth, 2014). This temporal variability necessitates multi-scale analysis approaches. The influence of superusers, individuals who frequently engage with the 311 system, presents another challenge. Their concentrated reporting patterns can skew spatial analysis to reflect engaged citizen behavior rather than underlying conditions (White & Trump, 2018). Similar to findings from housing surveys (Langton et al., 2001), this reporting bias demonstrates how citizen-generated data may not always accurately reflect actual conditions. This highlights the importance of triangulating multiple data sources and implementing robust controls when analyzing urban conditions through 311 data.

The evolution of 311 systems represents a collaboration between community and government in maintaining urban commons (DaPonte, 2024). While these systems have enhanced civic participation and urban service delivery, understanding their inherent biases and limitations remains crucial for accurate interpretation of the data they generate.

Integrated Pest Management (IPM)

While 311 data and spatial analyses have improved understanding of rat distributions, translating this knowledge into effective control measures remains challenging. IPM emerged as a systematic response to these challenges, moving beyond traditional reliance on poisons and traps to address the complex environmental and social factors identified in city-level studies. The framework consists of systematic steps: thorough inspection, precise species identification, continuous monitoring, selection of appropriate control methods, regular evaluation, and stakeholder education (Jenkins 2001). This approach prioritizes prevention and least-toxic solutions over conventional pesticide application, incorporating various strategies such as habitat modification, physical control methods, and biological control.

Research into urban rat control has revealed complex challenges requiring coordinated responses across multiple stakeholders. This is particularly evident in New York City, where despite intensive efforts, rat infestations remain persistent, with nearly 15,000 complaints recorded between 2010-2016 (Fochios, 2024). In response, NYC implemented innovative approaches, including appointing Kathleen Corradi as "Rat

Czar" to coordinate reduction efforts across all five boroughs, with a $3.5 million investment in the Harlem Rat Mitigation Zone (Fochios, 2024).

The regulatory landscape involves multiple layers of oversight and coordination amongst departments. Housing authorities must comply with federal Housing Quality Standards (HQS) and state-specific regulations, while the EPA regulates rodenticides under FIFRA (Fochios, 2024). Cities have taken varying approaches to chemical control - while NYC doubled its anticoagulant rodenticide use between 2015-2021, other jurisdictions like California have banned certain rodenticides due to environmental concerns (Fochios, 2024). Cities are increasingly adopting data-driven approaches, including predictive analytics and machine learning models, while also exploring alternatives like rat contraceptives.

Municipal codes and rodent management programs typically focus on FWAHFM management and suppression (Lee et al., 2022a). However, implementation often falters as elected officials hesitate to enforce penalties against constituents for violations that contribute to rat problems. This hesitation ultimately undermines community welfare by allowing rodent-conducive conditions to persist beyond property boundaries. Success is further complicated by difficulties in changing resident behaviors and inconsistent evaluation metrics, with cities often relying on residential 311 service request frequencies rather than standardized impact assessments (Himsworth et al., 2013; Sánchez et al., 2021; White & Trump, 2018).

By pursuing multiple IPM strategies in parallel and fostering interdepartmental collaboration, cities can develop strategic, long-lasting solutions for controlling commensal rodents in urban communities (Lee et al., 2021). This systematic approach ensures that pest control is not only effective but also sustainable, minimizing risks to human health and the environment while maximizing long-term cost-effectiveness through prevention rather than reaction.

Municipal Solid Waste Management (MSWM)

Central to mitigating access to FWAHFM, is the recognition of municipal solid waste management (MSWM), comprising regulatory, administrative, market, technology, and social subcomponents relating to waste (Louis, 2004). Disposal of municipal solid waste through landfilling, combustion, recycling, or composting is regulated under a combination of federal acts, state policies, local diversion bans, and municipal programs (Louis, 2004). There are also several regional differences that influence MSWM within different cities across the United States including market structures, population density, waste processing infrastructure, and community interest (Louis, 2004).

Organic Waste

Within MSWM, organic waste includes food and yard waste, not including food loss from unused products within the agricultural sector, such as unharvested crops (U.S. EPA, 2022). In 2018, out of all the waste that was sent to landfills, 24% was made up of food waste, and 7% was yard waste (U.S. EPA, 2022). Between 1960-2017, annual food waste generation surged by 70%, as reported by the EPA in 2022 (Figure 1).

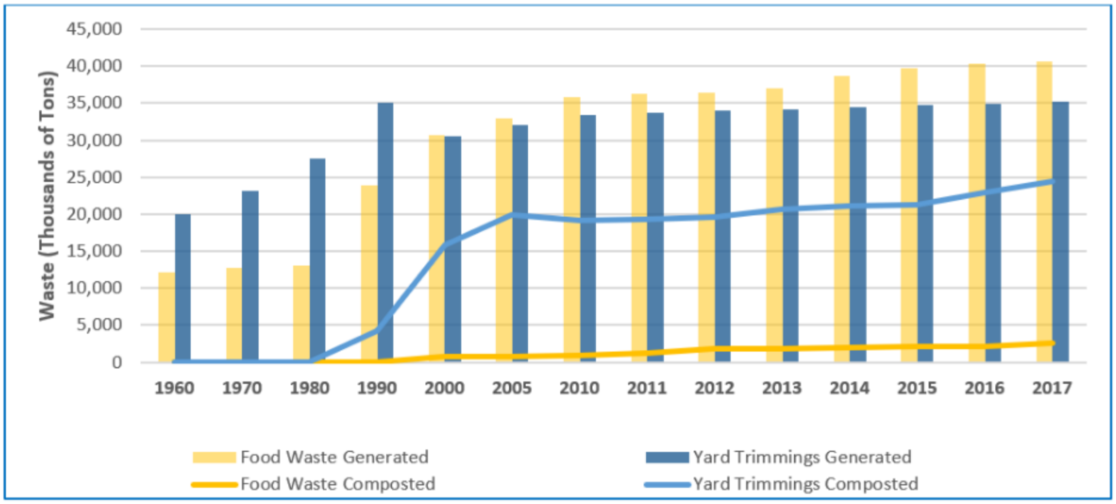


Figure 1. Organic waste generation and composting,1960-2017.

Screengrab from 2022 U.S. EPA report on organic waste management, demonstrating yard trimming and food waste generation and composting rates over time. (U.S. EPA, 2022)

In contrast, yard waste generation remained relatively stable during the same period (U.S. EPA 2022). The composting of yard waste experienced a remarkable 370% increase (U.S. EPA, 2022). However, growth in food waste composting was marginal, with most of the food waste continuing to be sent to landfills (*Downstream Management of Organic Waste* 2022).In addition to reducing the amount of food available to commensal rodents, diverting organic waste from landfills can provide significant environmental, public health, and economic benefits (Sandson et al., 2019).

When organics end up in landfills, they release methane, a potent greenhouse gas (GHG) that is 28-36 times more effective than carbon dioxide at trapping heat in the atmosphere over a 100-year period (U.S. EPA, 2022). This makes landfills the third largest source of human-caused methane emissions in the U.S., behind natural gas and petroleum systems and enteric fermentation from grass-eating animals (U.S. EPA, 2022).

Landfills also require substantial land area, which could otherwise be used for more productive purposes like agriculture, infrastructure, or industry (U.S. EPA, 2022). Alternate end-of-life methods like food donation, anaerobic digestion (AD), and composting offer cities the potential to generate renewable energy and other valuable byproducts that contribute to improved soil health (U.S. EPA, 2022).

Residential Composting in the United States

Food waste diversion in the United States has long existed, being introduced in the 1960s when San Francisco became the first city to offer a major composting program (Rubinstein et al., 2023). However, recent changes has led to significant growth in municipal efforts to manage organic waste through collection programs. According to BioCycle's 2023 nationwide survey, residential access to food waste collection in the United States has increased by 49% from 10.0 million in 2021 to 14.9 million in 2023 (Goldstein et al., 2023). BioCycle's access survey identified 400 municipally supported programs across 710 communities, offering either curbside collection, drop-off locations, or both (Goldstein et al., 2023). It also found programs to be predominantly concentrated in five states (California, Illinois, New York, Minnesota, and Connecticut), which account for 68% of collection access programs in the United States (Goldstein et al., 2023). The expansion has been largely driven by state-level policies, such as California's SB 1383 and Vermont's mandatory food waste diversion requirements, with more jurisdictions beginning to anchor food waste recycling into local Climate Action Plans as a landfill methane avoidance tool (Goldstein et al., 2023).

New York City has historically struggled with implementing comprehensive MWSM programs to maximize diversion from the landfill (Champeny, 2022) but progress is promising. With only two boroughs, Brooklyn and Queens, receiving composting service in 2024, there was a 23% year-over-year increase in food waste diverted from landfills, reaching nearly 130,000 tons (DSNY, 2024).

The expansion represents a significant shift in municipal investment, particularly notable given the city's current budget constraints and the historical challenges with collection costs, which have reached up to $1,700 per ton for organic waste collection (Champeny, 2022). To complement the curbside program, DSNY deployed over 400 Smart Composting Bins that residents can unlock anytime with an access card (DSNY, 2024). This saw significant public adoption with over 1.2 million bin unlocks in 2023, quadrupling the previous year's usage (DSNY, 2024). This initiative is explicitly linked to the city's rat control efforts, with Mayor Adams stating the program will "deal a blow to New York City's rats" by keeping millions of pounds of food and yard waste out of landfills (Rubinstein et al., 2023).

Boston's Integrated Approach

The Boston community is served by the City Council, connecting citizens with municipal resources, services, and city departments, and providing an outlet for feedback towards continuous improvement (Ordinance Establishing the Office of Pest Control, 2024). Boston's approach to commensal rodent management has historically been a cross-departmental effort amongst Inspection Services, Public Works, Urban Agriculture, Boston Water and Sewer, and the Parks Department (Ordinance Establishing the Office of Pest Control, 2024).

In a meeting in late January of 2024, the City Council voted unanimously to support creating an Office of Pest Control in the city, as well as the appointment of a

Director of Pest Management (Ordinance Establishing the Office of Pest Control, 2024). This proposal allocated additional resources to the cause of commensal rodent control, drawing inspiration from New York City's strategies (Ordinance Establishing the Office of Pest Control, 2024). The City Council's proposed vision of a more streamlined and innovative approach to pest control now sits with the Government Operations Committee, where stakeholders across city government will come together to discuss logistics before arriving at Mayor Michelle Wu's desk for approval (Ordinance Establishing the Office of Pest Control, 2024).

In August 2022, Boston's Department of Public Works initiated a free, weekly curbside compost service for residents (City of Boston, 2023). This program caters to households in buildings with six units or fewer that receive curbside trash collection through the city. The service is continuously expanding, accepting new participants on a rolling basis. The program is offered at no cost to residents who opt in, although enrollment is limited. It provides weekly service on regular trash collection days, enabling participants to recycle all food scraps, paper towels, and other compostable items, effectively transforming waste into clean energy and nutrient-rich compost.

Eligible residents can enroll through the city's official website by providing their name and zip code to join the waitlist (City of Boston, 2023). Boston has forged partnerships with local private companies, including Garbage to Garden, Save That Stuff, to manage the collection and processing of food scraps (City of Boston, 2023). The collected organic materials are either directed to a composting facility for conversion into nutrient-rich compost or processed at an anaerobic digestion plant to generate clean energy. The resulting compost is then sold in bulk to local farmers, supporting local food systems, and is also made available for purchase by program participants (City of Boston, 2023).

Complementing the opt-in curbside compost initiative, Boston also operates Project Oscar, a 24-hour community food waste program (City of Boston, 2024d). Project Oscar has established 14 locations throughout the city where residents can deposit their food scraps for composting at any time, providing round-the-clock access for food waste recycling (City of Boston, 2024c). Project Oscar's presence spans numerous Boston neighborhoods, with bins strategically placed in areas such as Brighton, Charlestown, City Hall Plaza, Dorchester, East Boston, Hyde Park, Jamaica Plain, Mission Hill, North End, Roxbury, South Boston, and the South End (City of Boston, 2024d). The city maintains an active approach to expanding Project Oscar, encouraging community involvement by soliciting suggestions for new bin locations from residents (City of Boston, 2024d).

Black Earth Compost is the partner for the collection and processing of waste from Project Oscar bins (City of Boston, 2024d). This collaboration ensures that food scraps are efficiently converted into nutrient-rich compost. The finished product is then distributed through various channels, including sales to garden centers across New England and bulk purchases by farmers and gardeners, further promoting sustainable practices in the region (City of Boston, 2024d).

These comprehensive initiatives demonstrate Boston's steadfast commitment to sustainable waste management, support for local food systems, and reduction of the environmental impact associated with food waste. By offering multiple avenues for food waste recycling, Boston aims to make composting an accessible and convenient practice for all residents (City of Boston, 2023; City of Boston, 2024d). This multifaceted approach contributes significantly to fostering a more sustainable and environmentally conscious community, aligning with broader urban sustainability goals, and setting a precedent for other municipalities to follow. However, how effective are these food wase control programs in reducing rat populations?

Boston's comprehensive composting programs represent a proactive approach to sustainable waste management, but their potential impact on urban pest control remains a critical area for investigation. While these initiatives primarily target environmental sustainability, their implementation may also affect rodent populations by reducing available food sources. This potential dual benefit raises important questions about the relationship between waste management strategies and urban pest control effectiveness. To systematically evaluate this relationship, this research examined specific data-driven questions regarding the intersection of composting implementation and rodent activity.

Research Questions, Hypotheses and Specific Aims

The initial question for my research was: Can residential food waste diversion through composting programs reduce rodent activity within Boston? Conducting an analysis based on datasets around composting participation obtained from Boston, I addressed the following specific research questions and hypotheses:

Q1: How has the implementation of residential composting in Boston affected rodent activity?

- H1: Increased residential food waste diversion in Boston was correlated with a decrease in citizen reported rodent sightings across the city. Specifically, the monthly composting tonnage and 311 service requests about rodents, was expected to have a correlation coefficient of at least $r = -.5$, indicating a moderately negative relationship.

  - H1A: Neighborhoods with composting participation above 300 households will demonstrate lower rodent sighting frequencies, with this relationship moderated by environmental and demographic factors.
  - H1B: Areas within 400 m of Project Oscar community compost bins will show a 5% decrease in rodent sightings after bin implementation, comparing pre- and post-implementation sighting frequencies at weekly, monthly, and quarterly intervals.

Q2: How does the influence of residential composting participation in reducing 311 rodent sightings vary, considering urban density?

- H2: The impact of residential composting participation on rodent sightings will be stronger in lower density areas compared to higher density areas. These differences will be particularly pronounced in the first four to eight weeks of program adoption as households establish their composting routines.
  - H2A: Areas above median density will demonstrate less effective rodent reduction (correlation of -.2 to -.3 between composting sign-ups and rodent sightings) due to increased bin sharing between households and more complex waste management coordination.
  - H2B: Areas below median density will show stronger rodent reduction (correlation of -.4 to -.5) due to individual household bin access and greater control over waste management practices.

Specific Aims

To address these questions and hypotheses, I:

1. Explored the relationship between composting participation data, 311 rodent complaint records, and population density characteristic data at the census tract level in Boston from August 2022 through April 2024.
2. Analyzed the relationship between composting implementation and rodent sightings in Boston, incorporating a) a city-wide exploration of temporal relationships and lag effects, b) a spatial analysis investigating localized effects of community compost bins, and c) the impact of population and housing density.
3. Synthesized my findings into evidence-based recommendations for optimizing composting strategies and integrating them with urban pest management efforts across diverse Boston neighborhoods.

Chapter II

Methods

This study constructed a methodological framework to examine the intersection of socioeconomic characteristics, like urban density, and municipal initiatives, like food waste control strategies, and rodent activity. To investigate, my research drew from three primary data streams: datasets provided by City of Boston's Zero Waste and Analytics departments, 311 Boston data set by Analyze Boston, and the U.S. Census 2020 demographics survey (City of Boston, n.d., City of Boston, 2024a; City of Boston, 2024b; City of Boston, 2024c; City of Boston, 2024d; City of Boston, 2024e; U.S. Census Bureau, 2020). Using citizen reported service requests as an indicator of rodent activity, I employed several analyses in Python to evaluate if and how composting participation influences rodent dynamics.

Data Sources

The city of Boston offers two complementary composting initiatives: opt-in weekly curbside collection and Project Oscar community compost bins (City of Boston, 2024c; City of Boston 2024d). Both programs were rolled out incrementally on a volunteer basis. Through outreach and successful information requests, I obtained data from the City of Boston's departments of Data Analytics and Zero Waste Program on weekly residential composting sign-ups by census tract from May 22, 2022 through August 4, 2024 (City of Boston, nd; City of Boston 2024a, City of Boston 2024e).

As shown in Table 1, curbside composting was introduced to the first 10,000 households to sign-up in August 2022, and has grown to 26,426 households by April 2024 (City of Boston, 2024e). Participation peaked in 2022 with 17,134 new sign-ups, followed by 6,872 in 2023 and 2,760 in the first eight months of 2024 (City of Boston, 2024e). Table 1 also details total food waste collection from curbside composting, which increased 228% from 510.44 tons in 2022 to 1,675.13 tons in 2023 (City of Boston, 2024e).

Table 1. Curbside composting participating and rodent sightings, 2018-2024.

Year	**Food Waste Tonnage**	**Compost Sign-ups**	**Rodent Sightings**
2018	0	0	3,452
2019	0	0	3,268
2020	0	0	4,228
2021	0	0	4,812
2022	510.44	17,134	5,944
2023	1675.13	6,872	5,965
2024	515.17 (Jan-Apr 2024)	2,760 (Jan-Aug 2024)	4,044 (Jan-Aug 2024)

Summary of data set from the Boston department of Zero Waste on curbside composting tonnage, household sign-ups, and 311 service requests with rodent-related keywords.

Table 2 outlines the Project Oscar community compost bin program (City of Boston, 2024d). The first bin was established in the North End in 2014, followed next by four bins in 2018 (City of Boston, 2024d). A significant expansion occurred in 2022 with eight new bins installed across various neighborhoods, coinciding with the curbside program launch, and reflecting Boston's commitment to zero waste initiatives (City of Boston, 2024c; City of Boston 2024d; City of Boston, 2024e). The program reached 14 bins with the addition of an East Boston location in 2023 (City of Boston, 2024d).

Table 2. Zero Waste Boston community compost bin locations, 2014-2023.

Start	Location	Latitude	Longitude
2014	North End	42.366291	-71.053725
2018	City Hall Plaza	42.360082	-71.058296
2018	Dorchester	42.349465	-71.06189
2018	Jamaica Plain	42.306648	-71.114944
2018	Brighton	42.351776	-71.153381
2022	Roslindale	42.299236	-71.069344
2022	Allston	42.329651	-71.083839
2022	Charlestown	42.376541	-71.061584
2022	Hyde Park	42.255306	-71.121628
2022	Mission Hill	42.332081	-71.099731
2022	Roxbury	42.313889	-71.099167
2022	South Boston	42.338001	-71.046783
2022	South End	42.343288	-71.073463
2023	East Boston	42.374008	-71.030437

Locations of community compost bins and year introduced Project Oscar initiative.

Table 1 also shows rodent sightings reported through 311 service requests (City of Boston 2024b). Data on rodent activity were sourced from the city's 311 service request system through the Analyze Boston open data hub (City of Boston, nd; City of Boston, 2024b). Boston's 311 system serves as a centralized non-emergency reporting channel that allows residents to request city services and report issues, including rodent sightings (City of Boston, 2024b). This system provides timestamped, geolocated reports that allow for tracking rodent activity across neighborhoods and over time (City of Boston, 2024b). For this analysis, I filtered service requests for keywords including: rodent, rodents, rat, rats, mouse, or mice (Table 3). The keyword "rodent" dominates reporting language (72% of all reports). The difference between "rat" (15.83%) and "rats" (1.02%) reports suggests residents typically report individual sightings rather than infestations. Similarly, "mice" appears more frequently than "mouse" (8.04% vs. 0.47%). Rodent sightings increased steadily from 3,452 in 2018 to 5,965 in 2023, with 4,044 sightings reported in just the first eight months of 2024 (City of Boston, 2023b).

Table 3. Distribution of rodent-related keywords in 311 service requests, 2018-2024.

Keyword	**Count**	**Percentage**
Rodent	23,216	72.09%
Rat	5,098	15.83%
Mice	2,590	8.04%
Rodents	823	2.56%
Rats	327	1.02%
Mouse	150	0.47%

Keyword filter applied 311 service requests to indicate rodent activity in Boston.

The urban density characteristics were obtained from the 2020 Census data through the U.S. Census Bureau's platform to differentiate neighborhoods within Boston (U.S. Census Bureau, 2020; U.S. Census Bureau, 2023). These data provided comprehensive population statistics and housing information at various geographic levels, identified through unique Geographic Identifiers (GEOIDs) (U.S. Census Bureau, 2023). GEOIDs are standardized numeric codes that uniquely identify all administrative/legal and statistical geographic areas for which the Census Bureau tabulates data (U.S. Census Bureau, 2023). The Census Bureau uses a hierarchical structure for these identifiers, where smaller geographic entities nest within larger ones (U.S. Census Bureau, 2023).

For Boston's neighborhoods, census tracts (11-digit GEOIDs) and block groups (12-digit GEOIDs) were particularly valuable, as they allowed for precise matching of demographic data to specific geographic areas (U.S. Census Bureau, 2023). This systematic approach enabled detailed spatial analysis of population density patterns across Boston's diverse neighborhoods, from densely populated urban centers to more residential areas, providing essential context for understanding potential correlations between urban density, composting program participation, and rodent sightings ((U.S. Census Bureau, 2023).

Analytical Techniques

To investigate the impact of urban food waste management strategies on rodent sightings, I employed analyses using the scripting language Python (McKinney, 2022). I utilized several specialized libraries within the Python ecosystem to process, analyze, and visualize the data.

This includes pandas (Python Data Analysis Library), where the name comes from "panel data," an econometrics term for multidimensional structured data sets (McKinney, 2022). This offers high-level data structures and functions designed to make working with structured or tabular data intuitive and flexible (McKinney, 2022).

GeoPandas is another open-source Python library that extends the functionality of pandas to support geospatial data analysis to perform complex spatial operations. This library significantly simplifies geospatial analysis workflows in Python, making spatial data analysis more accessible to data scientists and researchers who may not have specialized GIS training (Jordahl et al., 2020). This includes calculating distances between points, determining intersections of geometric shapes, and conducting spatial joins, without requiring a dedicated spatial database like PostGIS (Jordahl et al., 2020). The GeoPandas library also supports reading and writing various geospatial file formats and offers visualization capabilities (Jordahl et al., 2020).

NumPy, short for Numerical Python library, provided fundamental data structures and algorithms needed for scientific computing (McKinney, 2022). Its multidimensional array object was essential for efficiently manipulating the large datasets of rodent sightings across various urban locations and time periods (McKinney, 2022). Other libraries build upon NumPy's foundation, and. I leveraged NumPy's computational efficiency for statistical operations while using pandas' data manipulation capabilities for cleaning, merging, and restructuring the datasets (McKinney, 2022). Similarly, GeoPandas extends the NumPy foundation to specialized geospatial operations, allowing geographic data processing using familiar data structures while maintaining computational performance for spatial analyses (Jordahl et al., 2020). These integrations were particularly valuable when calculating correlation coefficients between composting adoption rates and rodent sighting frequencies across different time periods and geographic locations.

For the statistical analysis, I utilized SciPy which is a collection of packages addressing problems in scientific computing (McKinney, 2022). Specifically, I employed scipy.stats containing standard continuous and discrete probability distributions like density functions, various statistical tests, and descriptive statistics (McKinney, 2022). This was necessary to conduct hypothesis testing and calculate correlation coefficients between waste management implementation dates and subsequent rodent activity patterns.

Additionally, I employed descriptive statistical methods from the library scipy.stats to analyze the distribution characteristics of the data, which helped identify abnormal patterns in complaint frequencies following waste management implementations. To gain deeper insights into the temporal patterns, I used statsmodels' seasonal_decompose function to separate the time series data into trend, seasonal, and residual components (Seabold & Perktold, 2010). This decomposition allowed me to identify cyclical patterns in both composting adoption and rodent sightings and calculate correlations between corresponding components (Seabold & Perktold, 2010). For pattern recognition and machine learning analysis, I employed scikit-learn, another powerful Python library that provides simple and efficient tools for data mining and data analysis (Pedregosa et al., 2011). Specifically, I used scikit-learn's implementation of k-means clustering to categorize census tracts based on their composting sign-up rates and rodent complaint volumes.

Finally, for data visualization, I utilized Plotly, an interactive graphing library for Python that produces figures (Plotly Technologies Inc., 2015). Plotly provided advanced visualization capabilities beyond standard Python plotting libraries, enabling complex multi-panel visualizations that effectively communicated spatial and temporal patterns in the data (Plotly Technologies Inc., 2015). Additionally, Plotly's ability to create heatmaps and scatter plots with customizable color scales was instrumental in visualizing the geographic distribution of urban form metrics across Boston and illustrating the results of the k-means clustering analysis (Plotly Technologies Inc., 2015).

To complement these statistical visualizations with geospatial representations, I employed Folium, a Python library that creates interactive web maps by leveraging the Leaflet.js JavaScript library (Story, 2013). This toolset was particularly valuable for implementing hover tooltips that displayed detailed metrics for each census tract, allowing for intuitive exploration of spatial patterns in rodent sightings and composting adoption rates (Story, 2013). The combination of Plotly for statistical visualization and Folium for geospatial mapping provided a comprehensive visual framework for analyzing and communicating the complex relationships between urban form, waste management strategies, and rodent activity patterns (Plotly Technologies Inc., 2015; Story, 2013).

Data Preprocessing

I preprocessed data from multiple sources to ensure consistent analysis. Pandas facilitated several critical data manipulation tasks: merging datasets from different sources, handling missing values in rodent sightings indicated by 311 service requests, filtering observations by geographic boundaries, and aggregating rodent sightings across various temporal scales (weekly, monthly, and quarterly) (McKinney, 2022). Using pandas' datetime functionality, I standardized information from the City of Boston and U.S. Census Bureau into weekly intervals, counting 311 service requests and tracking residential composting sign-ups cumulatively (City of Boston, 2024a; City of Boston, 2024b; McKinney, 2022; pandas, 2024). For citywide composting analysis, I converted monthly food waste tonnage to daily estimates by distributing each month's total evenly across its days. This standardization aligned city-wide food waste collection data with program participation sign-up rates. The temporal alignment enabled calculation of correlation coefficients between 311 service requests about rodents and both cumulative program participation and monthly organic waste collection to address H1.

The spatiotemporal data integration involved standardizing all data to a common daily time series from May 2022 to June 2024. Using GeoPandas' GeoDataFrame structure, I geocoded 311 requests and community bin locations using their precise latitude and longitude coordinates (Table 2) to create point geometries for spatial analysis

(Jordahl et al., 2020). I managed the geographic data through systematic spatial operations and joins between census tracts and community bin locations. These geometries were then joined with census demographic data using unique GEOIDs, creating a comprehensive dataset that linked rodent sightings, composting participation, and detailed neighborhood characteristics at the census tract level, with the complete dataset containing 220 neighborhoods within Boston (U.S. Census Bureau., 2020).

Next, I applied a data filter requiring a minimum of 20 sightings and 20 sign-ups per GEOID (U.S. Census Bureau., 2020). This minimum ensured robust statistical analysis while maintaining representative data coverage across Boston neighborhoods. Detailed in Table 4, this approach preserved over 93.9% of rodent sightings (12,665 of 13,494 total complaints) and 94.1% of composting sign-ups (24,811 of 26,364 total sign-ups), while eliminating approximately 30% of census tracts (67 out of 220 total GEOIDs). Over the 30-month study period from January 2022 to April 2024, the excluded areas averaged less than one complaint or signup per month, representing

Table 4. GEOIDs sign-ups and 311 complaints retained or excluded from analysis.

Threshold Criteria	**Sum of GEOID**	**311 Rodent sightings**	**Compostin g Sign-ups**
≥20 complaints AND ≥20 sign-ups	153	12,665	24,811
<20 complaints OR <20 sign-ups	67	829	1,553
Detailed breakdown:			
<20 complaints, <20 sign-ups	45	210	121
<20 complaints, ≥20 sign-ups	9	120	1,307
≥20 complaints, <20 sign-ups	12	499	125

This table summarizes neighborhood by GEOID and associated data retained for analysis (top row) versus those excluded (remaining rows). Despite removing 30% of GEOIDs in Boston, the analysis retained over 93% of both rodent sightings and composting sign-up data.

minimal activity. As shown in Table 4, the 153 census tracts that met both thresholds contained most of both data types, accounting for 69.5% of Boston's geographic areas but capturing nearly 94% of the relevant activity data.

Additionally, areas with minimal sign-up activity but high rodent related 311 requests represented fundamentally different neighborhood dynamics—such as predominantly commercial zones—that would be inappropriate to group with higher-activity residential areas in the k-means clustering analysis that was performed to identify meaningful patterns in the relationship between composting adoption and rodent activity. The removed GEOIDs primarily constitute statistical noise that could potentially skew correlation findings between composting adoption and rodent sightings. Furthermore, certain GEOIDs with high rodent sightings but few signups, or conversely many signups but few rodent reports, might cancel each other out in the analysis, further justifying their separate examination.

By focusing on census tracts with sufficient data points, the analysis ensured that identified patterns reflect actual relationships between composting adoption and rodent activity rather than random fluctuations or data sparsity issues. This targeted filtering aimed to enhance analytical focus on areas with meaningful activity levels while maintaining most relevant data points, providing a more robust foundation for the subsequent temporal and spatial analyses, including the lag correlation analysis that examined potential delayed relationships between composting adoption and rodent sightings across different neighborhood clusters.

Data Clusters for Pattern Identification

Using k-means class from scikit-learn, I grouped census tracts across Boston to identify meaningful patterns in the relationship between composting adoption and rodent activity (Pedregosa et al., 2011; U.S. Census Bureau., 2020). Illustrated in Table 4, the remaining neighborhoods were grouped into four distinct clusters using k-means clustering (k=4), which provided sufficient differentiation between neighborhood patterns while maintaining interpretability (Pedregosa et al., 2011).

To explore the temporal relationship between composting adoption and rodent activity across different neighborhood clusters, I developed a dual-panel visualization approach. The left panel displayed the weekly progression of both composting sign-ups (shown as both weekly counts and cumulative totals) and rodent sightings for each cluster, using consistent scaling to facilitate cross-cluster comparisons. The right panel examined potential lagged effects through correlation analysis, calculating the statistical relationship between composting sign-ups and rodent sightings at different time delays.

Buffer Analysis for Community Compost Bins

To evaluate the localized impact of community compost bins, I performed a buffer analysis using GeoPandas' spatial functions to identify rodent sightings within 400-meter radius around each bin (Jordahl et al., 2020). The 400-meter radius (approximately 0.25 miles) was selected based on established research on pedestrian behavior in urban environments. Urban planners have found 0.25-0.5 miles to represent the typical walking distance that urban residents are willing to travel to access neighborhood amenities (Yang & Diez-Roux, 2012). This distance represents an approximately five-minute one-way walking trip, which is considered a reasonable distance for residents carrying food waste to community bins. This radius balances accessibility for residents while capturing the localized impact zone where increased human activity and potential food waste spillage during transport might influence rodent behavior (Yang & Diez-Roux, 2012).

The analysis tracked fourteen composting locations implemented across different time periods (2014-2023), with implementation dates standardized to the first of the month or year when exact dates were unavailable. To calculate rodent sightings within the vicinity of each composting bin, I used spatial join operations, which required converting geographic coordinates from WGS84 to UTM Zone 19N for improved calculations.

The analysis aggregated complaint frequencies across three temporal scales: weekly (7-day intervals), monthly (30-day intervals), and quarterly (90-day intervals). For each temporal scale, I calculated the average number of sightings before and after bin implementation using pandas' groupby and aggregation functions (McKinney, 2022). The variation as percent change in rodent sighting frequencies was calculated, with positive values indicating an increase in rodent sightings and negative values indicating a decrease. For locations with no pre-implementation sightings, absolute post-implementation counts were reported rather than marking them as infinite, providing more granular insight into the magnitude of change at these sites.

Spatial Visualization of Urban Density Patterns

In my analysis of urban density patterns, I developed six key metrics using 2020 U.S. Census data: population density (population per square mile), housing density (housing units per square mile), total population, total housing units, total area, and housing-to-area ratio. For comparative analysis, I split census tracts into two balanced cohorts for each metric, using median values as the dividing threshold.

I constructed the visualization framework using Plotly's make_subplots function to create dual-axis plots that paired weekly 311 rodent sighting requests with cumulative signup trends (Plotly Technologies Inc., 2015). To enable direct comparison across neighborhoods, I standardized each subplot with maximum y-axis ranges (140 for rodent sightings and 18,000 for cumulative signups). To investigate potential delayed relationships between the two variables, I conducted time-lag correlation analysis using pandas' shift() and corr() functions, examining temporal offsets ranging from 0-20 weeks.

The lag correlation analysis served as a key analytical tool for understanding the temporal relationship between composting adoption and rodent sightings. This approach identified potential delays by measuring correlations between rodent-related 311 service requests and composting sign-ups at different time intervals. For each census tract grouping, correlations were calculated at weekly intervals from zero (immediate relationship) to 20 weeks (approximately 5 months), providing insight into immediate and longer-term relationships. The analysis considered seasonal variations by examining these relationships across multiple seasonal cycles from July 2022 to early 2024.

To evaluate the geographic distribution of urban form metrics across Boston, I developed an interactive map using Python's folium library. I incorporated multiple data layers for each key metric (per square meter). Using GeoPandas, I transformed each GEOID boundary into web-compatible coordinate systems (Jordahl et al., 2020). Using Folium, I created choropleth layers for each GEOID with a YlOrRd (Yellow to Orange to Red) color scheme, representing density values (Story, 2013). I implemented interactive features through Folium's GeoJson functionality, adding hover tooltips that display detailed metrics for each census tract (Story, 2013). This spatial visualization tool validated both the urban density patterns and their relationship to rodent complaint distributions, supporting my approach used in subsequent analyses.

Chapter III

Results

Through analysis of Boston's 311 data, this study explored the complex relationship between municipal waste management initiatives and commensal rodent sightings. The results presented here examined this relationship through three key analytical lenses:

- Spatial clustering analysis of composting adoption and rodent sightings
- Temporal correlations between program participation and rodent sightings
- Effects of housing and population density on these relationships

Two specific scenarios were investigated: voluntary household composting and community compost bins. The findings revealed patterns that both challenge and confirm initial hypotheses about how these programs influence rodent populations. Rather than presenting a simple cause-and-effect relationship, the data suggested layered interactions between food waste diversion practices and rodent sightings across different Boston neighborhoods, as reported through 311 service requests.

Data Exploration

To provide a foundation for discussing the temporal patterns of rodent sightings, Figure 2 shows fluctuating 311 service requests about rodents over a period from January 2022 to August 2024. There appeared to be a consistent annual cycle illustrating noticeable seasonal patterns, with peaks occurring around late summer/early fall (July-September) and troughs in the winter months (December-February).

Figure 2. Monthly rodent sightings in Boston, January 2022-July 2024.

Temporal visualization of 311 service requests about commensal rodents self-reported by citizens in Boston from 2022 through mid-2024.

The most significant spikes in rodent sightings were observed in August through September 2022 and August through September 2024, both reaching approximately 820-850 rodent sightings. The lowest number of sightings typically occur in the winter months, with counts dropping to around 250-280 in January-February of each year (Figure 2). While the seasonal pattern is consistent, there are variations in the intensity of peaks and troughs across different years. The data showed an upward trend in complaint numbers towards the end of mid-2024, with the latest peak being one of the highest recorded (Figure 2).

City-wide Composting Tonnage

Figure 3 analyzes the relationship between composting tonnage and cumulative sign-ups for residential food waste composting in Boston, beginning in September 2022. The program's call for sign-ups dates to May 2022, when the City of Boston opened the sign-up for eligible households of six units or fewer to express interest. By August 1, 2022, the program launched with 13,154 initial household sign-ups distributed across Boston. Compost collection began immediately upon program launch in fall of 2022, signifying swift implementation (Figure 3).

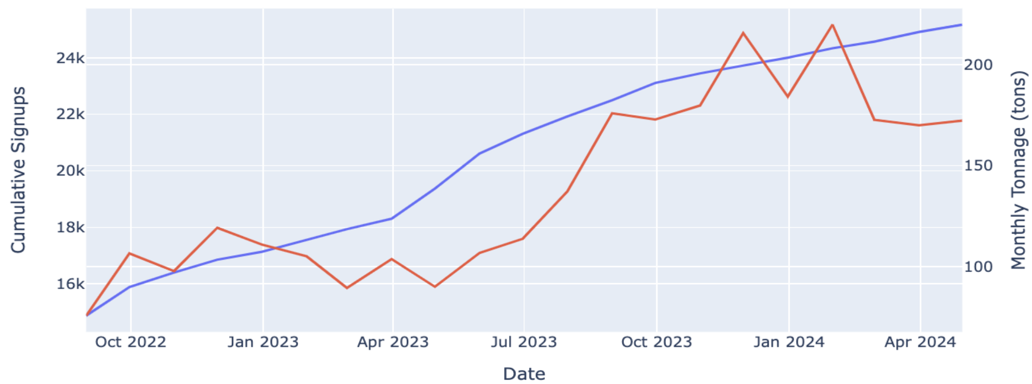


Figure 3. Composting tonnage and cumulative residential composting sign-ups.

Boston's total city-wide composting tonnage (red) and cumulative residential composting program sign-ups (blue) between September 2022 through April 2024.

Over the two year period, although there was growth in composting tonnage and sign-ups, there was a seasonal fluctuation pattern. The highest peak in composting tonnage occurs around January 2024, exceeding 200 tons; less pronounced tonnage peaks are visible in winter months of 2022-2023 (Figure 3).

While new monthly sign-ups generally decreased over time, the cumulative number of participants steadily increased. The cumulative growth in participants as seen in Figure 3 aligns more closely with the overall upward trend in composting tonnage, particularly from April 2023 onwards. The highest composting tonnage coincides with periods of higher cumulative participation, representing a positive correlation ($r = .87$, $p < 0.001$, $N = 21$) between total program engagement and waste diversion. The rise of composting tonnage over time in Figure 3 also suggests sustained program effectiveness, with an increase of approximately 150% from the initial collection volumes, and possibly improved composting practices among participants.

Residential Composting and Rodent Sightings

To test if a greater volume of compost collected in Boston is generally associated with fewer rodent sightings, I conducted a time series examination of the relationship between composting program sign-ups and 311 service requests about rodents. Figure 4 presents the weekly aggregated data of rodent sightings and new composting sign-ups. The chart reveals significant week-to-week volatility in sighting volumes, with a general increasing trend observable from early 2023 onwards. Seasonal peaks in rodent sightings are evident, particularly during summer months. In contrast, composting sign-ups showed a substantial spike at the program's initiation in early July 2022, followed by a rapid decrease and subsequent stabilization at lower levels. Minor fluctuations in sign-up rates occurred throughout the study period, but the overall trend remained relatively stable after the initial surge.

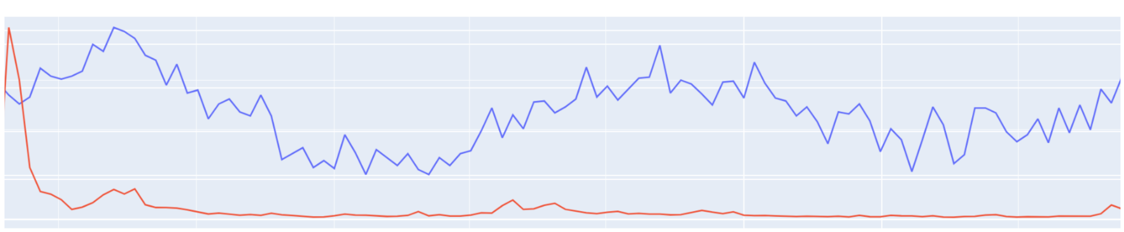


Figure 4. Rodent sightings and new residential composting sign-ups.

Boston's 311 service requests about rodent sightings (blue) and new residential composting program sign-ups (red) between May 2022 through July 2024.

Aggregation of the monthly data more clearly delineated the seasonal pattern of rodent sightings, with peaks typically occurring in summer months (Figure 5). The overall increasing trend in sightings over the two-year period is more pronounced in this monthly view. The initial spike in composting sign-ups in July 2022 is particularly evident, followed by a stabilization at much lower levels with slight seasonal variations.

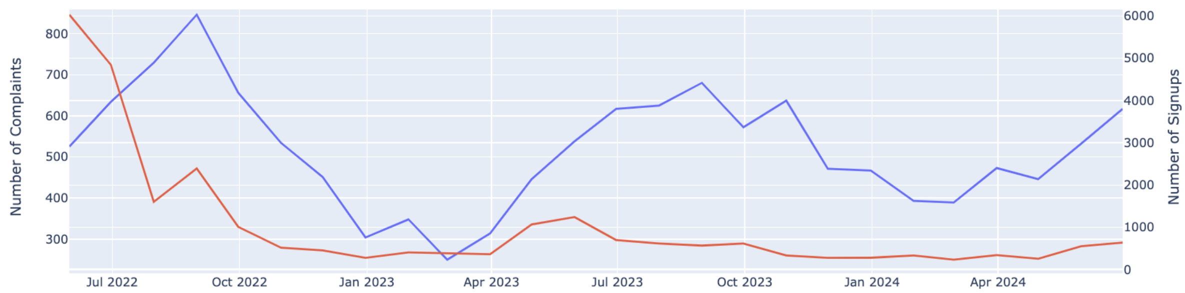


Figure 5. Rodent sightings and new residential composting sign-ups.

Boston's 311 service requests about rodent sightings (blue) and new residential composting program sign-ups (red) between May 2022 through July 2024.

The aggregations did not reveal a clear inverse relationship between composting sign-ups and complaint volumes. The initial surge in sign-ups did not correspond to a noticeable decrease in rodent sightings. Furthermore, despite relatively stable sign-up rates after the initial period, sightings continued to demonstrate an upward trend.

These observations suggest a complex relationship between composting program participation and 311 service requests. The data reflecting the initial launch of Boston's opt-in residential composting program (Figures 3, 4, & 5) do not support a strong negative correlation between composting sign-ups and complaint volumes, contrary to initial expectations. The persistent increase in rodent sightings, despite increasing new household sign-ups for the curbside composting, indicates that other factors may be influencing rodent-related 311 service request patterns.

Spatial Clustering Analysis by GEOID

I conducted a spatial clustering analysis using k-means clustering, an algorithm that groups similar data points together based on their characteristics, to examine the relationship between residential composting program participation and rodent-related 311 service requests across Boston's GEOIDs (Figure 6). Four distinct patterns emerged, revealing low, moderate, and high activity of community engagement in composting programs and rodent sightings reported through Boston’s 311 service request system. The analysis provided insights into how waste management practices may influence urban rodent populations while highlighting areas for targeted intervention.

Cluster 0, designated as low-composting and low-complaint areas (shown in red in Figure 6), exhibited minimal engagement with both composting sign-ups and 311 service requests. These areas recorded between 20-100 rodent sightings and 20-150 program sign-ups during the study period, with most areas clustering around 50 for either metric (Figure 6). This pattern suggested areas where community engagement with municipal services could be enhanced, or where alternative waste management solutions might be more appropriate.

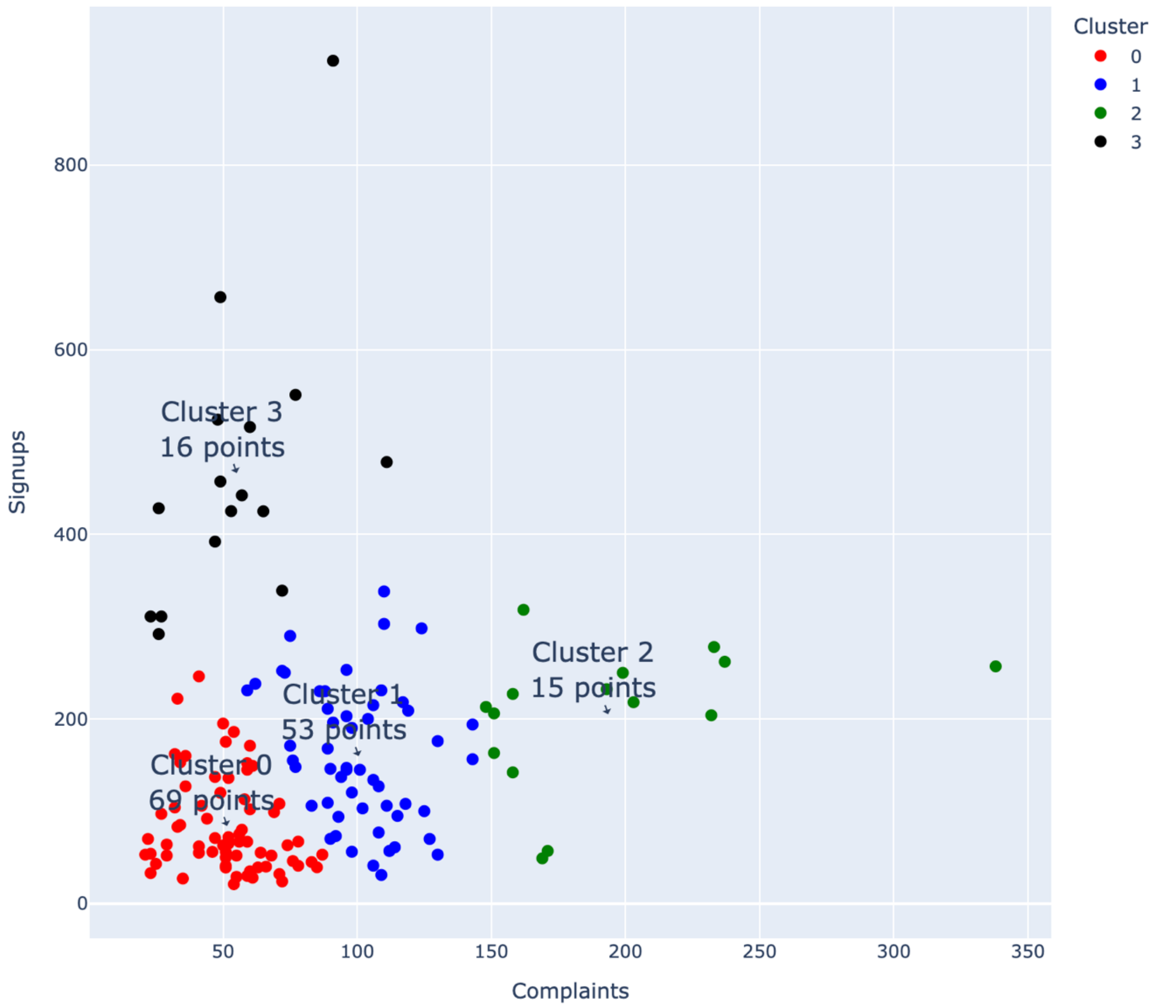


Figure 6. Cluster analysis of composting sign-ups and rodent sightings.

K-means clustering analysis for 153 GEOIDs in Boston indicating low to high activity residential composting sign-ups and 311 service requests about rodents.

Cluster 2, high-complaint and low-composting areas (shown in green) revealed areas where service requests were disproportionately high compared to program participation, with 150-350 sightings and 50-300 sign-ups (Figure 6). These areas, concentrated around 200-250 sightings likely reflect underlying urban challenges that require a comprehensive IPM approach, with improved waste management practices serving as one component of the solution.

Cluster 3, high-composting and low-complaint areas (shown in black) demonstrated exceptional program participation levels, with sign-up rates ranging from 300-900, while maintaining relatively low complaint levels between 50-150 sightings (Figure 6). The spatial analysis revealed that the relationship between program participation and urban service requests is not linear, suggesting the influence of multiple factors on these patterns. While housing density and population metrics provided additional context, their impact varied across clusters. Notably, extreme values were primarily observed in program sign-up rates rather than complaint numbers, indicating that while community participation can vary significantly, rodent-related service requests tend to fall within more predictable ranges (Figure 6).

For each cluster, I conducted a temporal analysis by aggregating the data by month to track the weekly progression of cumulative new sign-ups (red), and 311 service requests (blue) (Figures 7, 8, 9, & 10). To explore the temporal relationship between these variables, I employed a lagged correlation analysis (green) to examine how changes in sign-up rates correlated with subsequent changes in 311 service request frequencies indicating rodent sightings (Figures 7, 8, 9, & 10). Table 5 shows correlation results from the analysis of the relationship between composting program sign-ups and rodent sightings across different neighborhood clusters.

Table 5. Statistical analysis of composting and rodent sighting clusters.

	Pearson's correlation *(r)*	***p* value** *(p)*	**Sample size** *(N)*	**Significant lagged correlations** *(r(N) = r value, p value)*
Cluster 0 composting (low); complaints (low)	0.297	.141	26	Week 4: *r*(22) = -.591, *p* = .004 Week 5: *r*(21) = -.595, *p* = .004 Week 9: r(17) = .585, *p* = .014
Cluster 1 composting (med); complaints (med)	0.418	.033	26	Week 4: *r*(22) = -.603, *p* = .003 Week 5: *r*(21) = -.705, *p* < *0.001* Week 11: *r*(15) = .675, *p* = .006
Cluster 2 composting (low); complaints (high)	0.313	.120	26	Week 4: *(22)* = -.483, *p* = .023 Week 13: *r*(13) = .622, *p* = .023 Week 18: *r*(8) = -.789, *p* = .020
Cluster 3 composting (high); complaints (low)	0.069	.739	26	Week 4: *r*(22) = -.555, *p* = .007 Week 10: *r*(16) = .741, *p* = .001

Analysis of the relationship between residential composting program participation and rodent-related 311 service requests across four distinct neighborhood clusters in Boston. The table presents Pearson correlation coefficients (r) with their corresponding p values and sample size (N). Overall correlations represent the relationship without time lags, while significant lagged correlations (p < .05) could demonstrate time-dependent relationships at specific weekly intervals.

Note that correlation coefficients (r) range from -1 to 1, with values closer to 1 indicating stronger positive relationships, values closer to -1 indicating stronger negative relationships, and values near 0 indicating little to no relationship between variables.

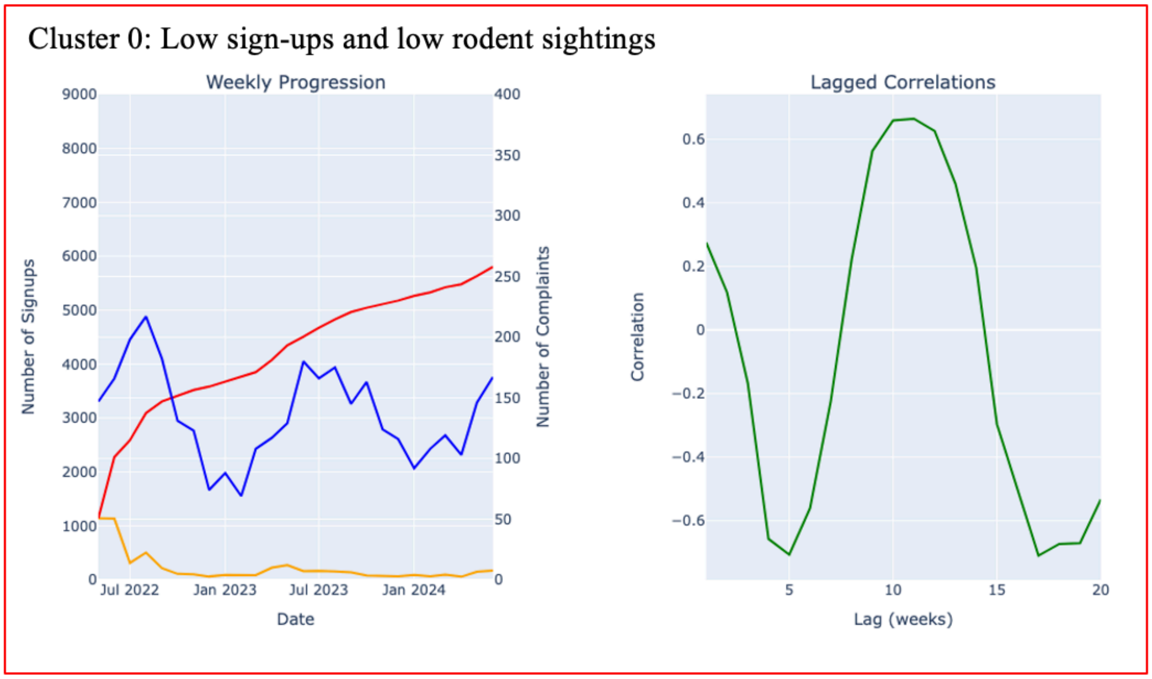


Figure 7. Temporal analysis of low-sign ups and low rodent sightings.

Progression of weekly and cumulative (red) composting sign-ups and 311 service requests (blue) over time with a lagged correlation (green) analysis indicating rodent sighting frequency for each GEOID activity within Cluster 0.

The temporal analysis of Cluster 0 showed consistently low composting adoption rates reaching about 5,500 sign-ups by 2024, with moderate but fluctuating rodent sightings averaging around 150 reports per week (Figure 7). The lag correlation analysis revealed a strong positive correlation (peaking at r = .585, p = .014) at week 9 (Table 5). Weekly sign-ups showed a sharp initial spike followed by minimal activity, while rodent sightings display cyclical patterns with peaks in mid-2022 and mid-2023. The correlation pattern shows both positive and negative relationships across different time lags, with strong negative correlations (r = -.591, p = .004 at week 4; r = -.595, p = .004 at week 5) occurring around weeks 4-5 (Table 5).

The overall correlation for Cluster 0 was relatively weak (r = .297, p = .141,

$N = 26$), indicating no strong linear relationship between composting adoption and rodent sightings when viewed without time lags (Table 5). However, the lagged correlation analysis revealed significant negative correlations at weeks 4-6 ($r = -.591$, $p = .004$ at week 4; $r = -.595$, $p = .004$ at week 5; $r = -.458$, $p = .042$ at week 6) and significant positive correlations at weeks 9-10 ($r = 0.585$, $p = .014$ at week 9; $r = .568$, $p = .022$ at week 10) (Table 5). Later lags show stronger negative correlations (reaching $r = -.677$ at week 19) with decreasing statistical significance due to smaller sample sizes (Table 5).

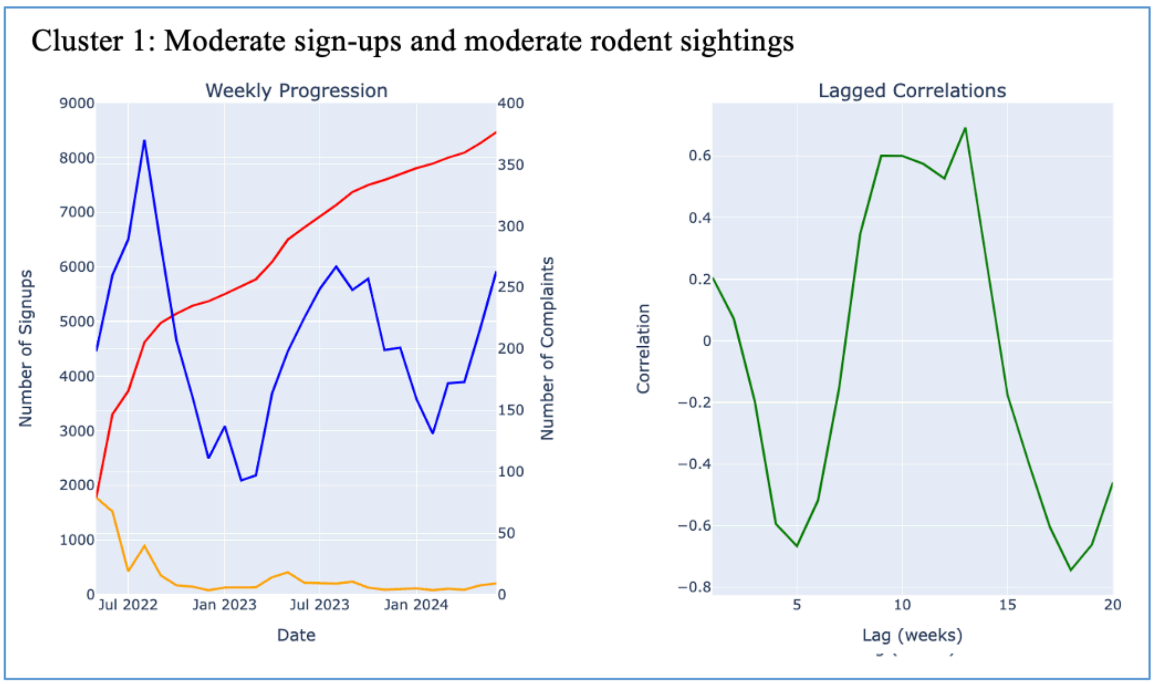


Figure 8. Temporal analysis moderate sign-ups and moderate rodent sightings.

Progression of weekly (yellow) and cumulative (red) composting sign-ups and 311 service requests (blue) over time with a lagged correlation (green) analysis indicating rodent sighting frequency for each GEOID activity within Cluster 1.

The temporal analysis of Cluster 1 in Figure 8 revealed steady growth in composting participation reaching over 8,000 sign-ups, with notable spikes in rodent sightings early in the program and again in early 2024. The lag correlation shows a strong positive relationship (peaking at $r = 0.675$, $p = .006$ at week 11) (Table 5). The weekly sign-up rate shows a gradual decline after initial adoption, while rodent sightings exhibit pronounced seasonality with winter lows and summer peaks. The lag correlation demonstrates multiple peaks and troughs, with the strongest negative correlation ($r = -.761$, $p = .028$) occurring at week 18 (Table 5).

Cluster 1 showed the strongest overall correlation ($r = .418$, $p = .033$, $N = 26$), which was statistically significant, suggesting a moderate positive relationship between composting sign-ups and rodent sightings without considering time lags (Table 5). The lagged correlation analysis revealed significant negative correlations at weeks 4-6 ($r = -0.603$, $p = .003$ at week 4; $r = -.705$, $p < .001$ at week 5; $r = -.554$, $p = .011$ at week 6) and significant positive correlations at weeks 9-13 ($r = .597$, $p = .011$ at week 9; $r = .660$, $p = .005$ at week 10; $r = .675$, $p = .006$ at week 11; $r = .613$, $p = .020$ at week 12; $r = .633$, $p = .020$ at week 13) (Table 5). The strongest negative correlation occurred at week 18 ($r = -.761$, $p = .028$), suggesting a complex cyclical relationship between these variables (Table 5).

The temporal analysis of Cluster 2 in Figure 9 showed moderate composting adoption reaching about 3,000 sign-ups, coupled with consistently high rodent sightings that display significant volatility throughout the period. The lag analysis shows multiple correlation peaks, with the strongest positive correlation ($r = .622$, $p = 0.023$) occurring at week 13 (Table 5). The weekly sign-up pattern indicates rapid early adoption was

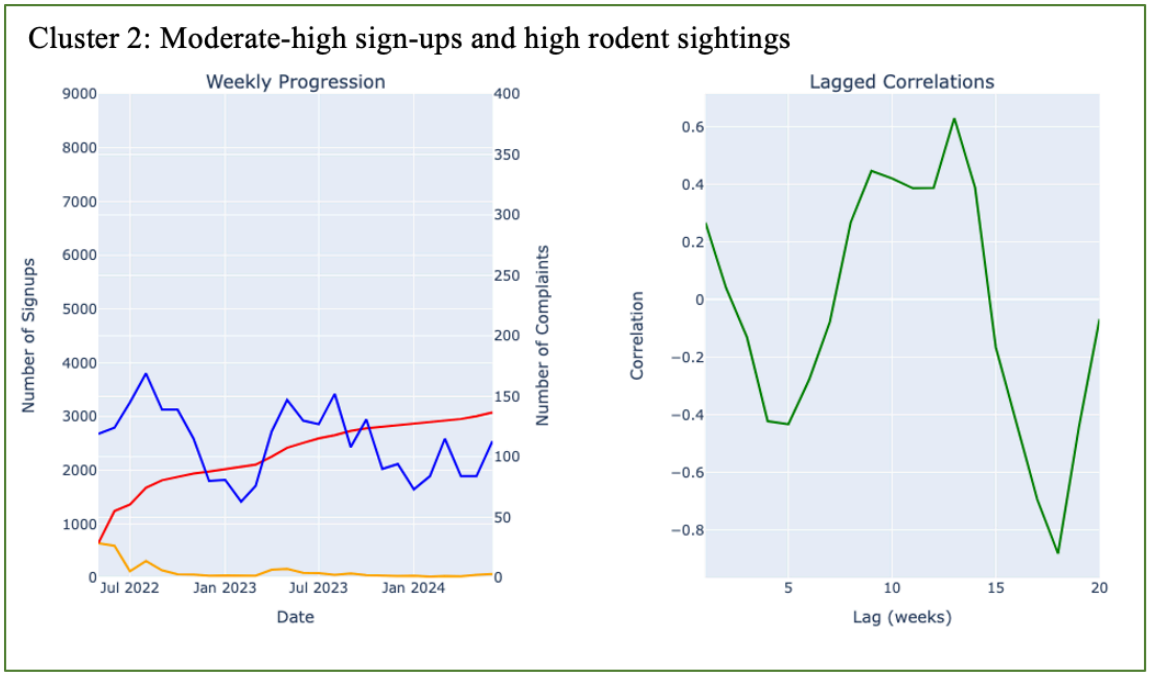


Figure 9. Temporal analysis of moderate-high sign-ups and high rodent sightings.

Progression of weekly (yellow) and cumulative (red) composting sign-ups and 311 service requests (blue) over time with a lagged correlation (green) analysis indicating rodent sighting frequency for each GEOID activity within Cluster 2.

followed by minimal growth, while rodent sightings were consistently volatile with peaks exceeding 150 reports per week. The lag correlation exhibited the most extreme negative value (r = -.789, p = .020) among all clusters at week 18 (Table 5).

For Cluster 2, the overall correlation was moderate but not statistically significant (r = .313, p = .120, N = 26) (Table 5). However, the lagged correlation analysis revealed significant patterns, including negative correlations at weeks 4-5 (r = -.483, p = .023 at week 4; r = -.435, p = .049 at week 5) and significant positive correlations at week 9 (r = .506, p = .038) and week 13 (r = .622, p = 0.023) (Table 5). Additional significant negative correlations appeared at week 17 (r = -.680, p = .044) and week 18 (r = -.789, *p* = .020), with the latter being the strongest negative correlation across all clusters (Table 5). This suggests that initial composting adoption may be followed by a decrease in rodent sightings after approximately 4-5 weeks, but with a potential increase after 9-13 weeks, followed by another decrease around 17-18 weeks.

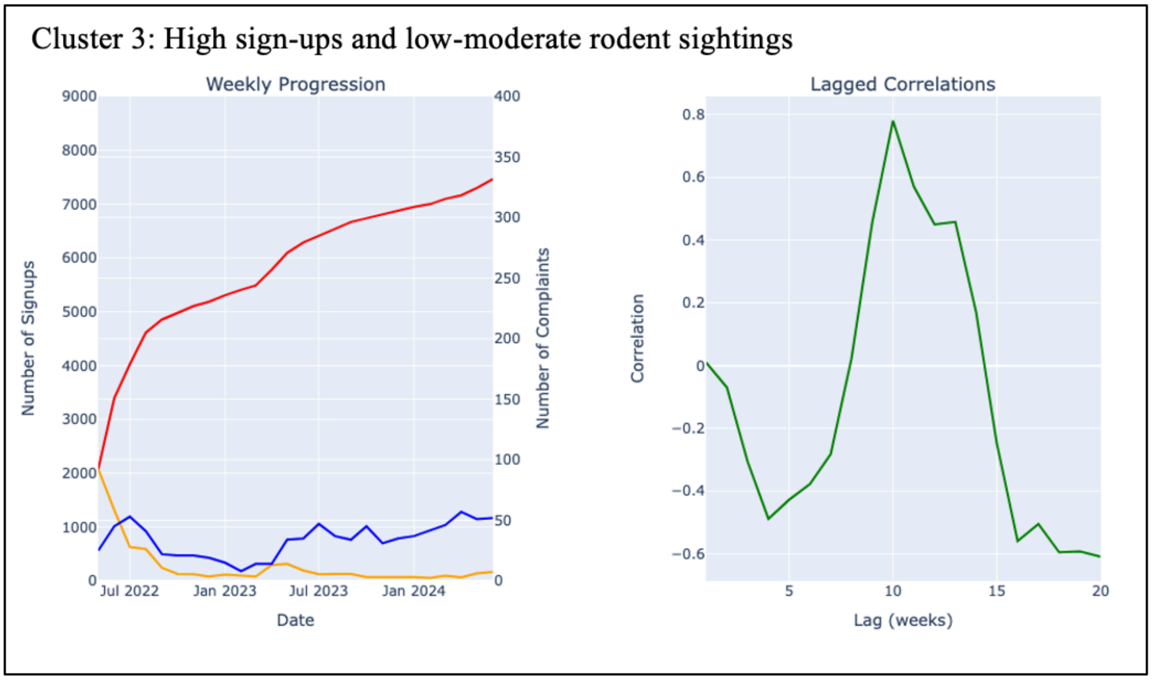


Figure 10. Temporal analysis of high sign-ups and low-moderate rodent sightings.

Progression of weekly (yellow) and cumulative (red) composting sign-ups and 311 service requests (blue) over time with a lagged correlation (green) analysis indicating rodent sighting frequency for each GEOID activity within Cluster 3.

The temporal analysis of Cluster 3 demonstrated strong composting program adoption reaching over 7,000 sign-ups, while maintaining relatively low rodent complaint levels averaging around 50 reports per week (Figure 10). The lag correlation analysis showed the strongest positive correlation (r = .741, p = .001) at week 10 (Table 5). The cumulative sign-up curve showed the steepest growth rate among all clusters, particularly in the first six months. Rodent sightings maintained the lowest baseline level of all clusters, with minimal weekly variation and no pronounced seasonal patterns. The lag correlation structure showed a distinct pattern with a strong positive correlation at week 10 followed by weaker correlations at longer lags.

Interestingly, Cluster 3 showed the weakest overall correlation (r = .069, p = .739, N = 26), indicating almost no linear relationship between composting adoption and rodent sightings when viewed without time lags (Table 5). However, the lagged correlation analysis revealed significant negative correlations at weeks 4-5 (r = -.555, p = .007 at week 4; r = -.480, p = .028 at week 5) and a strong significant positive correlation at week 10 (r = .741, p = .001) (Table 5). At longer lags, the correlations become increasingly negative (reaching r = -0.648 at week 19), though with decreasing statistical significance due to smaller sample sizes (Table 5). This suggests that in high-composting areas, the relationship between composting adoption and rodent sightings is more complex and time-dependent, with initial decreases in rodent sightings followed by potential increases after approximately 10 weeks, and possibly another decrease at longer time intervals.

Buffer Analysis of Community Compost Bins

The spatial analysis examined rodent activity within 400-meter radius buffer zones around 14 Project Oscar community composting bin locations across Boston neighborhoods (Figure 11). This analysis compared rodent sighting activity before and after bin implementation across weekly, monthly, and quarterly time periods (Table 6).

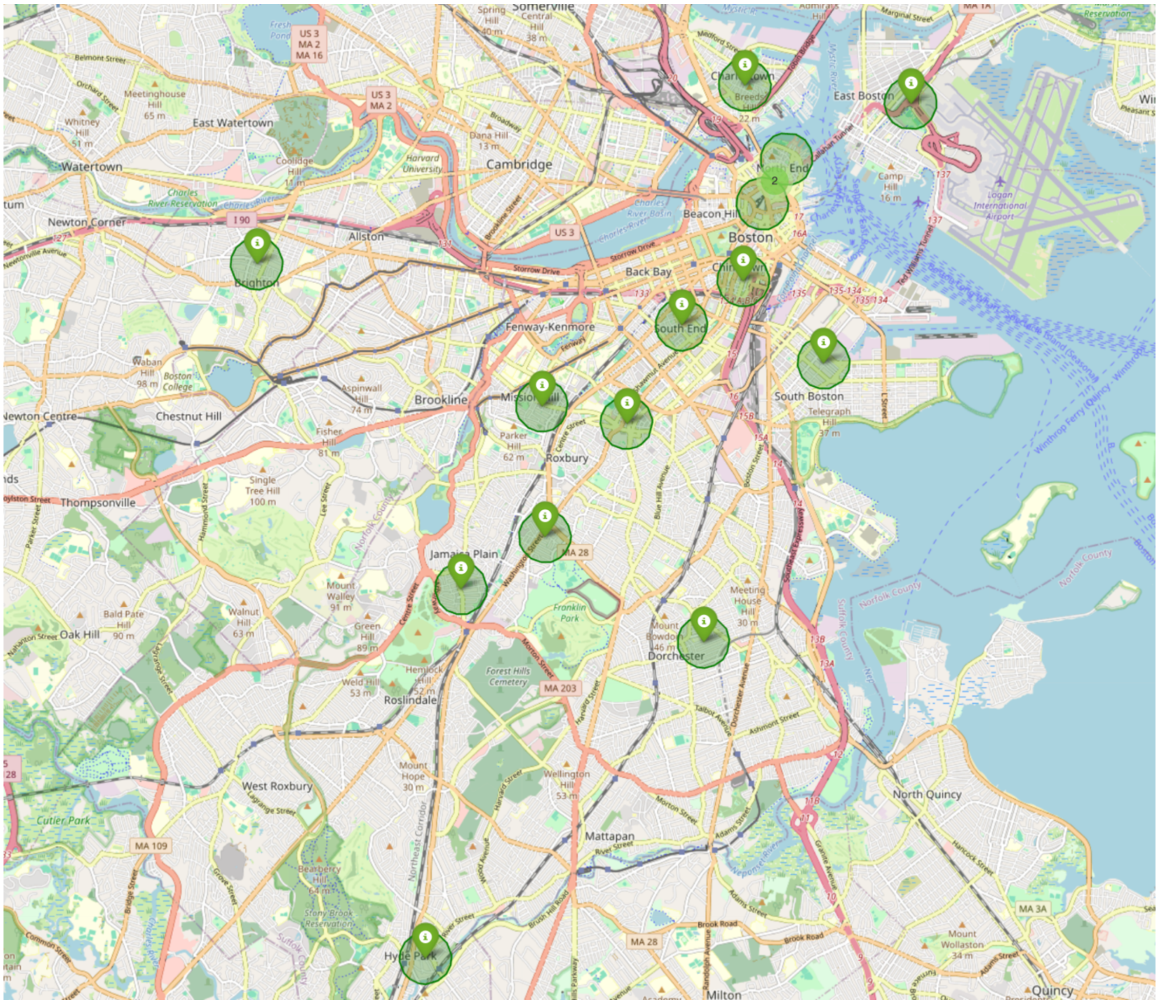


Figure 11. Project Oscar community compost bins.

Map of Boston indicating all locations of existing Project Oscar community compost bins as detailed in Table 2 with a 400 meter radius.

The South End exhibited the highest pre-existing rodent activity within its buffer zone, with 3.49 weekly sightings, 15.02 monthly sightings, and 43.47 quarterly sightings (Table 6). Following bin implementation, these numbers increased to 4.48 weekly, 19.48 monthly, and 56.00 quarterly sightings, representing a consistent 28-30% increase across all temporal scales (Table 6).

Table 6. Variance in rodent sightings with community compost bins.

	Weekly			Monthly			Quarterly		
	Before	**After**	**% var**	**Before**	**After**	**% var**	**Before**	**After**	**% var**
North End	-	2.45	-	-	10.62	-	-	31.85	-
City Hall Plaza	-	0.76	-	-	3.24	-	-	9.73	-
Dorchester	-	0.81	-	-	3.49	-	-	10.46	-
Jamaica Plain	-	0.51	-	-	2.19	-	-	6.58	-
Brighton	-	0.81	-	-	3.47	-	-	10.42	-
East Boston	0.33	0.36	9.31	1.42	1.53	8.11	3.87	4.33	12.07
Roslindale	0.48	0.72	49.61	2.06	3.07	49.05	6.19	9.22	49.05
Allston	0.34	0.93	175.2	1.43	4.00	180.5	4.05	11.50	183.8
Charlestown	0.77	0.83	8.22	3.29	3.61	9.66	9.53	10.38	8.91
Hyde Park	0.13	0.34	158.25	0.56	1.39	150.4	1.58	4.00	153.3
Mission Hill	0.55	0.81	47.07	2.39	3.50	46.77	6.89	9.63	39.72
Roxbury	0.59	0.90	51.48	2.58	3.91	51.56	7.47	11.25	50.53
South Boston	0.74	0.89	20.86	3.20	3.87	20.92	9.26	11.13	20.10
South End	3.49	4.48	28.54	15.02	19.48	29.70	43.47	56.00	28.81

Analysis of rodent sightings within 400-meter radius buffer zones around Project Oscar community compost bins, comparing activity before and after bin implementation across weekly, monthly, and quarterly intervals. The data shows the average number of rodent sightings during each period and the percentage variation between pre- and post-implementation. If no value, there was no recorded sightings before bin was placed, but there were 311 rodent requests made after bin placed.

The most substantial percentage increases occurred in Allston's Project Oscar compost bin buffer zone, where rodent sightings rose by 175.2% weekly (from 0.34 to 0.93 sightings), 180.5% monthly (from 1.43 to 4.00 sightings), and 183.8% quarterly (from 4.05 to 11.50 sightings) (Table 6). Hyde Park also experienced significant increases of 158.3% weekly (from 0.13 to 0.34 sightings), 150.4% monthly (from 0.56 to 1.39 sightings), and 153.3% quarterly (from 1.58 to 4.00 sightings) (Table 6).

In contrast, some neighborhoods showed more modest changes. Charlestown's rodent sightings increased by only 8.2% weekly (from 0.77 to 0.83), 9.7% monthly (from 3.29 to 3.61), and 8.9% quarterly (from 9.53 to 10.38) (Table 6). Similarly, East Boston showed minimal increases of 9.3% weekly (from 0.33 to 0.36), 8.1% monthly (from 1.42 to 1.53), and 12.1% quarterly (from 3.87 to 4.33) (Table 6).

The other previously unaffected locations showed varying levels of new rodent activity including City Hall Plaza: 0.76 weekly, 3.24 monthly, and 9.73 quarterly sightings; Dorchester: 0.81 weekly, 3.49 monthly, and 10.46 quarterly sightings; Brighton: 0.81 weekly, 3.47 monthly, and 10.42 quarterly sightings; and Jamaica Plain: 0.51 weekly, 2.19 monthly, and 6.58 quarterly sightings (Table 6).

While the buffer analysis provided insights into localized effects around community composting infrastructure, broader neighborhood characteristics also played a crucial role in program outcomes. An analysis of urban density within each GEOID examined how population and housing density patterns manifest across different neighborhood types, revealing how other community characteristics can impact composting program participation and rodent sighting reporting.

Urban Density Analysis

I investigated six key GEOID metrics: population density, housing density, total population, total housing units, total area, and housing-to-area ratio. I created choropleth maps to visualize population density (Figure 12), housing density (Figure 13), housing-to-area ratio (Figure 14), total rodent-related 311 service requests (Figure 15), and density of rodent-related 311 service requests (Figure 16). I calculated and mapped metrics for each GEOID polygon using a yellow-to-red color gradient to indicate least to most intensity within neighborhoods.

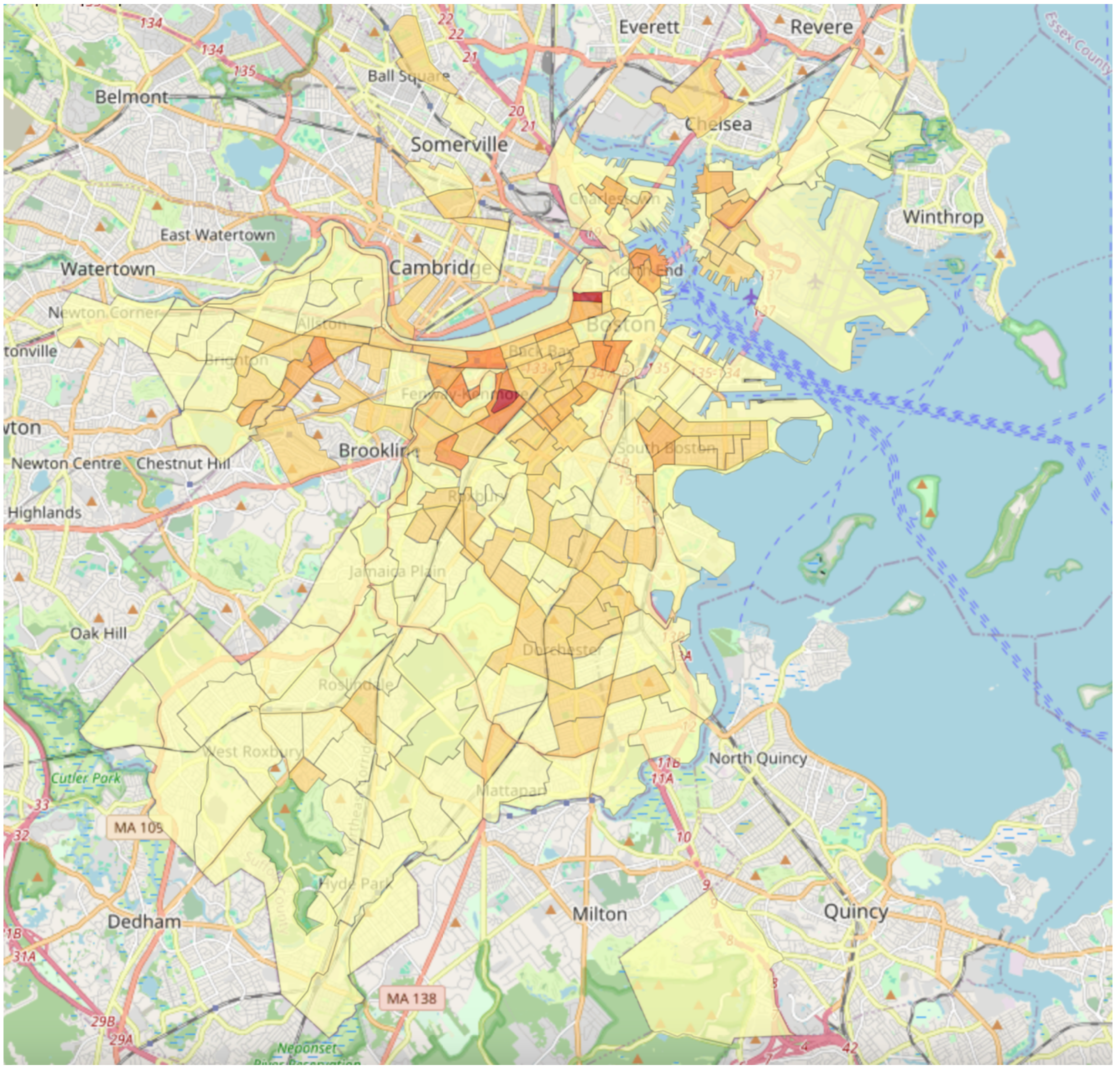


Figure 12. Population density distribution across Greater Boston.

Choropleth map of population density (people per square meter) characteristics of GEOIDs in Boston with darker areas (red) representing higher density and lighter areas (yellow) representing lower density.

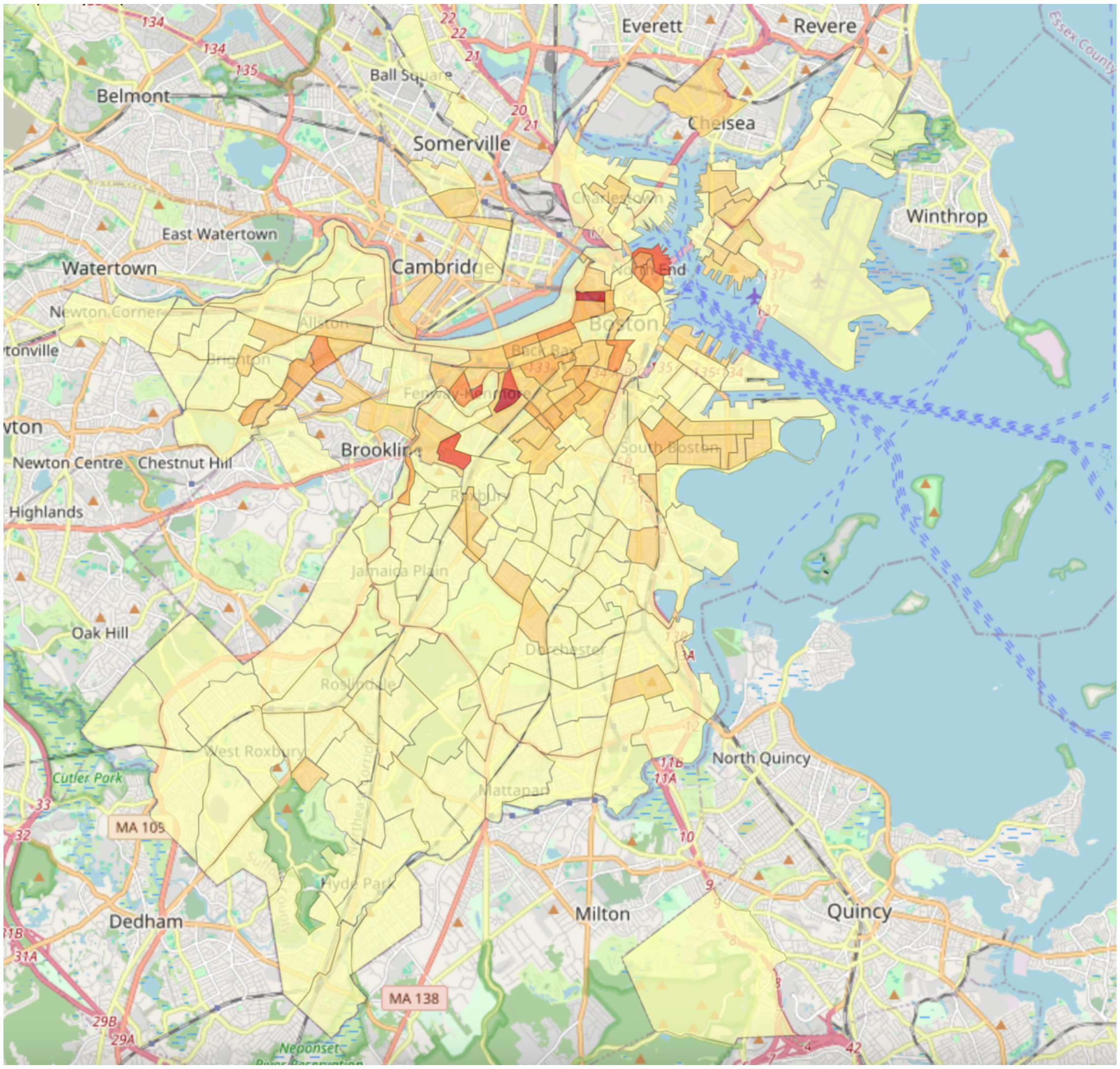


Figure 13. Housing density distribution across Greater Boston.

Choropleth map of housing density (units per square meter) characteristics of GEOIDs in Boston, with darker areas (red) representing higher density and lighter areas (yellow) representing lower density.

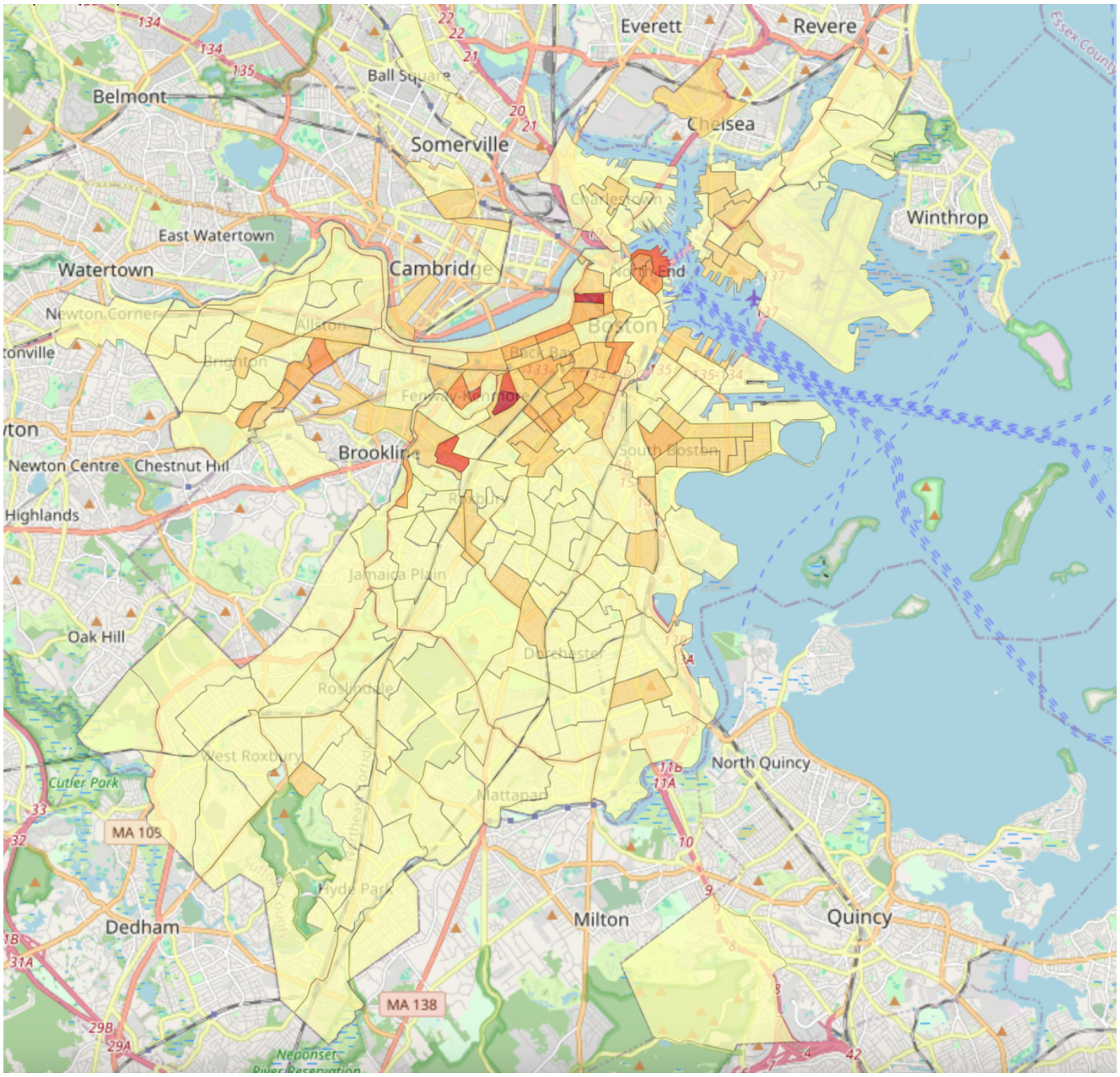


Figure 14. Housing to area ratio across Greater Boston.

Choropleth map of housing to area ratio (units per square meter) characteristics of GEOIDs in Boston, with darker areas (red) representing higher density and lighter areas (yellow) representing lower density.

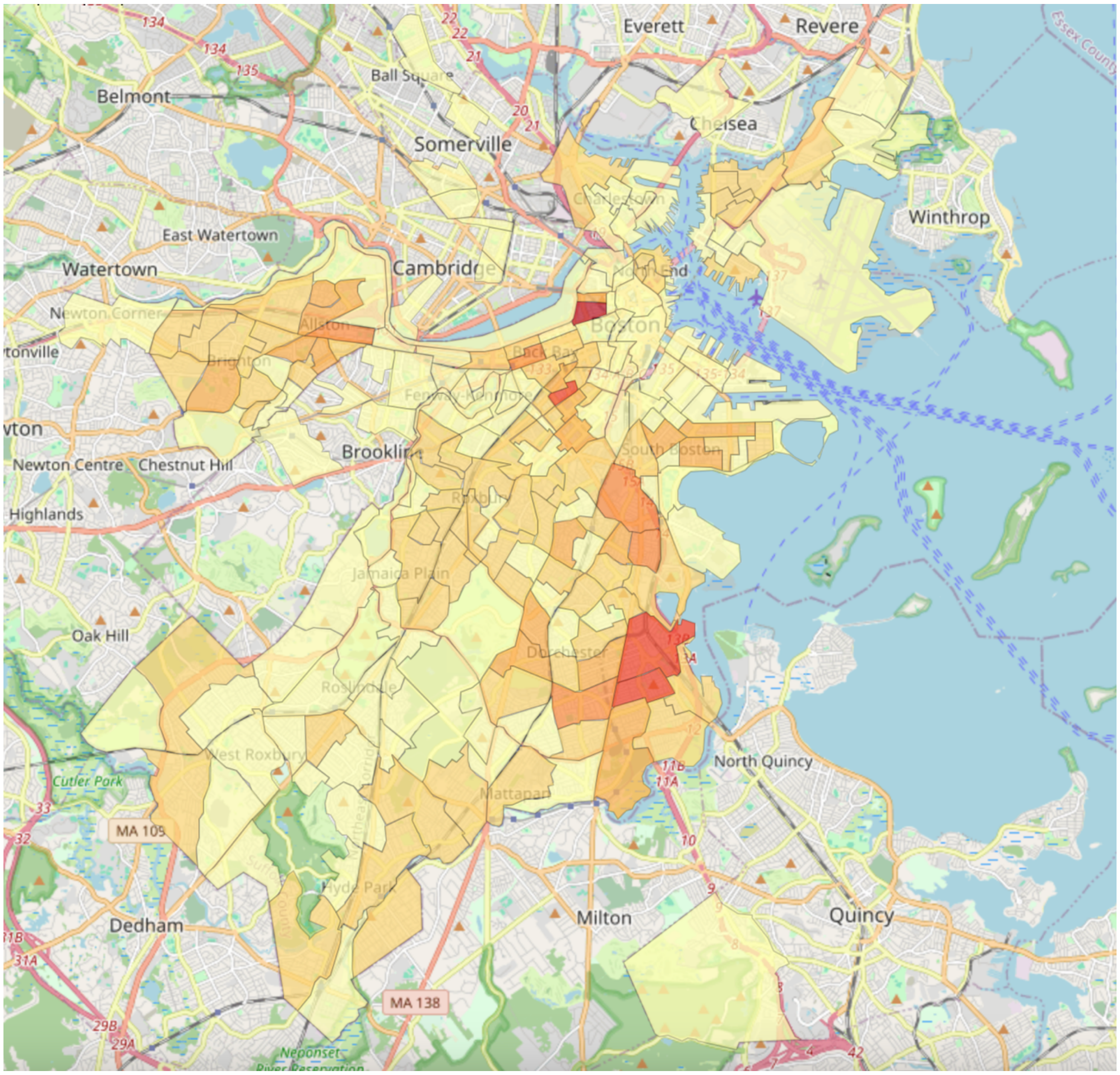


Figure 15. 311 Total rodent sightings across Greater Boston.

Choropleth map of 311 service requests indicating rodent sightings (number of requests) characteristics of GEOIDs in Boston, Massachusetts, with darker areas (red) representing higher values and lighter areas (yellow) representing lower values.

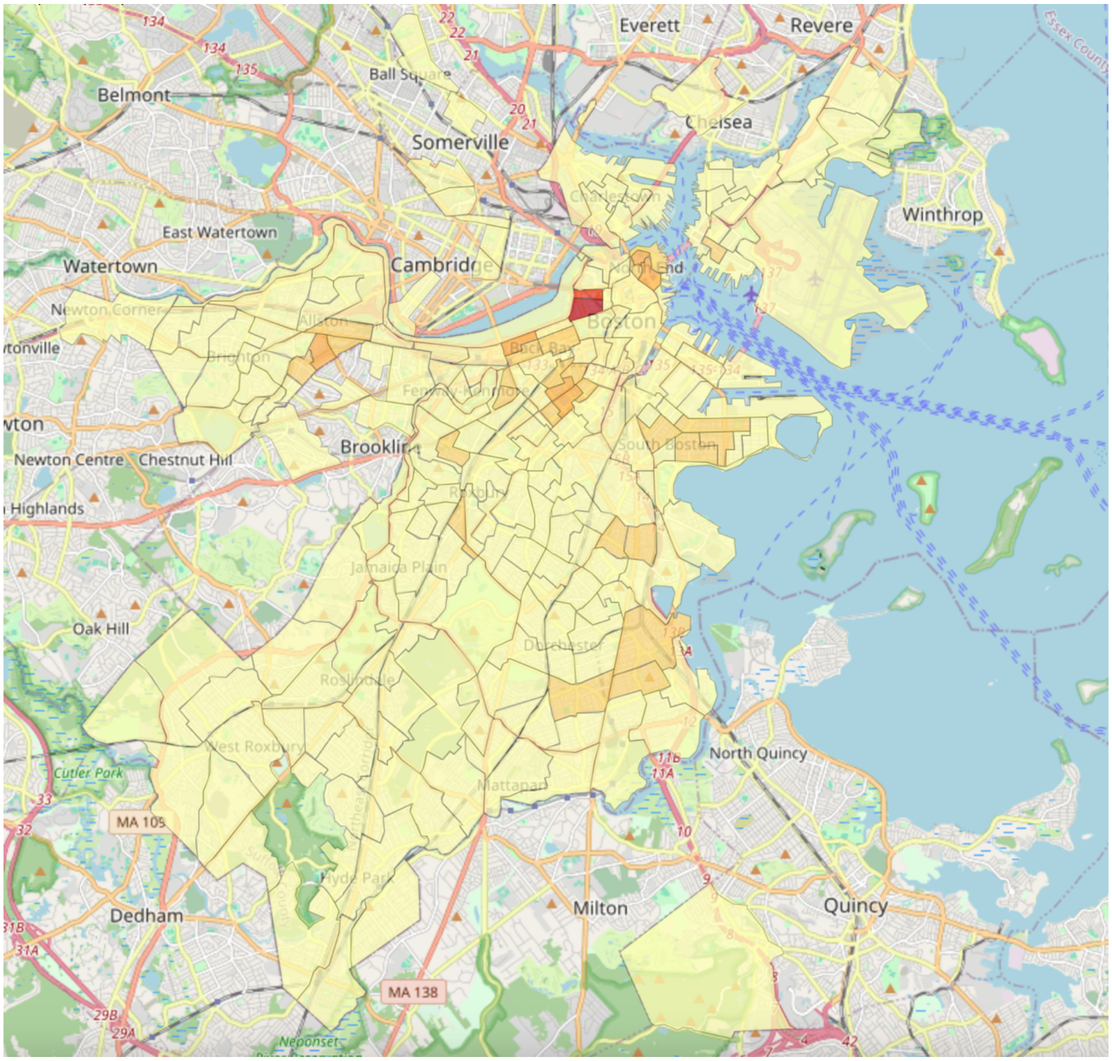


Figure 16. Rodent sighting density across Greater Boston.

Choropleth map of 311 service requests indicating rodent sightings (requests per square meter) characteristics of GEOIDs in Boston, with darker areas (red) representing higher density and lighter areas (yellow) representing lower density.

Table 7 presents the statistical relationship between demographic factors and rodent complaint patterns across areas with different demographic characteristics in Boston. The analysis reveals a distinct time-dependent pattern in how these demographic metrics correlate with complaint data.

Table 7. Statistical analysis of demographics and rodent complaints.

Demographic Factor	**Overall (Week 1-20, N = 114)**		**Initial (Week 1, N = 113)**		**Delayed (Week 15, N = 99)**	
	r	*p*	*r*	*p*	*r*	*p*
Population Density - Above Median	.275	.003	.248	.008	-.440	<.001
Population Density - Below Median	.149	.114	.215	.022	-.342	.001
Total Population - Above Median	.275	.003	.270	.004	-.349	<.001
Total Population - Below Median	.148	.116	.185	.049	-.470	<.001
Housing Density - Above Median	.277	.003	.241	.010	-.455	<.001
Housing Density - Below Median	.153	.105	.221	.019	-.335	.001
Total Housing - Above Median	.238	.011	.214	.023	-.420	<.001
Total Housing - Below Median	.176	.062	.234	.013	-.398	<.001
Total Area - Above Median	.196	.036	.227	.015	-.331	.001
Total Area - Below Median	.235	.012	.233	.013	-.458	<.001

This table presents Pearson correlation coefficients (r) and p-values examining the relationship between key demographic metrics and complaint data across different time lags. Data are stratified by above and below/equal to median values for each demographic factor.

A critical finding was the consistent shift from positive to negative correlations across all demographic factors by week 15. This negative relationship was statistically significant ($p \leq .001$) and moderate to strong in magnitude for all metrics. The strongest delayed negative correlations were observed in below-median total population areas ($r = -.470$, $p < .001$, $N = 99$) and below-median total area ($r = -.458$, $p < .001$, $N = 99$), suggesting that less densely populated areas experienced more pronounced delayed reductions in rodent complaints following composting implementation (Table 7).

The initial correlations (Week 1) are generally weak but positive (r = .185 to -.270), while delayed correlations (Week 15) demonstrate moderate to strong negative relationships (r = -.331 to -.470) (Table 7). This consistent pattern of correlation shifts from positive to negative across all demographic factors suggests a meaningful time-dependent relationship between urban demographics and rodent complaint reporting behaviors. The sample size decreases with increasing lag time (from N = 114 at lag 0 to N = 99 at Week 15) due to the temporal structure of the dataset, which is a common characteristic of longitudinal analyses (Table 7). This time-lagged approach provides insight into how the influence of demographic factors on rodent complaint patterns evolves over time, rather than capturing only immediate associations.

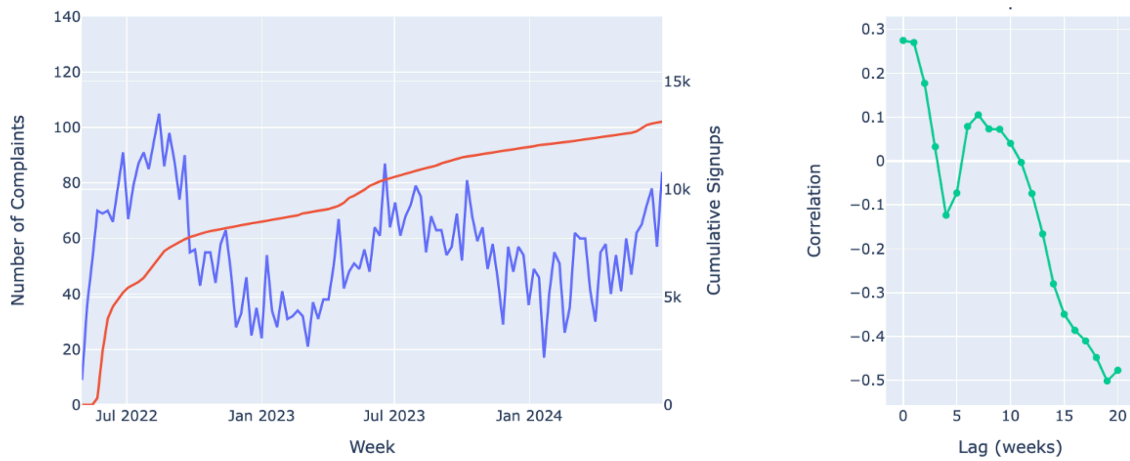
The spatiotemporal analyses observing population (Figures 17 & 18), housing (Figures 19 & 20), and total area (Figure 21) of each U.S. Census Block Group reveals distinct patterns in rodent-related 311 service requests and residential composting adoption across different neighborhood characteristics. All analyzed groups showed a general upward trend in cumulative residential composting sign-ups (red line) over the study period from July 2022 to early 2024. Meanwhile, weekly 311 rodent service requests (blue line) displayed considerable volatility.

However, there were slight differences in the pattern variation, providing insights on potential impacts of urban density within different neighborhoods in Boston. The lagged correlation analyses (green line) consistently demonstrated an initial positive correlation that transitions to negative values after approximately 10 weeks across all metrics, though the magnitude and timing of these transitions vary by neighborhood characteristics. Each metric was analyzed by dividing the GEOIDs into two groups based on their median values, allowing direct comparisons between areas with higher and lower density characteristics. This approach revealed nuanced differences in both program adoption rates and rodent activity patterns across Boston's diverse urban landscape.

Statistical analysis of these lagged correlations confirmed the significance of the observed pattern shifts. The initial positive correlations (weeks 0-1) reached statistical significance ($p < .05$) for most metrics, particularly in above-median density neighborhoods ($r = .196$ to $.277$, $N = 114$) (Table 7). The transition to negative correlations after week 10 was statistically significant across all demographic factors, with week 15 correlations ranging from $r = -.331$ to $-.470$ ($p \leq .001$, $N = 99$) (Table 7). This consistent statistical pattern provides strong evidence for a meaningful time-dependent relationship between urban demographics and rodent complaint behaviors.

GEOIDs with above-median population levels demonstrated cumulative composting participation at 13,121 sign-ups, characterized by distinct seasonal patterns in rodent sightings ranging from about 30 to 100 reports weekly (Figure 17). Statistical analysis revealed a statistically significant but weak positive correlation initially ($r = .275$, $p = .003$, $N = 114$), suggesting that in densely populated areas, there was a modest association between composting adoption and rodent complaints early in the program (Table 7). While statistically significant, this correlation explains only about 7.6% of the variance ($R^2 = .076$), indicating that other factors likely played substantial roles in rodent complaint patterns during the initial phase.

Total Population – Above Median



Total Population – Below or Equal to Median

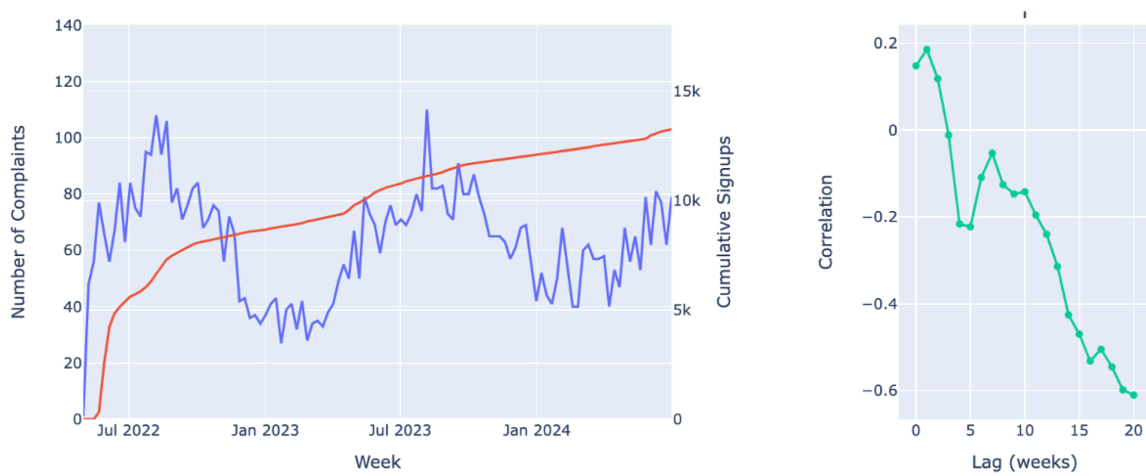


Figure 17. Total population size impact analysis.

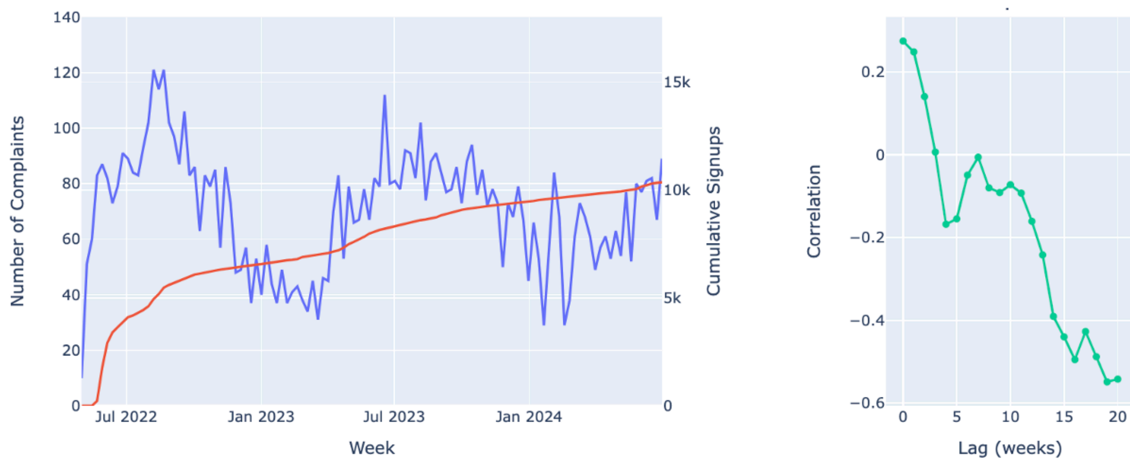
Analysis comparing temporal patterns of weekly 311 service requests (blue line), cumulative composting sign-ups (red line), and lagged correlations (green line) between GEOIDs above and below the median total population.

Areas below the median population threshold showed similar cumulative participation numbers at 13,243 sign-ups but demonstrated more consistent rodent complaint levels (typically 40-70 reports weekly) with less pronounced seasonal variation. The initial correlation for these less populated areas was weaker and did not reach statistical significance (r = .148, p = .116, N = 114), suggesting minimal to no detectable relationship between composting and rodent activity in these areas during the early implementation phase (Table 7).

The lag correlation structure exhibited distinct patterns for both groups. High-population areas showed an initially weak positive correlation peaking in the first few weeks (r = .3, p < .01), followed by a sharp decline around week 5, a brief recovery period with a small positive peak around week 7, and then a gradual transition to a moderate negative correlation by week 20 (r = -.5, p < .001, N = 94) (Table 7). This negative correlation, explaining 25% of the variance (R^2 = .25), represents a more substantive relationship than the initial positive correlation.

Areas with below-median population showed a similar overall pattern but with a lower initial positive correlation (r = .2, p = .049, N = 113), followed by comparable fluctuations in the middle weeks, ultimately reaching a stronger negative correlation by week 20 (r = -.6, p < .001, N = 94) (Table 7). This stronger negative correlation explained 36% of the variance (R^2 = .36), suggesting a more meaningful relationship developed over time in these less populated areas.

GEOIDs with above-median population density demonstrated cumulative composting program participation reaching approximately 10,352 sign-ups, while experiencing rodent sightings that fluctuated between 40-120 reports weekly (Figure 18). The complaint pattern in these high-density areas showed pronounced seasonality, with peak activity during summer months (July-September) and notable troughs during winter periods (December-February). The correlation analysis for high-density areas revealed a statistically significant but weak positive relationship initially (r = .275, p = .003, Population Density – Above Median



Population Density – Below or Equal to Median

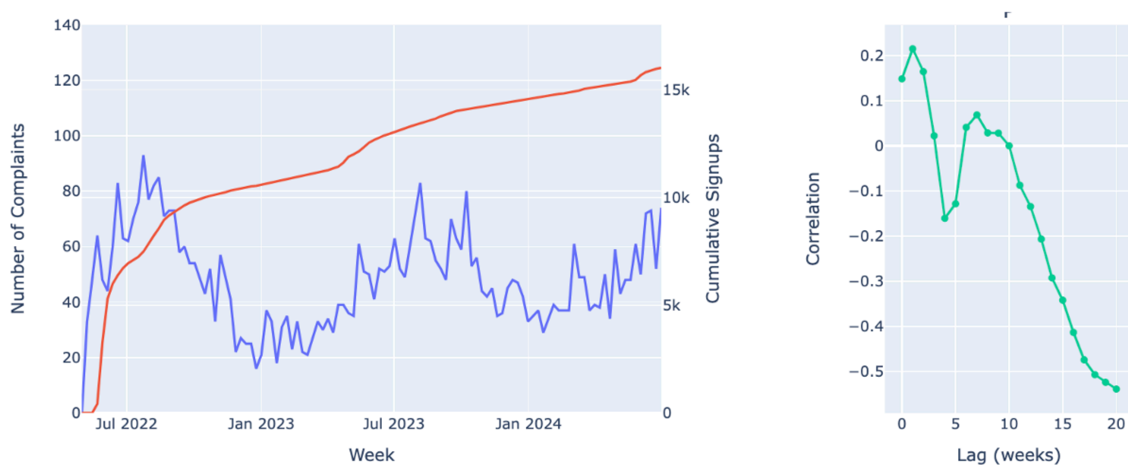


Figure 18. Population density impact analysis.

Analysis comparing temporal patterns of weekly 311 service requests (blue line), cumulative composting sign-ups (red line), and lagged correlations (green line) between census tracts above and below the median population density.

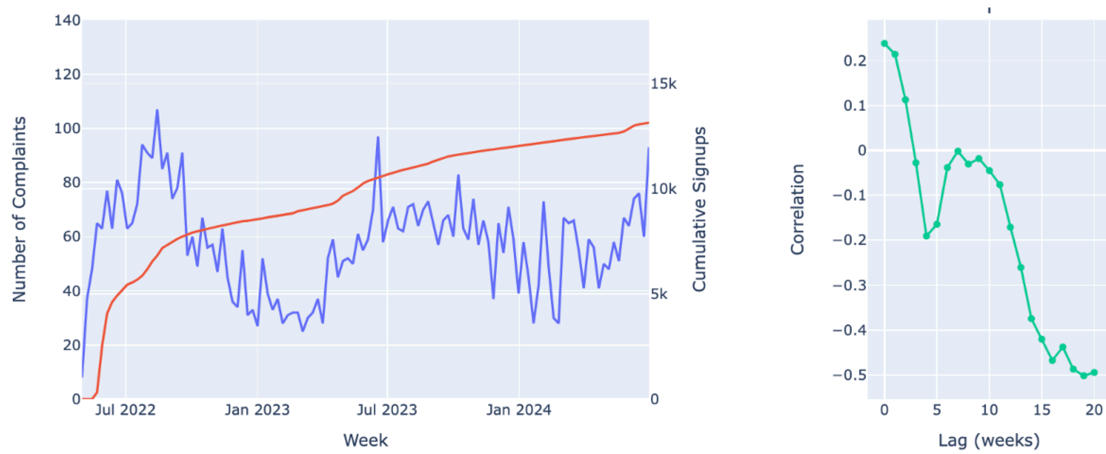
N = 114), explaining only 7.6% of the variance (R^2 = .076) (Table 7). This suggests that while there was a reliable association between early composting adoption and rodent complaints in dense areas, this relationship was not strong enough to indicate a causal connection, and other factors likely contributed substantially to rodent complaint patterns.

In contrast, areas below the median density achieved higher participation levels, reaching 16,012 sign-ups, while maintaining lower and more consistent rodent complaint levels ranging from 20 to 80 reports weekly. The initial correlation for these areas was not statistically significant ($r = .149$, $p = .114$, $N = 114$), indicating no detectable relationship between composting and rodent complaints in less dense areas during the early implementation phase (Table 7).

The lag correlation analysis revealed similar initial patterns in both groups, with weak positive correlations in early weeks transitioning to moderate negative correlations after week 10. By week 15, lower density areas exhibited a statistically significant negative correlation ($r = -.342$, $p = .001$, $N = 99$), explaining approximately 11.7% of the variance ($R^2 = 0.117$), while higher density areas showed a stronger negative correlation of $r = -.440$ ($p < .001$, $N = 99$), accounting for 19.4% of the variance ($R^2 = .194$) (Table 7). By week 20, both groups showed moderate negative correlations ($r = -.538$ and $r = -.542$, both $p < .001$, $N = 94$), explaining approximately 29% of the variance (Table 7).

GEOIDs with above-median total housing units showed cumulative composting participation reaching approximately 13,122 sign-ups, with substantial weekly variation in rodent sightings ranging from 30-100 reports (Figure 19). Statistical analysis indicated a statistically significant but weak positive correlation initially ($r = .238$, $p = .011$, $N = 114$), explaining only 5.7% of the variance ($R^2 = .057$) (Table 7). This suggests that while there was a detectable relationship between composting adoption and rodent complaints in areas with more housing units, this relationship was modest and likely one of multiple factors influencing rodent complaint patterns.

Total Housing – Above Median



Total Housing – Below or Equal to Median

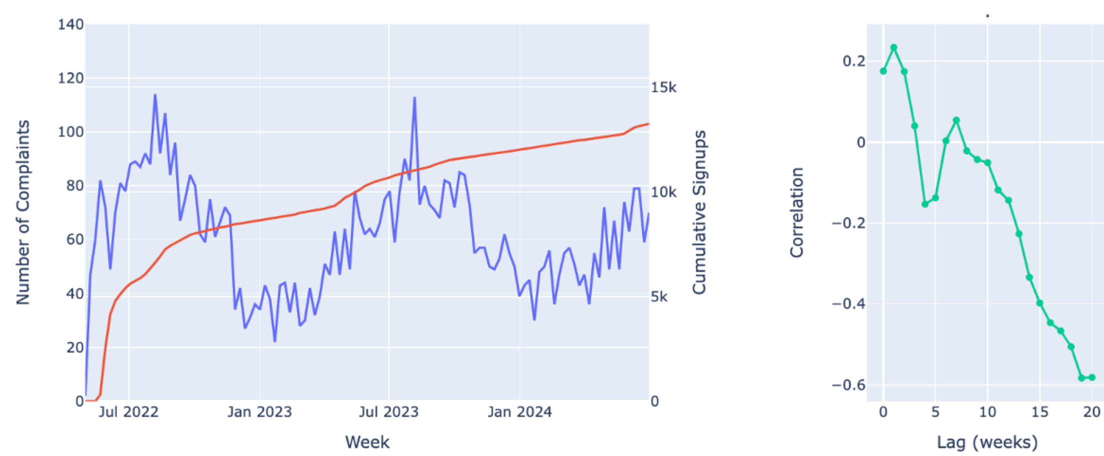


Figure 19. Total housing units impact analysis.

Analysis comparing temporal patterns of weekly 311 service requests (blue line), cumulative composting sign-ups (red line), and lagged correlations (green line) between GEOIDs above and below the median number of housing units.

Areas with below-median housing units maintained slightly lower participation levels at 12,000 sign-ups while demonstrating more consistent rodent complaint patterns between 20 and 80 reports weekly. The initial correlation for these areas approached but did not reach statistical significance ($r = .176$, $p = .062$, $N = 114$), indicating a weak and unreliable relationship during the early implementation phase (Table 7).

The lag correlation structure exhibited distinct patterns between the two groups: both started with weak positive correlations in the initial weeks ($r = .2$, $p < .05$, $N = 113$), followed by a sharp decline around week 5 (Table 7). By week 15, lower housing unit areas showed a statistically significant negative correlation of ($r = -.398$, $p < .001$, $N = 99$), explaining 15.8% of the variance ($R^2 = .158$), while higher housing unit areas showed a slightly stronger correlation of ($r = -0.420$, $p < .001$, $N = 99$), explaining about 17.6% of the variance ($R^2 = .176$) (Table 7).

By week 20, lower housing unit areas showed a stronger negative correlation, reaching approximately ($r = -.582$, $p < .001$, $N = 94$), explaining 33.9% of the variance ($R^2 = 0.339$), while higher housing unit areas maintained a moderate negative correlation of about ($r = -.494$, $p < .001$, $N = 94$), explaining 24.4% of the variance ($R^2 = .244$) (Table 7). This temporal pattern suggests that while initial relationships were weak, more substantial negative relationships emerged over time, with stronger effects in areas with fewer housing units.

GEOIDs with above-median housing density demonstrated cumulative composting participation reaching approximately 10,288 sign-ups, with distinct variability in rodent sightings ranging from 40-100 reports weekly and notable seasonal fluctuations (Figure 20). The correlation analysis revealed a statistically significant but weak positive relationship initially ($r = .277$, $p = .003$, $N = 114$), explaining only 7.7% of the variance ($R^2 = .077$) (Table 7). While this was the strongest initial correlation among all metrics examined, it still represents a relatively modest relationship, suggesting that

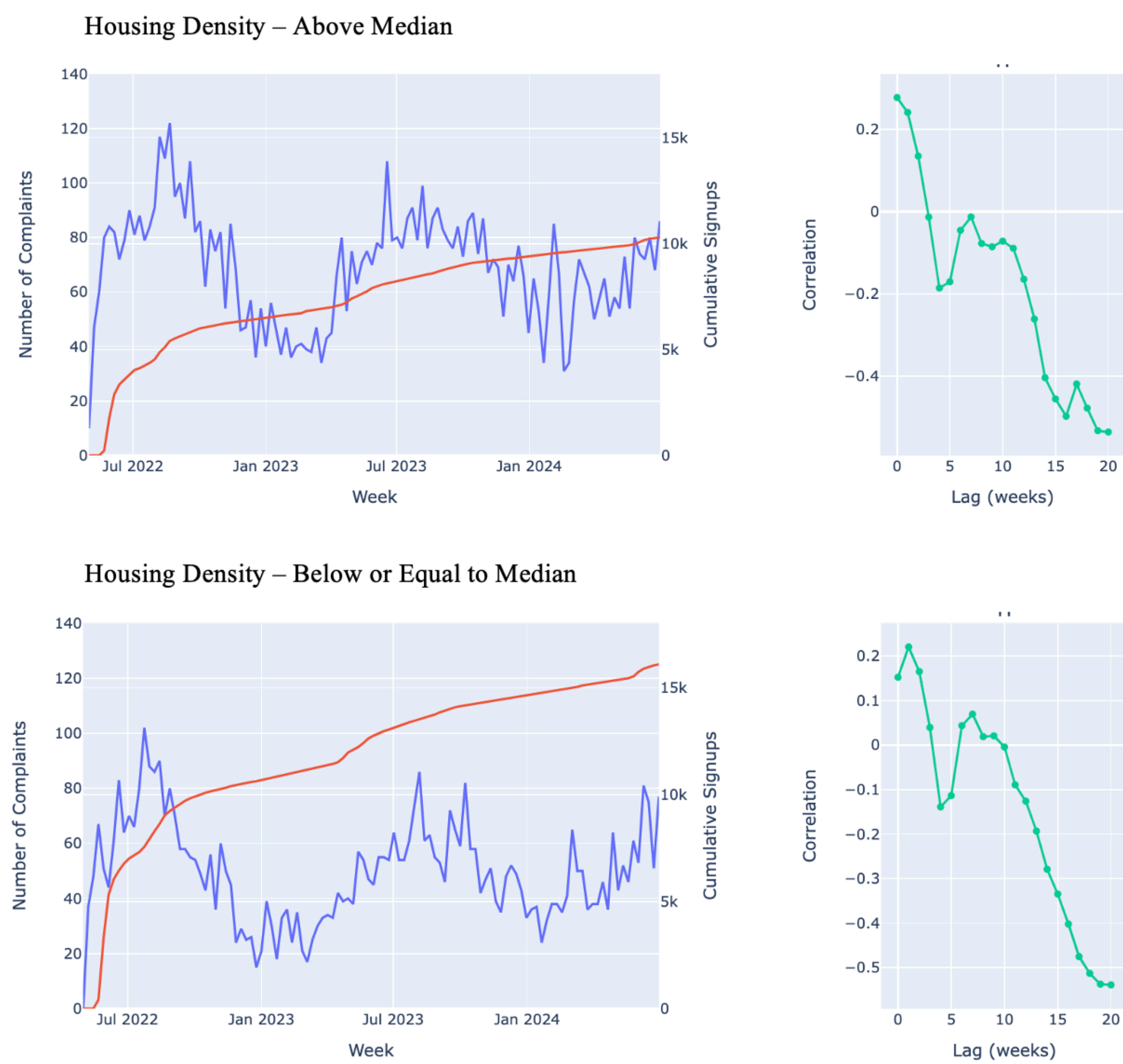


Figure 20. Housing density impact analysis.

Analysis comparing temporal patterns of weekly 311 service requests (blue line), cumulative composting sign-ups (red line), and lagged correlations (green line) between GEOIDs above and below the median housing density.

early composting adoption coincided with slightly higher rodent complaints in dense housing areas, but was likely not a dominant factor.

Areas below the median housing density achieved notably higher participation, reaching approximately 16,076 sign-ups, while maintaining more moderate rodent complaint levels between 20 and 80 reports weekly. The initial correlation for these lower-density areas was not statistically significant ($r = .153$, $p = .105$, $N = 114$), indicating no reliable relationship between composting and rodent complaints during the early implementation phase (Table 7).

The lag correlation analysis shows similar initial patterns for both groups, with weak positive correlations peaking in the first weeks ($r = .2$, $p < .05$, $N = 113$), followed by a decline around week 5. By week 15, the below-median density areas exhibited a moderate negative correlation ($r = -.335$, $p = .001$, $N = 99$), explaining 11.2% of the variance ($R^2 = .112$), while above-median density areas showed a stronger negative correlation of ($r = -.455$, $p < .001$, $N = 99$), explaining 20.7% of the variance ($R^2 = .207$) (Table 7). By week 20, both showed moderate to strong negative correlations ($r = -.54$, $p < .001$, $N = 94$), explaining approximately 29% of the variance (Table 7).

GEOIDs encompassing larger total areas achieved cumulative composting participation of approximately 15,622 sign-ups, maintaining relatively stable patterns in rodent sightings averaging between 40 and 80 reports weekly (Figure 21). Statistical analysis showed a statistically significant but weak positive correlation initially ($r = .196$, $p = .036$, $N = 114$), explaining only 3.8% of the variance $R^2 = .038$) (Table 7). This particularly weak relationship suggests minimal practical significance during the early implementation phase. Areas with below-median total area reached approximately 10,742 sign-ups, exhibiting more variable rodent complaint patterns throughout the study period. The initial correlation for these smaller-area locations was also statistically significant but weak ($r = .235$, $p = .012$, $N = 114$), explaining only 5.5% of the variance ($R^2 = .055$) (Table 7).

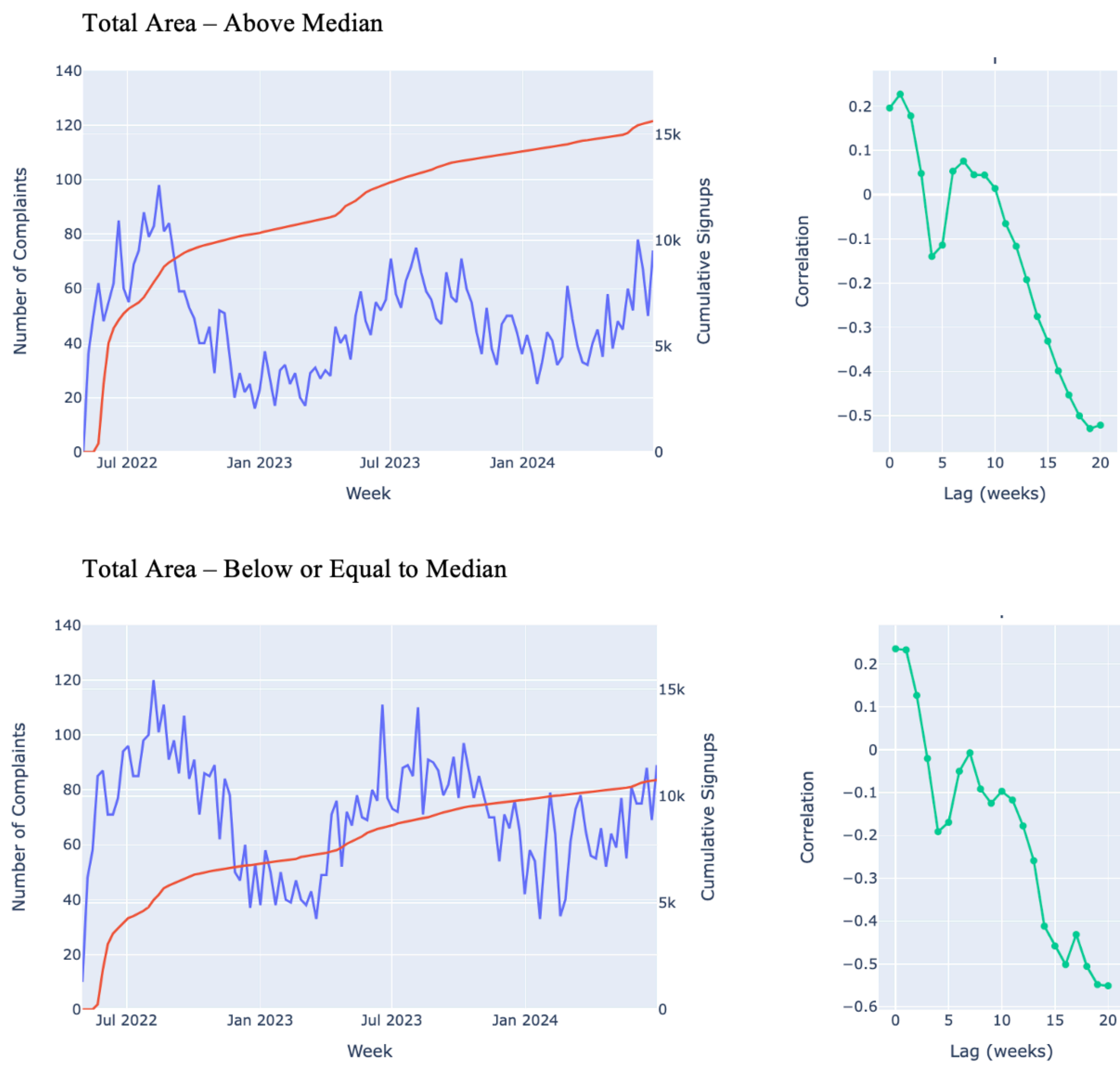


Figure 21. Total area impact analysis.

Analysis comparing temporal patterns of weekly 311 service requests (blue line), cumulative composting sign-ups (red line), and lagged correlations (green line) between GEOIDs above and below the median total area.

The lag correlation analysis demonstrated a complex temporal relationship where both groups show weak initial positive correlations during the first week ($r = .23$, $p < .05$, $N = 113$), with a sharp decline occurring around week 5 (Table 7). By week 15, smaller-area GEOIDs exhibited a moderate negative correlation of ($r = -.458$,

$p < 0.001$, $N = 99$), explaining about 21% of the variance ($R^2 = .210$), compared to larger-area GEOIDs with a weaker negative correlation of ($r = -.331$, $p = .001$, $N = 99$), explaining about 11% of the variance ($R^2 = .110$) (Table 7). By week 20, both groups showed moderate to strong negative correlations ($r = -.551$ and $r = -.521$, both $p < 0.001$, $N = 94$), explaining about 27-30% of the variance (Table 7).

Chapter IV

Discussion

> *Let's face it, the universe is messy. It is nonlinear, turbulent, and chaotic. It is dynamic. It spends its time in transient behavior on its way to somewhere else, not in mathematically neat equilibria. It self-organizes and evolves. It creates diversity, not uniformity. That's what makes the world interesting, that's what makes it beautiful, and that's what makes it work (Meadows, 2008).*
>
> —Donella Meadows

The dynamics between urban composting and rodent sightings in Boston exemplify a complex system. By examining residential composting participation and rodent sightings from 2022-2024, the results revealed how urban ecosystems defy simple cause-and-effect explanations. Key findings included complex time-lagged relationships between composting adoption and rodent reports, unexpected increases in rodent sightings near community compost bins, and the identification of distinct neighborhood patterns through cluster analysis. While initial hypotheses sought to assess correlations between increased composting and reduced rodent sightings, the findings revealed a more dynamic reality shaped by neighborhood characteristics, socioeconomic factors, and varying levels of community engagement.

Research Limitations

A methodological consideration in this analysis was the geographic unit used across datasets. For consistency in spatial analysis, all data including environmental justice indicators, demographic characteristics, rodent sightings, and composting participation were aggregated at the census tract level. In the 2020 Census, the U.S. Census Bureau divided Boston into 207 census tracts (each containing approximately 4,000 residents), with these tracts further subdivided into a total of 581 smaller block groups across the city. In this study, census tracts, also referred to as GEOIDs, provided a standardized unit for comparing these different variables.

Additionally, with a limited number of voluntary households enrolled in curbside composting as of August 2024, the participation rates created sparse data when distributed across census tracts. This combination of different geographic scales and low participation rates early in the program's implementation made it difficult to draw definitive conclusions about relationships between composting adoption, rodent activity, and neighborhood characteristics. Future analyses would benefit from higher participation rates to better understand these relationships at the census tract level.

Composting Participation Data Limitations

The City of Boston provided data on monthly composting tonnage and residential participation rates by census tract for their opt-in curbside composting program that launched in 2022. As of August 2024, 26,988 households, or about 9.7% of Boston's 279,495 total households reported in the 2020 census, had enrolled in the program. Because of the program's recent implementation, the available data represented only initial adoption patterns. Within each census tract, these data were even further limited, with only a handful of households in each neighborhood participating. This may have limited influences on rodent sightings, and further analysis would benefit when there are most households participating. The research limitations advocate for a follow-up to ascertain if the conclusions presented based upon these limited initial data might be representative. Past performance might not be indicative of future results.

The data's analytical utility was further constrained by the aggregation of collected tonnage, which was reported as city-wide monthly totals rather than by neighborhood or collection route. This aggregation made it impossible to verify whether higher residential enrollment in specific neighborhoods corresponded with greater quantities of food waste collected in those areas. Future research would benefit from continued monitoring of the program's impact as participation expands and if more granular collection data becomes available. There are other external stakeholders who do record actual weights through scales installed across collection areas or by utilizing measuring devices that attach to trucks. This type of data will continue to enhance future analyses, especially as composting participation increases within urban areas.

311 as an Indicator of Rodent Activity

The use of 311 service request data about rodent sightings presented several methodological challenges when used as an indicator of active populations. A key consideration identified by White and Trump (2018) related to the influence of superusers, or individuals who frequently submit service requests through the 311 system. The presence of these highly engaged residents disproportionately affects reporting patterns within specific neighborhoods. When evaluating the effectiveness of urban interventions such as composting programs, these reporting patterns required careful interpretation, as fluctuations in service requests may reflect changes in resident reporting behavior rather than actual shifts in rodent activity.

These methodological complexities were further illuminated by Sánchez et al.'s (2021) conceptual framework, which demonstrated that rodent sightings reported on 311 are influenced by three distinct factors: actual rat abundance, rat visibility, and human willingness to complain. For instance, seasonal variations may affect rat visibility without necessarily reflecting changes in the underlying rat population. Similarly, factors such as education levels, home ownership status, and residents' attitudes toward rats can influence reporting behavior independently of actual rodent abundance.

The analysis across different density metrics in Boston revealed how these reporting patterns interact with urban form and program outcomes. The population and housing analyses (Figures 17-21) demonstrated that the inverse relationship between density and program participation challenged fundamental assumptions about waste management efficiency in dense urban environments. While high-density areas showed rapid initial adoption followed by plateauing around 10,000 sign-ups, the more sustained growth in lower-density areas reaching 15,000 sign-ups suggested different barriers to participation based on urban form. This pattern persisted across multiple metrics, suggesting underlying structural relationships rather than neighborhood-specific characteristics.

To illustrate these relationships, Back Bay and Beacon Hill provided instructive examples. These compact neighborhoods, each around one square mile in size and easily walkable to downtown employment centers, form Boston's most densely populated area. These neighborhoods contain approximately over 63,000 jobs and about 25,000 residents and feature the city's tallest skyscrapers and highest-priced residential properties. Their population has stayed constant since 1980, according to U.S. Census data. This stability, combined with the areas' unique development histories, created distinct urban environments that influence rodent activity and reporting behavior. The high concentration of employment across various sub-areas and the diverse traffic patterns likely increased rodent visibility.

These characteristics illuminate how neighborhood stability and socioeconomic characteristics shape both program adoption and reporting behaviors. The pronounced seasonal fluctuations in these areas (100-120 weekly reports during summer peaks) compared to lower-density areas (40-60 reports) suggests that increased human activity and waste generation in dense urban cores may amplify both rodent visibility and reporting behavior. However, their patterns differ from other high-density areas, suggesting that density alone does not determine program outcomes (Figure 22).

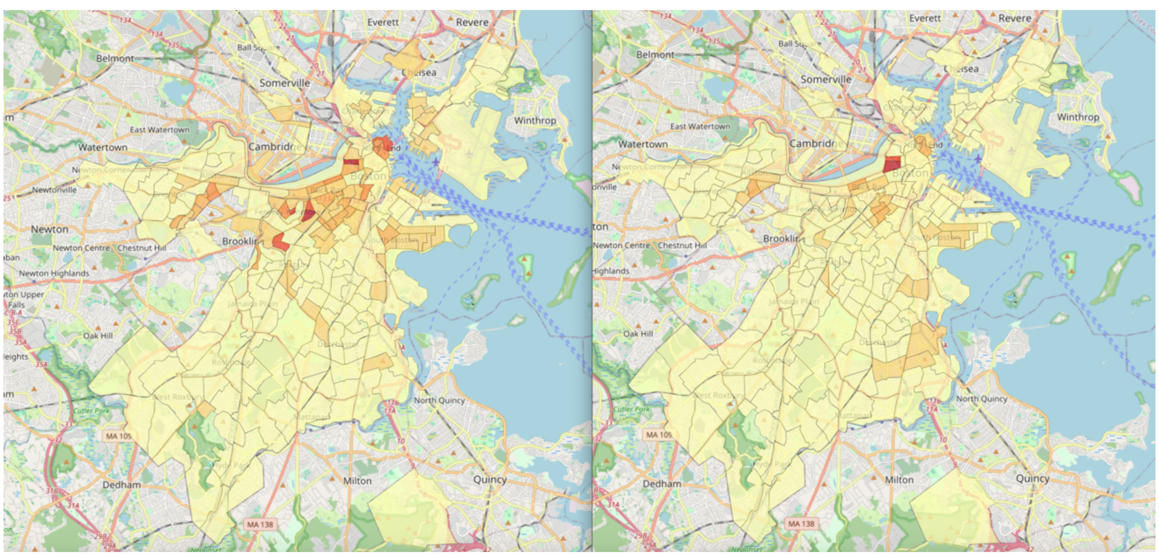


Figure 22. Housing density (Figure 14) and rodent sighting density (Figure 17).

A side by side comparison of housing density (left) and rodent-related 311 service request density (right) across Boston's census tracts. Both maps use a yellow to dark red gradient, where darker red indicates higher density values.

The lag correlation analyses (Figure 19 & Figure 21) indicated complex periods of adaptation and adjustment following composting implementation. The consistent initial positive correlation coefficients (r = .2-.3, $p < .05$) across neighborhood types suggested an immediate disruption period following program implementation, while the varying strengths of eventual negative correlation coefficients (r = -.4 to -.6, $p < .001$) indicated different long-term adaptation patterns based on urban characteristics. These variations highlight how neighborhood features influence not just initial program adoption but also long-term behavioral changes in both human and rodent populations.

The emergence of distinct seasonal patterns across density gradients (Figures 17-21) provided insights into how urban form influences both rodent behavior and human reporting patterns. The more extreme seasonal variations in high-density areas suggested that concentrated human activity amplifies both rodent presence and visibility, while more moderate fluctuations in lower-density areas might indicate more stable rodent populations or different human reporting thresholds.

The housing-to-area ratio analysis (Figure 22) particularly challenged assumptions about urban density's relationship with composting program effectiveness. The stronger negative correlations in lower-density areas by week 20 (r = -.5 to -.6) suggested more effective long-term program integration in these neighborhoods, possibly due to factors such as greater storage space for bins, more consistent waste generation patterns, or different social dynamics around program adoption. This pattern persisted even when controlling for geographic size through the total area analysis (Figure 21).

These findings provided insights for implementing IPM strategies within cities, while acknowledging that composting represents just one solution rather than several strategies in combination. The identification of areas with high engagement and low sightings (as seen in Cluster 3) suggested that active participation in food waste diversion programs might contribute to reduced rodent sightings. In areas with high sightings but moderate participation (Cluster 2), targeted outreach should focus on promoting comprehensive IPM strategies, with composting presented as one component of an integrated solution (Figure 6). These patterns can inform the development and implementation of IPM strategies that incorporate food waste diversion as a key component.

The spatiotemporal analysis across population, housing, and area-based metrics revealed distinct patterns in both composting adoption and rodent activity across Boston's neighborhoods. Areas with lower density characteristics consistently achieved higher cumulative composting participation compared to their higher density counterparts, regardless of the specific density metric used. The lag correlation structures showed similar initial patterns across all metrics, transitioning from positive to negative correlations after week 10, though the timing and magnitude varied by neighborhood characteristics.

Beyond density considerations, the analysis revealed additional patterns when viewed through the lens of environmental justice (EJ) criteria. In Boston, EJ populations are identified through three key criteria established by the Massachusetts Executive Office of Energy and Environmental Affairs: minority status, income level, and English language proficiency. A census block group is designated as an EJ population if it meets any of the following thresholds: minority residents comprise 40% or more of the population; median annual household income is at or below 65% of the statewide median; or 25% or more of households have no member over the age of 14 who speaks English only or very well.

The spatial distribution of these EJ criteria (Figures 23-26) illustrated distinct patterns across Boston's neighborhoods. The distribution of minority populations (Figure 24) limited English proficiency households (Figure 25), and income-based EJ status (Figure 26) create a mosaic of socioeconomic characteristics. The overlapping criteria created areas where multiple EJ criteria intersect (Figure 24).

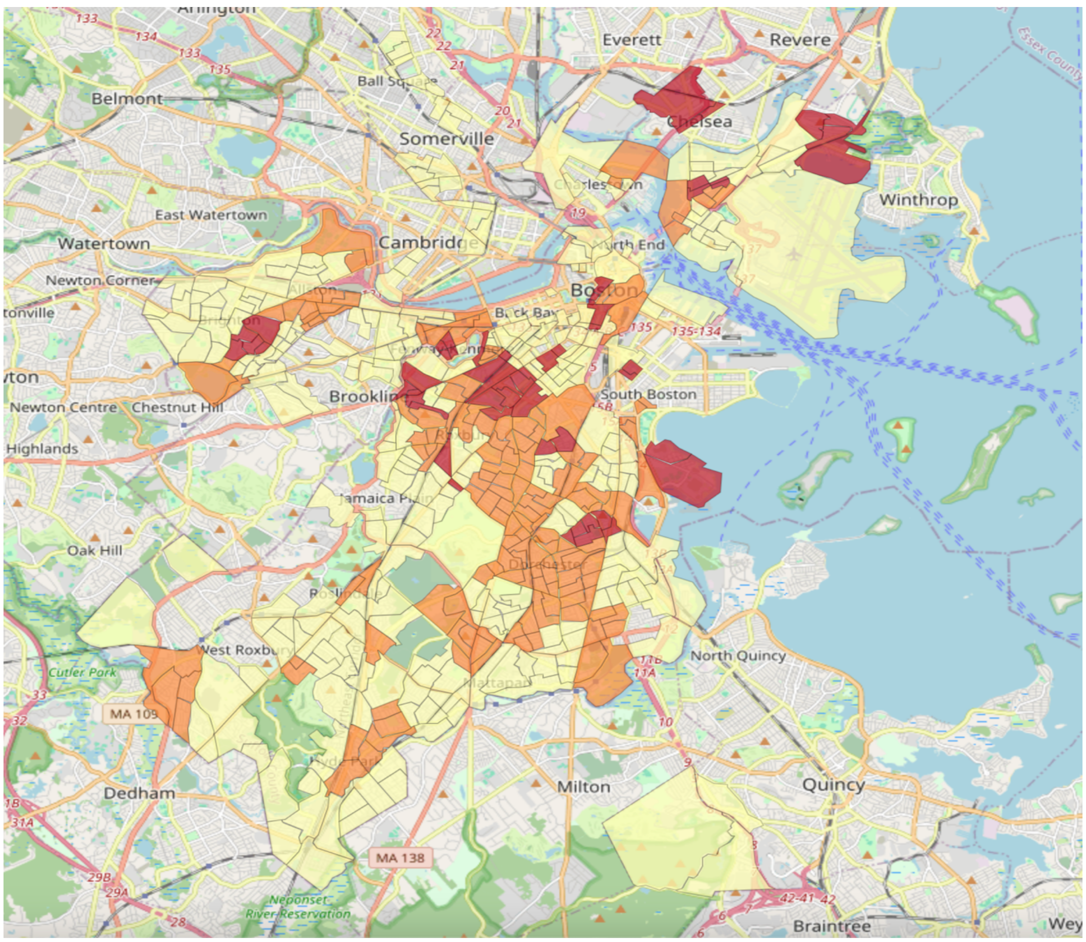


Figure 23. Number of environmental justice criteria met in Boston, 2020.

Map in a red gradient scale from 0 to 3, number of EJ criteria met by census tract. The darkest red areas meet all three criteria (minority status, income, and English proficiency), orange areas meet two of three, and yellow meets one.

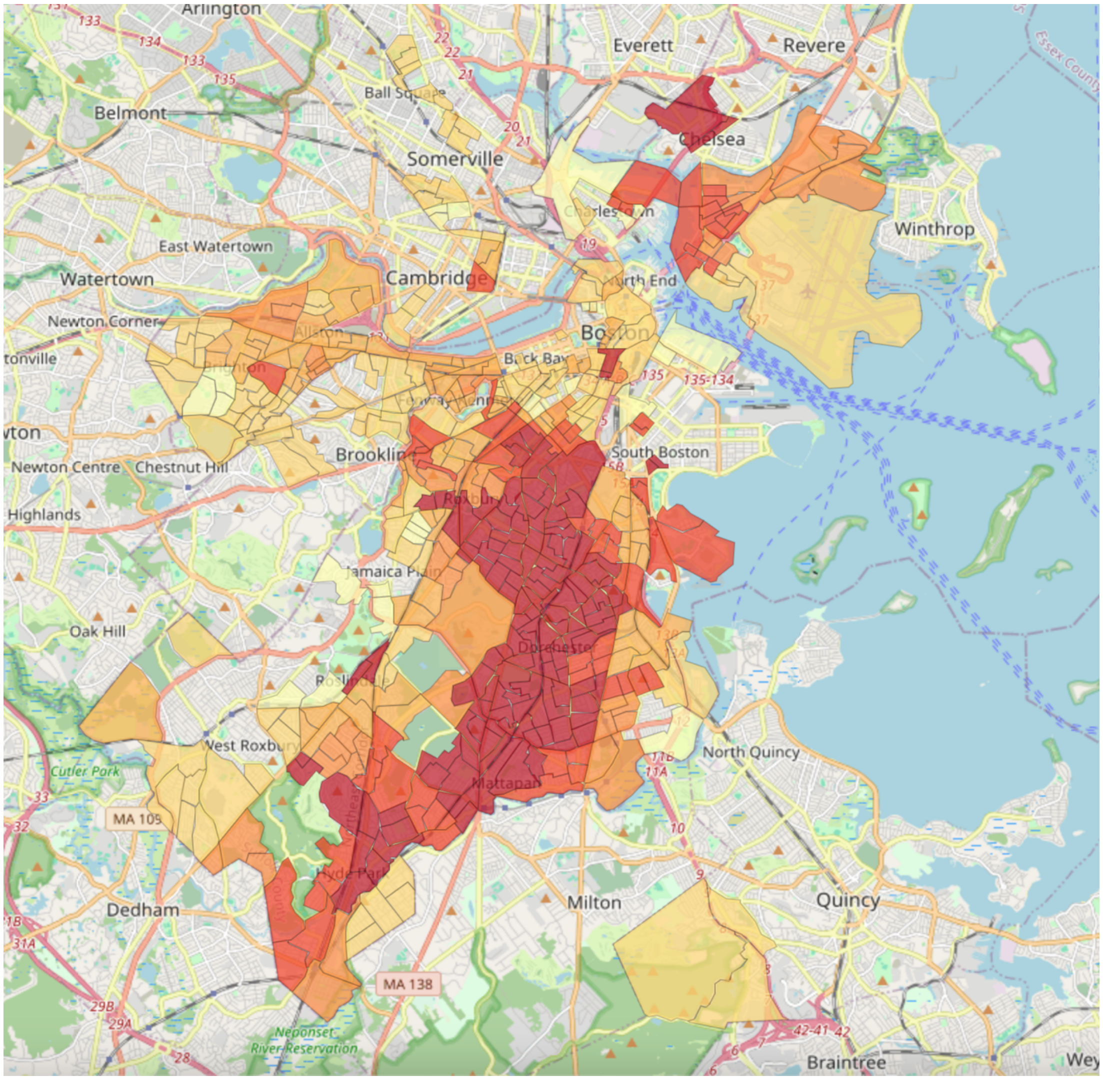


Figure 24. Percentage of households with minority population in Boston, 2020.

Map in a red gradient scale from 0.0 to 1.0, showing the percentage of residents who identify as non-white in each census block. Darker red indicates higher percentages of minority populations.

The analysis revealed contrasts between neighborhoods of similar density but different socioeconomic profiles. Notably, neighborhoods like Back Bay and Beacon Hill showed high population density (Figure 13), high housing density (Figure 14), and high rodent sighting density (Figure 17), while none of the EJ criteria were met. In contrast, parts of Dorchester and Roxbury, despite showing similar housing density patterns,

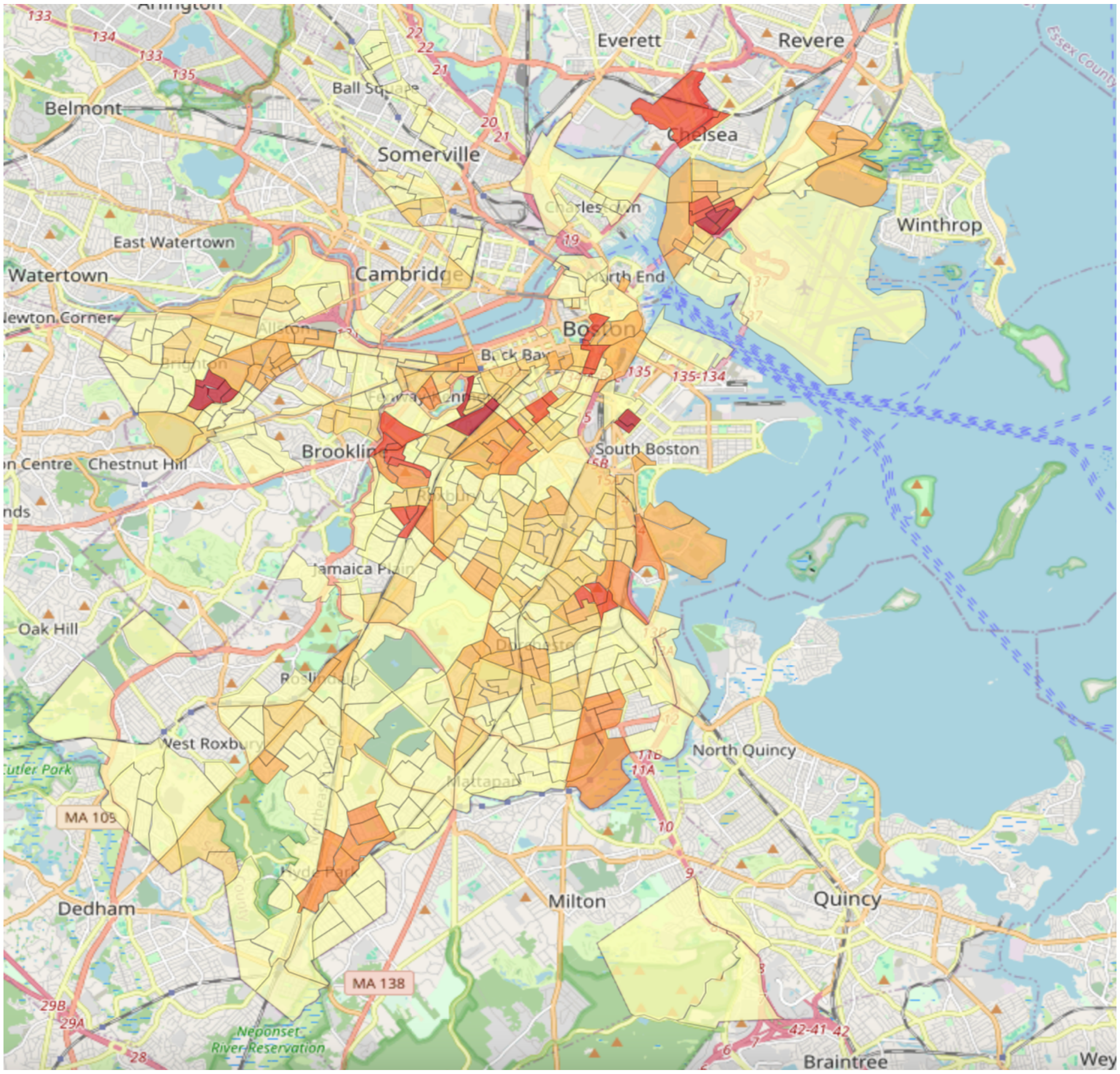


Figure 25. Percentage of households with limited English proficiency in Boston, 2020.

Map in a red gradient scale from 0.0 to 1.0, representing the percentage of residents who report speaking English less than 'very well' in each census block. Deeper red areas indicate higher concentrations of limited English proficiency.

presented fewer rodent sightings while meeting multiple EJ criteria. These differential reporting patterns in EJ communities likely reflected the complex interplay of factors identified in Sánchez et al.'s (2021) framework. Residents in EJ areas may have had multiple barriers to utilizing the 311 system, including limited English proficiency affecting their ability to submit reports, reduced awareness of municipal services, and different cultural attitudes toward institutional engagement. Other residents may rely instead on informal community networks or direct landlord communication rather than 311 services.

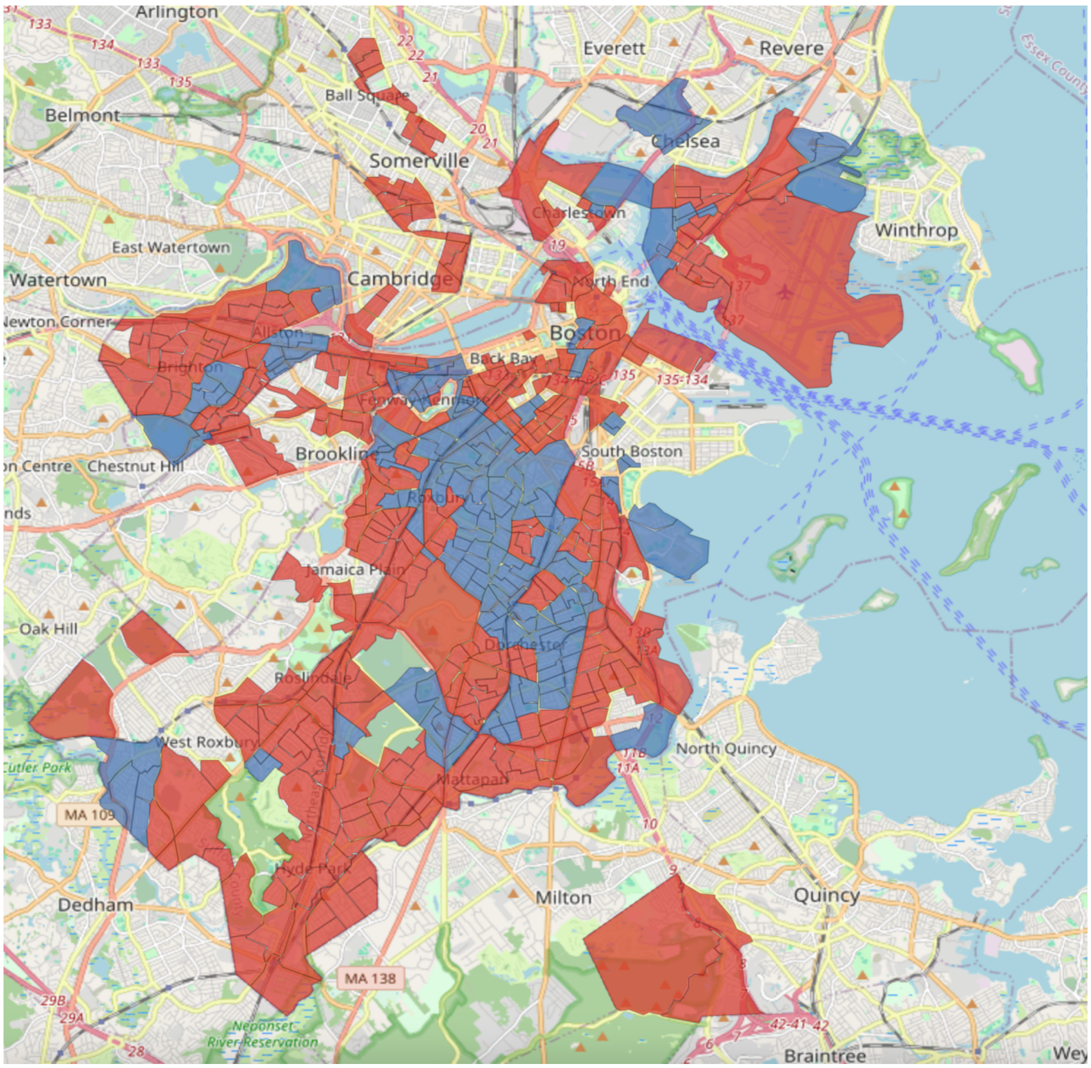


Figure 26. EJ income status by census tract in Boston, 2020.

EJ income status across census tracts in Boston. Blue areas represent median annual household income at or below 65% the statewide median. Red areas represent tracts that qualify as EJ based on other criteria but do not meet the income criterion.

Furthermore, as White and Trump (2018) noted regarding superusers, the presence of highly engaged residents can skew reporting patterns. EJ communities may have had fewer superusers due to language barriers, reduced digital access, or lower levels of confidence in municipal response systems. The lower reporting rates in EJ areas may also reflect competing priorities for residents facing multiple economic challenges, where work schedules and survival needs may limit engagement with city services.

Variations in reporting patterns also may have reflected broader disparities in neighborhood resources and infrastructure. While high-density areas across Boston all contended with rodent-related challenges, affluent neighborhoods benefited from robust private-sector solutions, including professional property management, and systematic pest control services. These areas also demonstrated greater awareness of and comfort with municipal reporting systems and increased likelihood to engage with city services. Conversely, high-density areas meeting EJ criteria faced compounded challenges where limited resources intersect with aging infrastructure.

Ultimately, these findings underscore the need for environmental justice considerations in urban pest management policies. The stark contrast in reporting patterns between neighborhoods suggested that traditional metrics of service requests may inadequately capture the full scope of rodent-related challenges in disadvantaged communities. Future research should explore how these varying neighborhood contexts influence not just reporting behavior but also the effectiveness of rodent control interventions and the long-term sustainability of pest management strategies. The results also highlighted the importance of developing nuanced policy approaches that address both the physical conditions conducive to rodent activity and the social and economic barriers that may prevent certain communities from fully accessing municipal services and resources.

Future Opportunities

The spatial patterns revealed through this analysis suggest several key areas for future research and policy development. The varying relationships between housing density and rodent reporting patterns across neighborhoods with different socioeconomic profiles (Figure 18) indicated potential disparities in 311 service access or utilization. While Boston's 311 system offered service in 12 languages through its mobile app and access to 381 languages via phone interpretation services, potential enhancements could include voice-to-text reporting options, pictorial reporting interfaces, and community ambassador programs to assist residents with limited technological literacy or English proficiency (DaPonte, 2024).

To address neighborhood-specific needs, interventions could include partnerships with local associations to establish reporting hubs, training resident liaisons for 311 assistance, developing multilingual educational materials about reporting rodent sightings through 311, and creating targeted communication channels such as community message boards or digital platforms. Areas meeting multiple environmental justice criteria (Figure 18) would particularly benefit from these targeted interventions. These enhancements should be implemented alongside equally accessible composting education and infrastructure to ensure that waste management benefits reach all communities regardless of socioeconomic status. By addressing both reporting disparities and program access simultaneously, municipalities can create more equitable environmental services that advance both waste diversion and pest management goals.

As represented in Figure 6, Clusters 0-3 represented neighborhoods with different levels of composting and rodent sighting activity, providing different opportunities for improvement. For example, in areas resembling Cluster 0 (low composting, low complaints), municipalities could implement foundational engagement strategies including educational campaigns highlighting the multiple benefits of composting, targeted door-to-door outreach, and small-scale pilot programs to gradually build community participation. These neighborhoods may benefit from complementary waste audits to establish baseline data.

In Cluster 1 neighborhoods (moderate composting, moderate complaints), cities could focus on program enhancement through incentive structures such as visible community benefits from composting proceeds and targeted communication about the neighborhood-specific impacts of the program. The significant negative correlation ($r = -.705$) observed at week 5 suggests these areas may experience rapid improvements with sustained participation (Table 5).

For Cluster 2 areas (high complaints, moderate composting), municipalities should prioritize comprehensive IPM approaches that integrate composting with additional strategies including targeted enforcement of waste management regulations, systematic property inspections, and coordinated multi-agency responses. The strong negative correlation ($r = -.789$) at week 18 indicates these neighborhoods may require longer adaptation periods but could ultimately show substantial improvements (Table 5).

In Cluster 3 neighborhoods (high composting, low complaints), which may serve as model communities, cities should document and replicate successful practices, engage residents as program ambassadors for other neighborhoods, and develop case studies highlighting factors contributing to their success. The strong positive correlation at week 10 (r = .741) followed by subsequent declines suggests these areas experience temporary disruptions before achieving sustained benefits (Table 5).

Across all neighborhood types, municipalities should recognize the approximately 10-15 week adjustment period identified through lag correlation analysis and communicate realistic expectations to residents about the timeline for potential rodent reductions. Community compost bins require particular attention, with enhanced containment features, more frequent servicing schedules, and systematic monitoring of surrounding areas to address the observed increases in rodent sightings within their vicinity.

By tailoring composting strategies to specific neighborhood characteristics and acknowledging the complex temporal relationship between program implementation and rodent activity, cities can develop more effective and equitable approaches to both waste management and pest control that respond to the distinct needs and challenges of diverse urban communities.

Given that Boston's municipal composting program has operated for only two years, future analyses must evaluate whether current patterns reflect temporary adjustment periods or long-term trends. While 311 data offered insights into resident reporting behavior, it may not comprehensively capture accurate rodent activity in the future. This analysis suggested several critical areas for future investigation.

Validation studies comparing 311 reports with professional pest control assessments, environmental health inspections, and systematic field surveys would evaluate the reliability of 311 data as a rodent activity indicator. This multi-method validation approach could establish standardized metrics for assessing rodent populations and develop correction factors for reporting biases across different neighborhood contexts. Such validation would help determine whether areas with low reporting rates truly have fewer rodents or simply lower reporting propensity.

Alternative monitoring tools could enhance understanding of urban rodent populations. Motion-triggered cameras could provide objective measures of rodent activity patterns and movement in specific locations, helping validate patterns suggested by 311 reports. Standardized inspection protocols across urban contexts could generate comparable datasets that complement citizen-reported information, providing a more comprehensive picture of rodent activity and movement patterns across neighborhoods.

Longitudinal analysis of trends across different neighborhood types will become increasingly valuable as composting program data accumulates. This approach could illuminate how rodent populations and reporting behaviors adapt to changes in waste management practices, seasonal variations, and evolving urban conditions, while distinguishing between temporary adjustments to new composting systems and longer-term shifts in commensal rodent ecology.

Environmental data beyond density measures would provide essential context for understanding rodent population dynamics. Factors including housing infrastructure age, green space distribution, building maintenance records, food establishment density, and construction activity influence rodent habitat suitability and population growth. Analysis of these variables alongside reporting patterns could identify environmental predictors of rodent activity and intervention points for pest management strategies.

Qualitative research examining neighborhood-specific reporting behaviors would contextualize quantitative findings. Resident interviews, focus groups, property manager surveys, and community mapping workshops could uncover reporting barriers, preferred communication channels, and cultural attitudes toward pest management. This ethnographic approach could explain reporting pattern variations and inform the development of culturally appropriate pest management strategies.

Analysis of property management practices across areas with similar density but different socioeconomic profiles could reveal institutional factors affecting rodent control. Comparing maintenance schedules, pest control contracts, waste management practices, tenant communication strategies, and complaint response times between professionally managed properties and smaller landlord-operated buildings could identify best practices and areas for improvement. This investigation could also illuminate how management practices interact with socioeconomic factors to influence rodent populations and reporting behaviors.

This comprehensive research agenda could inform more equitable and effective urban pest management strategies that address the challenges of different Boston neighborhoods while providing insights into the longer-term impacts of municipal composting programs on commensal rodent populations.

Conclusions

This thesis examined the relationship between food waste management practices and urban rodent activity in Boston through analysis of residential composting participation and 311 service requests from 2022-2024. By interpreting the model results and assessing statistical significance, I developed an understanding of the complex dynamics of commensal rodents and human behavior. The study evaluated three key hypotheses regarding: the correlation between increased composting participation and reduced rodent sightings, the impact of community compost bins on local rodent activity, and the influence of urban density characteristics on these relationships. I employed multiple analytical approaches including cluster analysis, buffer zone assessment, and time series correlation.

The analysis of over 26,988 households enrolled in Boston's curbside composting program, representing about 10% of the city's total households, alongside patterns of 311 service requests for rodent sightings, illuminates the promises and limitations of prescribing certain waste management strategies to achieve a defined goal, in this case a reduction in rodent sightings. These findings challenge conventional assumptions while highlighting the importance of considering environmental justice and community context in urban policy implementation and research.

The k-means cluster analysis (Figure 6) revealed partial support for H1A, which predicted that neighborhoods with higher composting participation (>300 sign-ups) would show lower rodent sighting frequencies (50-150 sightings) compared to areas with moderate participation (50-300 sign-ups). Cluster 3 (Black), characterized by high composting sign-ups (300-900) and low-moderate rodent sightings (50-150), demonstrated this hypothesized relationship. Further analysis revealed that the effect was most pronounced at a threshold of approximately 400-500 households per neighborhood, suggesting the hypothesized threshold of 300 households was low.

However, this relationship was not uniform across all clusters in Figure 6, as evidenced by Cluster 2 (Green), characterized by high rodent sightings (150-350) despite moderate program participation (50-300 sign-ups). This suggested that while areas with high composting engagement tend to report fewer rodent sightings, the relationship between program participation and rodent activity is moderated by additional environmental or demographic factors not captured in the analysis.

The analysis of buffer zones around Project Oscar community compost bins resulted in findings that directly rejected H1B, which predicted a 5% decrease in rodent sightings after bin implementation. Contrary to the hypothesis, all monitored sites showed substantial increases in rodent-related service requests following compost bin implementation. The largest changes occurred in Allston, where service requests rose by 175% weekly (from 0.34 to 0.93), 181% monthly (from 1.4 to 4.0), and 184% quarterly (from 4.1 to 11.5). Five locations transitioned from no recorded service requests to consistent reporting patterns. Even the South End, which had the highest baseline service request frequency, showed an increase of approximately 29% across temporal scales. While these increases cannot definitively establish causation due to potential confounding factors such as heightened community awareness and reporting behavior, they clearly contradict our original hypothesis of a 5% decrease.

The urban density analysis revealed patterns that explicitly rejected hypotheses H2, H2A, and H2B. Contrary to predictions, higher density areas initially showed positive correlations (r = .27) between composting adoption and rodent sightings, rather than the expected immediate negative correlations. Similarly, lower density areas did not demonstrate the predicted strong negative correlations. The hypothesized four to eight week adjustment period was also not supported, with neighborhoods showing more complex adaptation patterns that extended beyond the predicted timeframe. While the overall premise that urban density would influence composting-rodent relationships was supported, both the direction and magnitude of these relationships differed substantially from initial predictions.

Temporal patterns also differed from the hypothesized four to eight week adjustment period, with high density areas showing more complex adaptation patterns. These differences in neighborhood response were further reflected in program participation rates, with lower density areas achieving higher cumulative composting sign-ups (approximately 15,000) compared to higher density areas (around 10,000) by early 2024, suggesting that urban characteristics influenced both program adoption and its relationship with rodent activity.

The use of 311 service requests as a proxy for rodent activity presents important methodological considerations for interpreting these findings. While providing valuable spatial and temporal data about rodent sightings, 311 reports may reflect varying levels of resident engagement with municipal services rather than actual rodent populations. The analysis revealed higher reporting rates in areas of greater socioeconomic advantage, suggesting potential underreporting in environmental justice communities despite similar or potentially higher rodent presence. The installation of community infrastructure like compost bins may have also influenced reporting behavior independent of actual rodent activity, complicating causal interpretations of the data.

These findings highlight the complex relationship between waste management strategies and urban rodent control. While individual household composting shows promise in certain neighborhood contexts, particularly when participation exceeds the identified threshold of 400-500 households, shared community infrastructure may create new challenges that require careful consideration. Future waste management initiatives should account for infrastructure design, neighborhood characteristics, and environmental justice factors to optimize waste diversion and pest management outcomes. These findings suggest that waste management strategies should be tailored to specific neighborhood characteristics rather than implemented uniformly across diverse urban environments. Additionally, equity considerations should be incorporated into both program design and evaluation metrics to ensure that environmental benefits are distributed fairly across communities with varying socioeconomic profiles.

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