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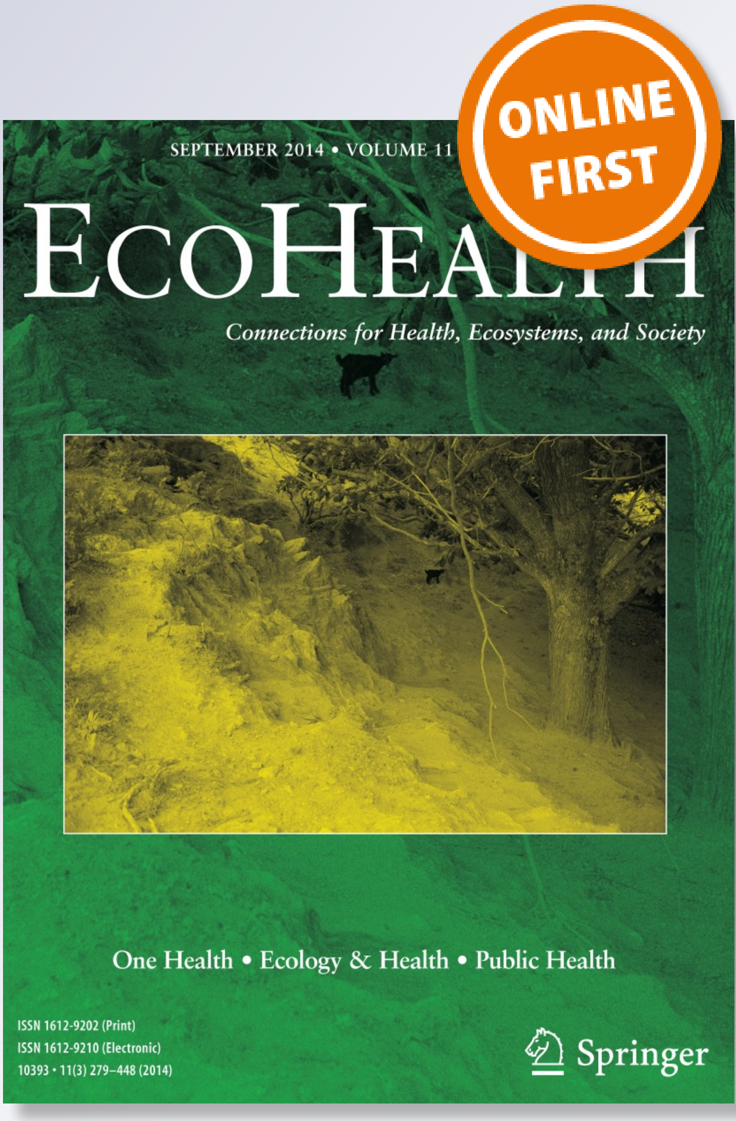

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Original Contribution

Commensal Rodents in the City of Buenos Aires: A Temporal, Spatial, and Environmental Analysis at the Whole City Level

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Abstract: Commensal rodents are some of the main vertebrate pests in urban areas; however, knowledge about factors that favor them at large scales is scarce. We studied spatial and temporal variations in rodent infestation levels at the whole city scale using the complaints of rodent sightings and questionnaire surveys to city neighbors. Demographic, socio-economic, and environmental characteristics handled with a geographic information system were evaluated as possible indicators of rodent infestation. The number of rodent sightings was lower in months with low mean temperature with two months time lag and higher in areas with high number of meat and metal industries. Rodent infestation estimated by the questionnaire survey showed spatial autocorrelation defining large areas with similar infestation levels. It decreased when the apartment density increased, while increased when the proportion of area occupied by shantytowns, the density of meat industries, and the proportion of area occupied by moderate urban development increased. Rodent control programs at the whole city level would have better results if public health pest agencies and/or governments will focus the efforts on areas with more precarious conditions as well as the industrial areas in the cold season when have lower rodent abundances.

Keywords: geographic information system, management decisions, rodent infestation, spatial autocorrelation, urban, vertebrate pest

Introduction

Commensal rodents like *Rattus rattus* (Linnaeus), *R. norvegicus* (Berkenhout), and *Mus musculus* (Linnaeus) involved in the transmission of numerous diseases to humans and domestic animals (Gratz 1994; Battersby 2004), and represent some of the main pests in many urban areas around the world (Meerburg et al. 2009). In addition, rodents may inflict considerable economic losses by damaging stored food, buildings, and infrastructure (Drummond 2001; Battersby 2004). In spite of the efforts that have been made to control commensal rodents, these animals are still causing serious problems in many towns and cities around the world (Colvin and Jackson 1999; Fernández et al. 2007).

The difficulty controlling rodents in cities can be attributed to different causes. Cities provide a relatively diverse and stable environment to rodents, since food and

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structural resources are consistently available (Colvin and Jackson 1999). In addition, rodents exhibit a high reproductive potential (Timm 1994; Aplin et al. 2003) and a great capacity to recover their population size after poisoning control measures (Colvin and Jackson 1999; Lambropoulos et al. 1999; Singleton et al. 1999, Fernández et al. 2007). These rodents also show a wide range of responses to different environmental characteristics (Timm 1994; Pocock et al. 2004, Vadell et al. 2014), thus hindering predictions about demographic responses of their populations to changes in the environment. Singleton et al. (1999) argued that, in order to disentangle the main factors that limit the growth of pest populations, field studies should be conducted at an appropriate spatial scale and for an appropriate length of time.

To achieve successful rodent control, knowledge on the ecology and distribution of the different species as well as on their interaction with humans, stored products, and other rodents should be obtained (Frantz and Davis 1991). Therefore, base information concerning factors that promote the presence of a pest species is necessary to determine the correct control measures, as well as the appropriate time and locations to implement them (Frantz and Davis 1991; Jackson 1998). In addition, these data will allow an evaluation of the possibility that these factors can be managed for preventative purposes (Childs et al. 1998; Fernández et al. 2007; Tamayo-Uria et al. 2013b).

Unfortunately, knowledge about factors that favor commensal rodents in urban environments at large scale is poor since few studies have assessed the ecology of rodents at the whole city scale. These studies include those carried out in New York (Childs et al. 1998), São Paulo (Masi et al. 2010), Budapest (Bajomi 1993), and cities all over England (Langton et al. 2001). This lack of studies is probably due to difficulties in assessing the abundance of rodents at a city scale using traditional methods such as rodent traps (Cavia et al. 2012). None of the above studies used traps to estimate rodent abundance, and none of those studies could be easily replicated in many other cities. For example, Childs et al. (1998) used records of rodent bites recorded at hospitals, information that is not frequently available in other cities, whereas Langton et al. (2001), Masi et al. (2010) and Bajomi (1993) used expensive methodologies in terms of personnel involved and time invested. For the reasons above, the development of easy-to-apply and low-cost alternative tools to assess rodent infestation levels would help both to systematically monitor their population fluctuations and to identify "priority areas" for the implementation of control programs.

We studied the rodent infestation levels at a scale that includes the entire city of Buenos Aires, by using data from 1—the record of complaints of rodent sightings received by the Government of the city of Buenos Aires and 2—questionnaire surveys to city neighbors at 103 sites regularly distributed in the city. The goals of the present study were (1) to analyze the temporal variations in rodent infestation; (2) to identify areas of the city with highest rodent infestation levels, and (3) to determine the possible causes of variations in rodent infestation.

Materials and Methods

Study Area

Fieldwork was conducted in Buenos Aires, Argentina (34°37′S, 58°24′W), a city with temperate climate, a surface of 202 km^2, and 2,776,138 inhabitants (7.21% of the

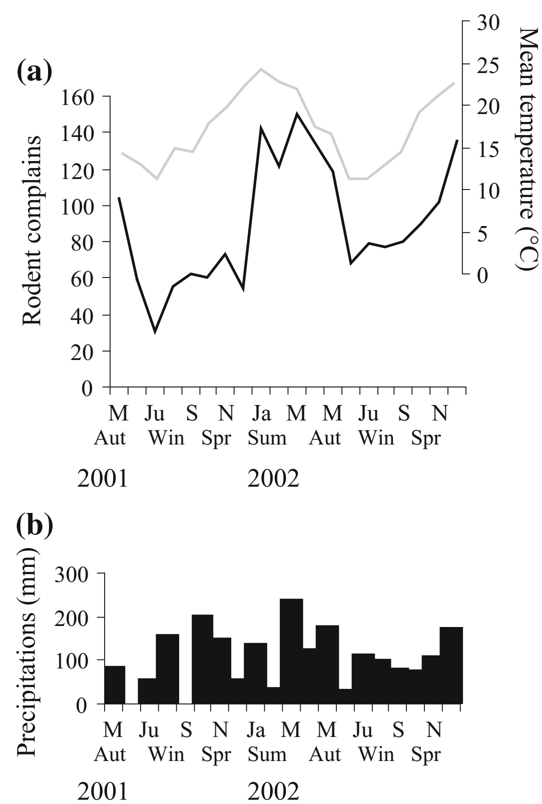

Figure 1. **a** Number of complaints of rodent sightings collected by the Government of the City of Buenos Aires (*black line*) and monthly mean temperature (*gray line*) and **b** cumulative monthly rainfall between May 2001 and December 2002.

country's population, INDEC 2012). It is divided in 16 Management and Neighborhood Participation Centers areas (CGPs, according to the Spanish acronym). In these CGPs, people density ranges from 59.5 to 346.0 inhabitants/hectare (mean density: 168.3 inhabitants/hectare), while house density ranges from 16.8 to 132.1 houses/hectare (mean density: 57.2 houses/hectare, INDEC 2012).

Temporal and Spatial Variation in Rodent Infestation Levels Based on Rodent Sightings

To analyze the temporal variation in the abundance of rodents, we studied the variation in the number of rodent sightings reported by citizens between May 2001 and December 2002. Following Tamayo-Uria et al. (2013b), rodent sightings were considered as indicators of evident rat infestations. The record of rodent sightings considered was that of the complaints reported to the Government of the city of Buenos Aires. The sightings were grouped by CGP according to their location. To analyze the seasonal variations in the number of rodent sightings by CGP, we performed a one-way ANOVA for repeated measures, gathering reports of the different seasons (summer: from January to March, autumn: from March to June, winter: from July to September, and Spring: from October to December). We analyzed the association between the number of rodent sightings received per month throughout the city and the monthly mean temperature and monthly precipitation (exogenous factors of the population), using simple and partial correlations. This analysis was also performed applying time lags up to four months.

A total of 32 characteristics of the 16 CGPs were evaluated as possible indicators of rodent infestation (predictive variables, Table 1). Based on commensal rodent biology, we selected demographic and socio-economic variables along with variables of the environmental structure. Since the number of inhabitants is different among different CGPs, the number of complaints of rodent sightings per CGP was standardized per the number of inhabitants. Some of the predictive variables were expressed in hectares because the areas of the different CGPs are not equal (Table 1). Demographic and socio-economic variables were estimated using ArcView Gis 3.2.a. (ESRI 1999) from data of the National Census of Population and Dwelling 2001 (INDEC 2001), and the environmental structure variables were based on a land-cover classification from De Pietri and Karszenbaum (2000) and digital maps (AABA 2010). De Pietri and Karszenbaum (2000) classified the total area of Buenos Aires into five classes using a LANDSAT TM image obtained on December 4, 1997: tree cover, herb cover, highly vegetated urban cover, moderately vegetated urban cover, and low vegetated urban cover (Table 1).

A forward stepwise multiple regression analysis (Quinn and Keough 2002) was performed using the number of rodent sightings reported per 10,000 inhabitants as response variable, and the demographic, socio-economic, and environmental structure variables as explanatory ones. Previously, we analyzed whether multiple regression analysis assumptions were fulfilled.

Spatial Variation in Rodent Infestation Levels Based on a Questionnaire Survey

To analyze the spatial variations in the infestation of rodents from an indicator other than rodent sightings, the infestation of rodents was assessed through surveys to neighbors. The survey was conducted during summer 2003 in 103 regularly distributed sites, spaced by 1414 m, of Buenos Aires. In each site, a minimum of 40 neighbors were asked whether they had seen rats or mice, gnawed objects or rodent feces in their houses/job (depending on whether they lived or worked near the site surveyed) and in the neighborhood. If the interviewee answered affirmatively, the following final question was asked to separate recent sightings from non-recent ones: When was the last time you saw one? The address of the house or working place was recorded to be later georeferenced. In each of the 103 sites, rodent infestation was estimated using the data of the surveys with the following indexes: 1) the proportion of people who reported having seen rodents in their dwelling (PropD) and in their neighborhood (PropN) during the last quarter. A previous study conducted this questionnaire survey simultaneously with rodent trapping campaigns in neighbors of the city of Buenos Aires (Cavia et al. 2012). During this study, 347 dwellings were sampled, a total of 25 *R. rattus*, 52 *R. norvegicus*, and 28 *M. musculus* were trapped with 1769 cage trap-nights and 1837 Sherman trap-nights. Trap success of commensal rodents showed higher correlation coefficients with PropD at different spatial or temporal scales: block scale (Spearman $r = 0.579$, $P < 0.05$), neighbor scale (Spearman $r = 0.716$, $P < 0.05$), and seasonal scale (Spearman $r = 0.929$, $P < 0.05$, for more details see Cavia et al. 2012, pp. 162–167). Trap success showed greater association with PropD in comparison with PropN (Cavia et al. 2012). Based on these evidences and

Table 1. Demographic, Socio-economic, and Environmental Structure Variables Analyzed to Explain the Number of Complaints of Rodent Sightings per CGP and the Proportion of People Who Reported Rodent Sightings in Their Dwelling (PropD) During the Last Quarter in the 103 Sites Where Surveys were Carried Out in the City of Buenos Aires.

Variable names	Variable description
People density[a]	Number of people living in the area every 1000 ha
Density of working people[a]	Number of jobs in each area every 1000 ha
Density of people living or working[a]	Number of people living and / or working in the area every 1000 ha
Density of Type B houses[a]	Number of type B houses in each area every 1000 ha. "Type B houses" refers to all households that meet at least one of the following conditions: have dirt floor or loose brick floor or other material (no floor tiles, mosaics, marble, wood or carpet) or have no piped water supply inside the house or do not have flush toilet
Density of Type A houses[a]	Number of type A houses in each area (those not considered Type B houses) every 1000 ha
Density of apartments[a]	Number of apartments in each area every 1000 ha
Density of shanty houses[a]	Number of shanty houses in each area every 1000 ha
Total density of houses[a]	Number of total houses (apartments, type "A" and "B" houses and shanty houses) in each area every 1000 ha
Tenant density[a]	Number of houses with tenants in each area every 1000 ha
Density of families with UBN[a]	Number of families with unsatisfied basic needs (UBN) every 1000 ha
Density of industries[a]	Number of industries (metals, food, clothing, meat, chemical and others) every 1000 ha. Industries were considered both according to each type and according to all grouped
Proportion of land area occupied by different types of coverage[b]	Proportion of land area occupied by each of the five land-cover types defined by De Pietri and Karszenbaum (2000): (1) Tree cover (when >75% of the pixel was covered by trees) (2) Herb cover (when >75% of the pixel was covered by herbs) (3) Highly vegetated urban cover (when 75–50% of the pixel was vegetated and <50% was built up), (4) Moderately vegetated urban cover (when 5–50% of the pixel was vegetated and 50–80% was built up) and (5) Low vegetated urban cover (when <5% of the pixel was vegetated and >80% was built up)
Proportion of area occupied by green spaces[c]	Surface occupied by squares, parks and landscaped areas (of public or restricted use) regarding the total surface of each area
Proportion of area occupied by shantytowns[c]	Surface occupied by shantytowns regarding the total surface of each area
Mean, minimum and maximum height[c]	For each area, the mean, minimum and maximum height over sea level (in meters) were estimated
Number of trash mounds[c]	Number of trash mounds in each area every 1000 ha
Distance to trash mounds[c]	Distance (in meters) to the nearest trash mound in each area
Distance to train[c]	Distance (in meters) to the nearest railroad tracks in each area
Distance to sewer[c]	Distance (in meters) to the nearest sewers in each area
Distance to river[c]	Distance (in meters) to the nearest river in each area
Distance to water bodies[c]	Distance (in meters) to the nearest water body in each area
Age of settlement[c]	Age of population settlement in each area

[a]Variables estimated from the National Census of Population and Dwelling (INDEC 2001).
[b]Variables estimated from the land-cover classification from De Pietri and Karszenbaum (2000).
[c]Variables estimated from digital maps of the city of Buenos Aires (AABA 2010).

Table 2. Demographic, Socio-economic and Environmental Variables that were Positively and Negatively Associated with Each of the First Three Axes of the Principal Component Analysis (with Pearson $r > |0.5|$).

Environmental characteristic	Axis 1	Axis 2	Axis 3
Proportion of area occupied by green spaces	–		
Proportion of land area with highly vegetated urban cover	–		
Proportion of land area with herb cover	–		
Proportion of land area with tree cover	–		
Proportion of land area with herb or tree cover	–		
Age of settlement	+		
Tenant density	+		
Total density of houses	+		
People density	+		
Density of families with UBN	+		
Density of people living or working	+		
Maximum height over sea level	+		
Density of clothing industries	+		
Density of apartments	+		
Proportion of land area with low vegetated urban cover	+	–	
Proportion of land area with moderately vegetated urban cover	+	+	
Density of Type A houses		+	
Density of Type B houses		+	
Density of metal industries		+	+
Density of industries	+		+
Density of meat industries			+
Density of food industries	+		+
Density of other industries	+		+

The variables from Table 1 not associated with this axis (Pearson $r < |0.5|$) are not included.

that in the present study, PropD and PropN were associated ($r = 0.60$, $P < 0.001$), and the following analyses were performed only for PropD.

The semivariogram function for PropD was computed to analyze the spatial dependence of the rodent infestation index. To estimate the range, the nugget, and the sill, the semivariogram function was fitted using a spherical model (Bailey and Gatrell 1995). Four directions were considered to account for isotropy: 0°, 45°, 90°, and 135°. To analyze the spatial pattern of rodent infestation in the city, PropD was interpolated using an ordinary Kriging procedure (Bailey and Gatrell 1995) using SPLUS 6.1 (Insightful 2002).

The association between PropD and the environmental characteristics examined was analyzed through a forward stepwise multiple regression procedure (Quinn and Keough 2002). The variables used as predictors were the same as those for rodent sightings collected by each CGP, but estimated for each of the 103 sites. These variables were estimated using ArcView Gis 3.2.a. (ESRI 1999). To estimate the proximity of each site to different environmental structures, distance maps were built from digital maps of Buenos Aires (AABA 2010). All other environmental characteristics were estimated around the area of each site, using Thiessen polygons (Table 1, Bailey and Gatrell 1995). Because PropD is a proportion, multiple regressions were performed using Generalized Linear Models (GLM) with a Binomial distribution used for errors, and a logarithm link function (Zuur 2009). To account for over-dispersion, when the dispersion parameter was greater than 1.5, the standard errors (SE) were corrected using a quasi-Binomial model (Zuur 2009). A Principal Component Analysis (PCA) was also performed to identify groups of associated explanatory variables. The effect of the spatial dependence on rodent infestation was analyzed including an autocovariation matrix in the generalized linear model, according

Table 3. Multiple Regression Models, [Parameter Estimates and Standard Errors (SE)] for Proportion of People who Reported Having Seen Rodents in Their Dwellings in the Last Quarter (PropD) as a Function of Demographic, Socio-economic, and Environmental Variables in the City of Buenos Aires.

	Parameter	SE
All sites		
Intercept	−1.946	0.132***
Density of apartments	−0.008	2.843**
Proportion of area occupied by shanty towns	9.452	0.003**
Density of meat industries	3.079	1.551*
Dispersion parameter	1.829	
% explained deviance	24.21	
Excluding sites with shantytowns		
Intercept	−2.798	0.273***
Density of meat industries	3.300	1.279*
Proportion of land area with moderately vegetated urban cover	1.222	0.435**
Density of apartments	−0.006	0.002*
Dispersion parameter	1.523	
% explained deviance	20.86	

General Linear Model with a binomial distribution was used for errors and a logarithm link function was applied. To account for over-dispersion, the standard errors (SE) were corrected using a quasi-Binomial model. The models that best described the PropD for all the sites surveyed and excluding the sites where shantytowns were present are shown (see text for details).

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. All sites: null deviance = 361.06, d.f. = 102; residual deviance = 273.65, d.f. = 99; excluding sites with shantytowns: null deviance = 207.01, d.f. = 92; residual deviance = 163.82, d.f. = 89.

to the methodology described by Dormann et al. (2007). The autocovariation matrix was computed using the *spdep* package for R (R Development Core Team 2013), according to the parameters estimated from the semivariogram function. The autocorrelation of the model residuals was analyzed by computing the semivariogram function. These analyses were conducted using R 3.0.1 (R Development Core Team 2013) and S-PLUS 6.1 with a spatial extension module (Insightful 2002).

Indexes obtained from complaints of rodent sightings and from the questionnaire surveys (calculating PropD and PropN by CGP) were compared using a Spearman correlation test to analyze concordance between indexes.

Results

Temporal and Spatial Variation in Rodent Infestation Levels Based on Rodent Sightings

A total of 1795 rodent sightings were reported between May 2001 and December 2002 in the 16 districts of the city of Buenos Aires. In the summer, autumn, and spring of 2002, the number of rodent sightings reported was higher than that reported in spring of 2001 and winter of 2001 and 2002 ($F_{5,75} = 17.60$, $P < 0.000$, Fig. 1a and b). The number of rodent sightings reported was greater when the monthly mean temperature was higher, being the strongest association with a time lag of two months (Fig. 2a). No association was observed between rodent sightings reported and monthly rainfall, analyzed with time lags of up to four months (Fig. 2b). These associations were still not significant when the effect of mean temperature was removed using partial correlation analysis ($P > 0.05$ for all cases, Fig. 2c). The greatest number of rodent complaints was received from the CGP 9 followed by CGP 6, while CGPs 1, 8, and 13 recorded the lowest numbers (Fig. 3a). The environmental model included two explanatory characteristics, indicating that a higher number of rodent complaints was reported in the CGPs where there are more meat industries (meat-packing and meat cold storage factories) and metal industries ($R^2 = 0.873$, $F_{2,13} = 44.55$, $P < 0.001$, $b_{\text{MEAT INDUSTRIES}} = 0.098 \pm 0.020$ SE, $P < 0.001$, $b_{\text{METAL INDUSTRIES}} = 0.164 \pm 0.040$ SE, $P = 0.001$). In turn, the density of metal industries per CGP was positively associated with that of chemical industries and with that of type

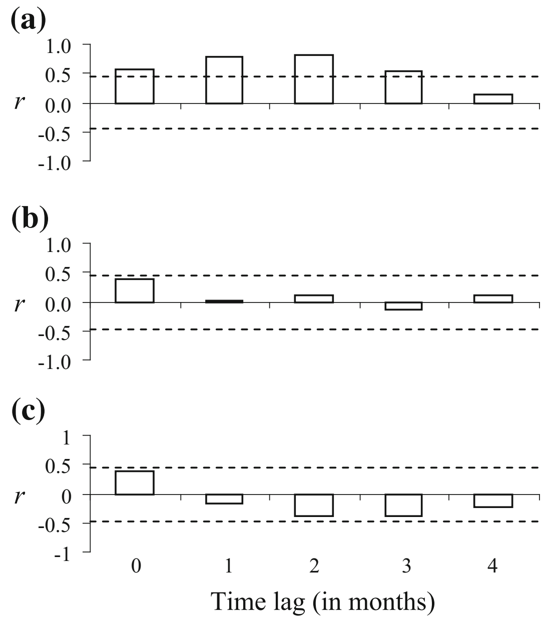

Figure 2. Correlogram for the number of rodent sightings with **a** mean temperature, **b** precipitations, and **c** precipitation partialited out the effect of mean temperature (lag = 2). The time lag is up to 4 months. *r* Pearson correlation coefficient. The *dotted lines* represent the critical value for 5% significance.

B houses (Pearson $r = 0.736$, $P = 0.002$ and Pearson $r = 0.666$, $P = 0.007$, respectively).

Spatial Variation in Rodent Infestation Levels Based on a Questionnaire Survey

A total of 4243 people distributed in 103 points of Buenos Aires were surveyed. Of them, 98.02% of the records were georeferenced (Fig. 3b), whereas the remaining ones were eliminated. On average, the infestation index PropD was 0.108 ± 0.090 SE, and the mean PropN was 0.301 ± 0.015 SE. The relationship between these two indices was linear and highly significant ($r = 0.599$, $t_{103} = 7.527$, $P < 0.001$, PropN = 0.2042 + 0.979 * PropD).

According to the semivariogram, PropD showed a spatial autocorrelation that reached 11686 meters, defining large areas with similar levels of infestation (Fig. 3c). The semivariograms showed no variations among the four different directions, indicating isotropy (results not shown). When this rodent infestation index was interpolated, a large area in the southern part of the city and a smaller patch in the north east of the city with values above the mean value were observed. Meanwhile, from the center and north of the city, the values were below the mean value (Fig. 3d).

The PCA conducted for the demographic, socio-economic, and environmental explanatory variables showed associations between many of them. The first three axes were retained, explaining 33.39%, 15.72%, and 9.98% of the total variance, respectively. The first axis described the strongest environmental gradient in the city related to the increasing urban conditions, as it was positively associated with characteristics as population density, apartment density, and the proportion of urban area with low vegetation cover, and negatively associated with characteristics as proportion of areas occupied with green spaces, proportion of urban area with high proportion of vegetation, and proportion of tree and/or herb covers (Table 2). The second axis was related to residential neighborhoods where houses with gardens predominate, as it was positively associated with house density (type A and B) and the proportion of urban areas with moderate proportion of vegetation (Table 2). The third axis was related to neighborhoods where different types of factories are common, as it was positively associated with the density of metal and food industries and total density of industries (Table 2).

According to the best GLM model, PropD decreased when the apartment density increased and increased when the proportion of area occupied by shantytowns and the density of meat industries increased (Table 3). The incorporation of the spatial dependence did not improve the model ($F_{1,98} = 2.48$, $P > 0.1$). The semivariogram created for the residuals of the models showed no spatial dependence. After a graphical check of the residuals (results not shown), we observed that PropD showed extreme values in some of the polygons which included shantytowns. To analyze which factors would be determining the abundance of rodents in the areas where shantytowns were absent (approximately 91% of the remaining area), the multiple regressions analyses were repeated eliminating the polygons where more than 2% of the surface was occupied by shantytowns. For this subset of sites, the best multiple regression model that described the rodent infestation index also retained the apartment density and the density of meat industries in the area, and incorporated the proportion of area occupied by urban development with moderate vegetation cover. This latter variable had a positive effect on the rodent infestation index (Table 3). Again, the incorporation of the spatial dependence did not improve the model ($F_{1,\ 88} = 1.51$, $P > 0.20$), and the semivariogram

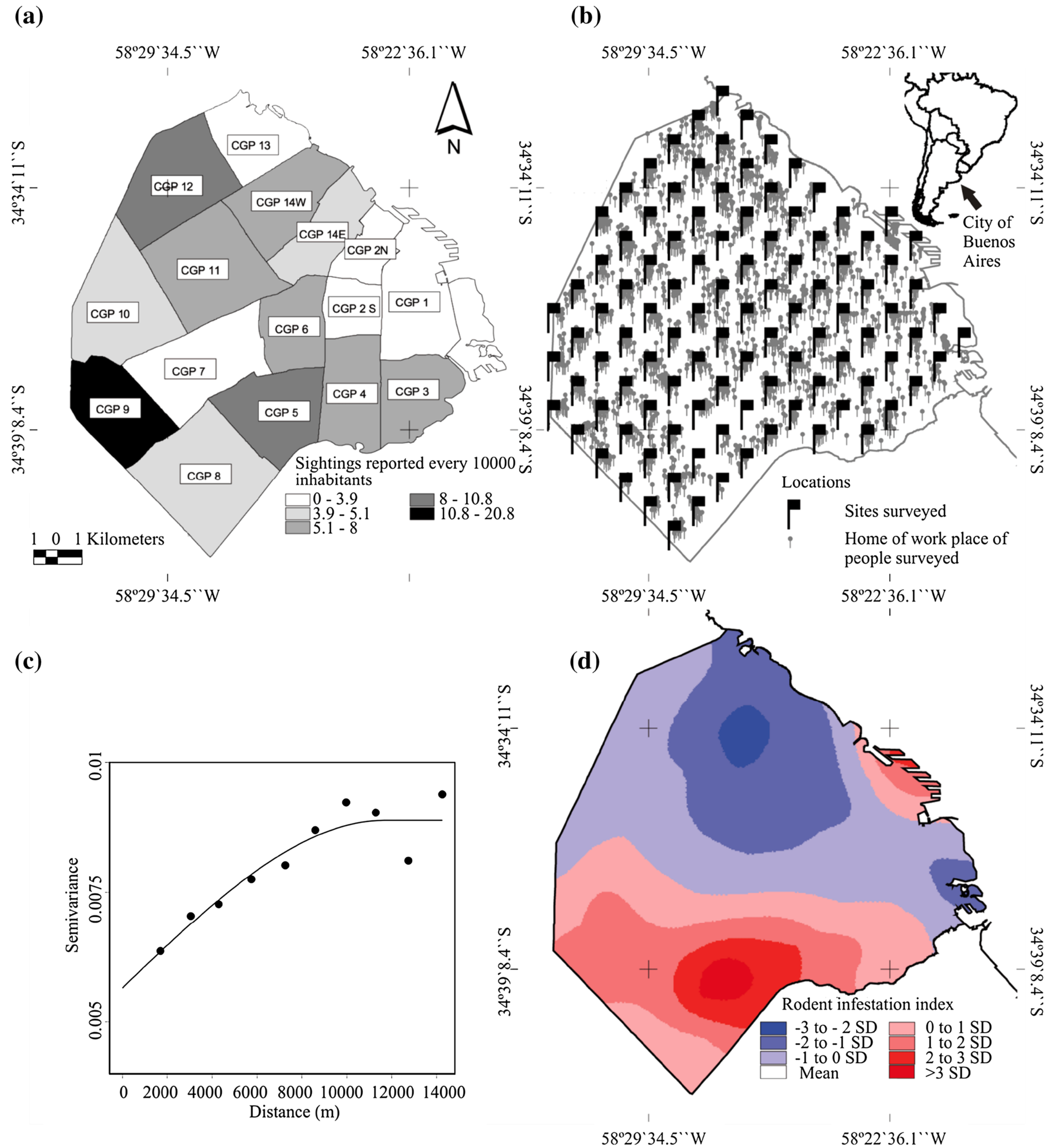

Figure 3. Spatial analysis of rodent infestation indexes. **a** Number of rodent sightings reported by CGP every 10000 inhabitants, **b** location of sites where surveys were carried out (*black flags*, $N = 103$), and location of the home or work place of people surveyed (*little gray pins* $N = 4159$), **c** semivariogram obtained for the spatial distribution of the rodent infestation index (*PropD* proportion of people who reported rodent sightings in their dwelling during the last quarter, range = 11686 m, nugget = 0.006, sill = 0.003), **d** interpolated rodent infestation index *PropD* in the city of Buenos Aires, Argentina.

created for the residuals of the models showed no spatial dependence.

Finally, the number of complaints of rodent sightings reported every 10,000 inhabitants by CGP was not associated with PropD or PropN by CGP (number of complaints vs PropD, Spearman $r = 0.2058$, $P = 0.444$, and number of complaints vs PropN: Spearman $r = 0.3911$, $P = 0.134$).

Discussion

By conducting surveys, we were able to determine that the different areas of the city of Buenos Aires differ in the abundance of rodents. This method was previously compared with estimates of abundance of rodents in urban environments showing that the variations in the infestation indexes used in that study reflect changes in abundance of rodents (Cavia et al. 2012). This methodology allowed us to construct a map of infestation that enabled us to identify areas with different levels of relative abundance of rodents (Fig. 3d), which would be difficult using traditional sampling techniques, such as trapping, in such a short time and at the spatial scale studied here. It is noteworthy that all questionaries were completed in 32 days by 4 to 5 people who performed the surveys simultaneously for 5 hours daily. Thus, this technique allows estimating the level of rodent infestation in a certain neighborhood in only one day. Furthermore, several of the areas identified in this study as those with greater abundance of rodents agree with those described by Coto (2001) for this city. Also, the sensitivity to the spatio-temporal population changes shown by this infestation index indicates that this index could be used in control programs and has the advantage that it requires no manipulation of animals, thus avoiding the potential risk of exposure of operators to rodent-borne diseases.

On the other hand, the information on the species obtained both through surveys and complaints is limited, so in this case additional trapping surveys would be needed. A previous study indicates that the urbanized areas of this city are inhabited only by the commensal rodents *R. rattus*, *R. norvegicus*, and *M. musculus* (Cavia et al. 2009).

Although the number of complaints of rodent sightings received was related to the density of meat and metal industries and agrees with the findings of other authors (Bajomi and Sasvári 1986), this index would not be appropriate to evaluate the spatial variations in rodent abundance. This is, first, because it was spatially independent of the other rodent infestation indexes used in the present study, which were reported highly associated with commensal rodent trap success (Cavia et al. 2012). Second, because motivations of citizens to contact with government agencies would depend on their socio-economic level (Thomas 1982), the number of complaints may be more affected by differences in the motivation of the people who live in different CGP areas than by differences in abundance of rodents. It is noted, for example, that CGP 1 and 8 received the lowest number of complaints of rodent sightings (Fig. 3a). In these areas, there are several shantytowns where both high values in the proportion of people who answered having seen rodents in their dwellings and neighborhood in the last quarter (Fig. 3c) and high abundance of commensal rodents had been previously documented (Coto 2001; Fernández et al. 2007; Vadell et al. 2010; Cavia et al. 2012). Possibly, the existing rodent problems in these neighborhoods do not motivate people to claim to the City Government because they have other essential needs. In contrast, in neighborhoods with high incomes, the presence of rodents on public spaces would motivate neighbors to make these complaints. The possible differences in motivation in different CGP areas would not invalidate the analysis of variations over time, because, except in cases where the motivation varies abruptly by particular events, it could be considered constant for short periods of time. In Madrid, a similar study was performed analyzing both the temporal variations (Tamayo-Uria et al. 2013a) and spatial variations of complaints (Tamayo-Uria et al. 2013b). Special care should be taken with the conclusions obtained on the spatial analysis, because the possible effect of the fact that a greater number of complaints are expected at sites with greater abundance of people was not controlled. Therefore, as expected, in that study, the rodent infestation rate was higher where the number of people was higher (Tamayo-Uria et al. 2013a). This result is opposite to that found in our city where low levels of rodent infestations were observed in areas with high building density related to high density of people (Tables 2 and 3).

Moreover, both Bajomi (1993), Vadell et al. (2010), and Tamayo-Uria et al. (2013b) all observed seasonal cycles of abundance of rats (*R. norvegicus* and *R. rattus*) in urban areas, which were positively associated with average temperature. In the present study, the same pattern was observed. These changes could be also explained by changes in the activities performed by both people and rodents, as suggested by Tamayo-Uria et al. (2013b). The time lag of 1 or 2 months found in rodent complaints regarding the average monthly temperature would indicate that this is a result of abundance changes, since abundance changes may be expressed in time lag with respect to environmental changes (Krebs et al. 2005).

On the other hand, the analysis of the relation of demographic, socio-economic, and environmental characteristics with rodent infestation estimated by questionnaire surveys allowed the identification of factors that are related to different levels of rodent abundance at the scale analyzed. However, causal effects cannot be determined mainly because many of the predictive variables were correlated at the scale analyzed (Table 2). The characteristics analyzed in this study vary gradually in the city, showing large areas with similar characteristics, as the spatial pattern of rodent infestation. This is probably why the spatial autocorrelation observed disappears when the effect imposed by the environment is removed.

Areas with different problems and different approaches to their control can be defined. Within the city, shantytowns should be a priority for the design and implementation of control programs because they are the ones that showed the greatest abundance of rodents, and therefore, this environmental characteristic explains much of the differences in the abundance of rodents at the whole city scale. This agrees with the general idea that precarious conditions are favorable for commensal rodents (i.e., Childs et al. 1998; Lambropoulos et al. 1999; Langton et al. 2001; Traweger et al. 2006; Masi et al. 2010). These shantytowns are dominated by *R. norvegicus* and *M. musculus* (Fernández et al. 2007; Cavia et al. 2009) and are environments that can be found only in South America, so it is not possible to easily adapt control programs developed elsewhere in the world. Fernández et al. (2007) suggests that rodent control in shantytowns is possible, but long-term policies of environmental sanitation and health education are necessary to achieve low levels of infestation. Moreover, these rodent species are not only potential disease reservoirs since in these shantytowns they are actually carrying several pathogens that produce diseases to humans, such as *Leptospira* spp. (Seijo et al. 2002), hantavirus Seoul (Cueto et al. 2008), and human helminth parasites (Hancke et al. 2011). This scenario, in association with other socio-environmental vulnerabilities, as poor public services, would increase the effect of these zoonoses within shantytowns.

Meanwhile, in the rest of the urban matrix (excluding parks, natural reserves, and shantytowns), *R. rattus* is practically the only species caught (Cavia et al. 2009). This is consistent with that observed in this study, as surveys were performed where respondents primarily made reference to sightings of rats (Cavia and Muschetto, personal observations). In this matrix, sites with high concentration of buildings represent less favorable environments for these rodents as was also reported in England and São Paulo (Langton et al. 2001; Masi et al. 2010). These environments show a limited availability of open spaces (such as courtyards, gardens, etc.) that can be colonized by rodents, as the compact structure of areas with high density of apartments would limit the entrance pathways. Although dwellings are connected through the sewage system, Gras et al. (2012) dismissed the relevance of this way of entering dwellings by rodents. This is only one probable reason that explains why high concentration of buildings represents less favorable environments to rodents since all indicators of high levels of urbanization are highly associated in this study area (i.e., people, stores and homes densities, Table 2).

In Buenos Aires, the density of apartments seems to summarize well the relationship between environmental characteristics related to high levels of urbanization and low levels of rodent infestation. Similarly, the areas with higher values of proportion of urban areas with moderate vegetation coverage were more favorable for rodents. In these areas of the city, houses are the predominant home types, indicating that some amount of vegetated areas, like the gardens of houses, as well as the increased permeability of this type of construction, would favor commensal rodents. In this type of urbanization, *R. rattus* would find favorable conditions which, in combination with the presence of waste on public streets from industry activities (Marsh 1994), would enable it to reach maximum values of abundance. Also, the existence of industries in residential neighborhoods would also generate a conflict of interests between residents and companies, which results in the greatest number of rodent complaints to the City Government.

In summary, based on the use of alternative methods of rodent sampling, this work shows that at the scale of an entire city like Buenos Aires, rodents present high infestation levels in early autumn and lower ones in winter and both the areas with more precarious socio-economic conditions as well as the industrial areas would be the most favorable for commensal rodents. Moreover, the most densely urbanized areas showed the less favorable conditions for commensal rodents. Since these characteristics are unhelpful as part of sanitation management programs because they are broad scale and almost impossible to modify, they should be used to help in the identification of priority areas in order to concentrate control efforts.

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