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Non-linear spatial modeling of rat sightings in relation to urban multi-source foci☆

C. Ayyad[a,*], J. Mateu[a], I. Tamayo-Uria[b]

[a] Department of Mathematics, University Jaume I, Castellón, Spain
[b] Institute for Global Health (ISGlobal), Barcelona, Spain

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ABSTRACT

The brown rat has been living with humans in a wide variety of environmental contexts; it adversely affects public health by transmission of pathogens that can cause human diseases and allergies. Understanding behavioral aspects and environmental factors of pest species can contribute to their effective management and control. This aim of this study was to investigate the spatial distribution of rats in Latina district of Madrid (Spain), and its relationship with several potential multi-source foci. A focus is any particular social and environmental urban scenario that favors the clustering and proliferation of rats. We have developed a statistical framework to provide valid information on the spatial distribution and behavior of the rats around identified potential foci that favor the concentration of rats in urban environments. We extended the standard Poisson regression model by the inclusion of a multiplicative non-linear function of the distance, an unstructured random effect, and a spatial random effect to account for the spatial structure of socio-demographic and environmental covariates were also considered in the model to control for potential confusion. We found evidence of an association between the spatial distribution of rats aggregated by census tracts and distance to foci, and this association was controlled by the covariates considered in this study.

Introduction

In the last few decades, changes in cities, in particular slum developments, have facilitated the proliferation of pests and diseases associated with them. Cities have encroached on through the natural habitats of rodents and other pests, resulting in the re-emergence of diseases thought to be eradicated (see [5]). Due to the impossibility of reversing urban expansion, it is essential to identify methods to optimally manage pests. Scientific assessments aimed at improving our understanding of the biology and behavior of urban pests can inform public health policy regarding their urban management and control.

Urban plagues often cause significant expense to public administration owing to the implementation of strategies for eradicating them. One such common and harmful urban pest is *Rattus norvegicus*, a species prevalent in most European cities. The brown rat (*R. norvegicus*) cohabits with humans in a wide variety of environmental contexts [10,5]. Its impressive adaptability and tremendous reproductive rate facilitate its proliferation worldwide [12,23]. Its negative effects on society include the transmission of pathogens, bites, and allergies, besides extensive damage to the infrastructure of cities and storage facilities with consequent economic effects [3]. Thus, rats can be the source of severe public health and environmental problems. They are vectors of serious pathogens and diseases, such as Salmonellosis (*Salmonella enterocolitis*), murine typhus (transmitted by the rat flea), Weils disease (spread by rat urine), hantavirus, leptospirosis, *Cryptosporidium parvum*, hemorrhagic viral fever, and Q fever [14].

Several cities worldwide have performed studies on the dynamics of urban pests [20,21,13]. Nevertheless, there are gaps in basic knowledge and information regarding prevention that limit the effectiveness of control strategies [5]. For example, in Madrid (Spain), the annual budget to eliminate pests (including rat pests) has increased drastically from 276,000 euros up to a million euros in 2004. The aim of the present project was to study the spatial distribution of rats in Latina district of Madrid (Spain) (see Fig. 1), and its relationship with potential multi-source foci. A focus is any

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* Corresponding author.
E-mail address: cayyad@uji.es (C. Ayyad).

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particular social and environmental urban scenario which favors the clustering and proliferation of rats.

Rattus norvegicus proliferation takes place in the confluence of favorable conditions, such as the presence of water, green areas, markets, and garbage dumps around residential areas. It is estimated that 3% of the buildings adjacent to the habitat of urban rats will have the presence of these animals at their surroundings [11]. The presence of *R. norvegicus*, and several species of cockroaches, including *Blatta orientalis* and *Periplaneta americana* [17–19], is a direct indicator of the existence of a combination of several factors that promote the survival of vectors causing serious economic, health, and environmental damage. Studies to define these factors have been carried out in various places worldwide [13]. However, the biology and behaviors of each animal are different in each city owing to geographic, environmental, demographic, social, and structural factors. Although many factors are common, there are others that are particular to each zone, and thus, any study of this type should identify which are the important (local) variables. Our choice of the potential foci and variables in the district of Latina in Madrid is justified by the work reported by [18].

The general aim of this study was to develop a statistical framework to provide valid information on the spatial distribution and behavior of the rats around identified potential foci that favor the concentration of rats in urban environments. At present, essentially no standards exist for the description of the spatial dynamics of urban pests. Literature on the spatial modeling of the behavior of *R. norvegicus* in an urban scenario is limited; previous studies in this regard include that of Costa et al. [8], who analyzed the prevalence of zoonotic pathogens and the rates of co-infection among urban, slum-dwelling Norway rats in Salvador, Brazil; that of Childs et al. [7], who examined rat bites; and that of Walsh [22], who analyzed rat sightings in New York City to formulate a hierarchical Bayesian conditional autoregressive Poisson model, where spatial distances acted linearly to generate general covariate information. Our approach differs in that we consider a multiplicative non-linear distance effect with respect to foci as putative sources of the aggregation of rat communities. Simpler statistical modeling strategies have previously been used in other contexts related to urban environments [2,1,6] but none of them uses non-linear effects on distances to foci to model the spatial structure of the data. Hence, as well as contributing directly to improved pest management in a major European city, this case-study can serve as a basis for other studies using the same methodological framework.

The organization of the paper is as follows: Dataset description section presents and describes the dataset, the study-region, and the available covariate information. The statistical modeling strategy is depicted in Statistical model formulation section, and the results of the analysis are presented in Results section. The paper ends with a general discussion in Discussion and conclusions section.

Dataset description

Study area

The city of Madrid, with a population of 3,255,944 inhabitants, is located approximately at the latitude 40°25′ N, at an average altitude of 655 m above sea level (Fig. 1). It has a temperate climate of continental Mediterranean type. The study was carried out in the Latina district (Fig. 1), in which rat infestation has been the most problematic, according to data compiled by the TUVC (Technical Unit for Vector Control of the Institute of Public Health of Madrid). The Latina district is structured into seven neighborhoods, with an area of 25.43 km^2, and a human population density of 10,092 inhabitants per km^2, i.e. approximately 0.26 million inhabitants.

Latina is considered a marginal district with high rates of immigration, unemployment, crime, and public disorder in comparison to those in other districts in Madrid. It is considered a night-time entertainment area with several restaurants and pubs. Latina's environmental quality is quite acceptable owing to the presence of green and tree zones, although at certain points in the district there can be peaks of air and noise pollution caused primarily by traffic, leisure activities and local entertainment. The efforts made by the City Hall for street cleaning are valued as positive, and the improvements are directed to increase the number of containers (dumpsters on the sidewalks) and monitoring. We emphasize that many of the features indicated here and that describe Latina district meet the definition of slums set by the UN. Therefore, the analysis and results obtained for Latina can be considered quite general and representative of slum developments in much larger cities as well.

Some further indications to better understand the current socio-demographic and environmental scenarios we are dealing with are in order. In terms of the *socio-demographic structure*, we note the following aspects in Latina district: (a) approximately 21.1% of the population lives below the poverty line, in particular within the set of elderly, immigrants and homeless people; (b) there is latent citizen insecurity, and a lower average size of the family unit, with an increase in the number of single-person households; (c) there is inadequate provision of social services to meet the needs of young, or old people and of immigrants; (d) there are problems of alcoholism and drug abuse among young people; and (e) a latent risk of social exclusion is present in important sectors of the population. In terms of the *environment*, we note these other aspects: (a) a limited number of companies is certified in quality standards and/or environmental management; (b) a national road goes through the district causing major traffic congestion, air pollution and noise; (c) the edge of the river in the district is highly urbanized, acquiring an artificial nature; (d) certain road infrastructures impose a barrier to the fauna; (e) there are reduced ratios of waste separation (separate recyclables into mixed paper or cardboard; and metal, glass, plastic or carton), from 23 kg/inhab/year in 2000 down to 21.55 kg/inhab/year in 2003, together with reduced cleaning and irrigation in the streets; and finally (f) the percentage of soil intended for green areas, the ratio of m^2 per capita, waste generation and recycling are lower than in the city of Madrid as a whole.

Data

When a sighting of a rat is reported to the Technical Unit for Vector Control (TUVC), information about the location, date and person reporting that sighting is collected and entered in a dedicated database. Each reported pest sighting corresponds to an individual record in this database. We note that in general the reporting person is an individual who identifies rats in the street and calls the TUVC. The demographics of the reporting individuals in Latina district are the same as in the whole Madrid city. In addition, Latina is a slum neighborhood of Madrid city and its inhabitants have an equal socio-economic profile. Therefore, there is no particular bias in the reporting of sightings.

Our data contains the locations of 470 validated rat sightings (hereafter interchangeably referred to as rat infestations) reported to the TUVC from January 2006 to December 2008. Rat sightings and all 8985 buildings were geo-referenced and mapped in Latina district, as shown in Fig. 2. Latina district is administratively divided into 205 census tracts, expanding the whole region. The distribution of these tracts is shown in Fig. 2. For each tract, we counted the total number of rat observations.

Spatial data for 8 potential risk factors (see Table 1) were obtained by querying existing official databases of the Municipality of Madrid, and from the Spanish National Institute of Statistics

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