ISSN 1612-4758, Volume 83, Number 3

J Pest Sci (2010) 83:231–241
DOI 10.1007/s10340-010-0290-9

Socioeconomic and environmental risk factors for urban rodent infestation in Sao Paulo, Brazil

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Received: 16 April 2009 / Accepted: 18 January 2010 / Published online: 14 February 2010

Abstract This article provides analyses of data on the premises infestation by commensal rodents collected during the 2006 Urban Rodent Survey, in Sao Paulo city, Brazil. A two-stage cluster sample survey was used to visit 23,512 premises, and logistic regression models were estimated in order to understand the relationships among the risk factors and the infestation probability. The premises infestation rates were 23.1% for all rodents, 12.7% for roof rat, 9.4% for Norway rat and 1.7% for house mouse. Factors found to be related to infestation levels were: socioeconomic conditions (human development index and income), premises features (commercial, strictly residential and vacant lots), and environmental resources (access, harborage and food). The analysis of odds ratios showed that access by the building structure favours roof rat and access by the sewage system favours Norway rat. Harborage in ceiling cracks are determinant for roof rat, harborage in wall cracks and in dense bush for Norway rat, and harborage in waste or in building material for house mouse infestations. Available animal food favour all the three species, fruit trees favour Norway and roof rats, human food is important for house mouse: therefore a natural partition of the environmental resources among the species was observed. The results obtained in this article add some knowledge on the biology and behaviour of commensal rodents.

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Keywords Commensal rodents · Urban factors · Environmental factors · Risk factors · Logistic models

Introduction

From almost 2,000 rodent species in the world (Nowak 1991), approximately 50 of them may cause damage to agriculture or public health, and are considered commensal. This article will be focused on the three most common and most important for public health species in the city of Sao Paulo, according to the Sao Paulo Municipal Law no. 48839 of 2007: the Norway rat or brown rat (*Rattus norvegicus*), the roof rat or black rat (*Rattus rattus*) and the house mouse (*Mus musculus*). These rodents had been introduced in Brazil during European colonization (Lund 1994). Rodents are able to spread more than 60 known diseases (Meehan 1984), and leptospirosis is the most important of such diseases in Brazil. It is endemic in Sao Paulo: 2,542 cases and 370 deaths had been registered in the 1998–2006 period. Data from the surveillance system showed that 43.8% of the total number of cases was contaminated by flood water, 21.6% during cesspool and sewerage cleaning, and 13.3% by direct contact with rodent urine (data from Sao Paulo Municipal Health Secretary).

Several techniques and procedures were proposed in order to evaluate the rodent population size as well as the extent and severity of rodent infestation in a given area. Capture-mark-recapture and relative density survey are two examples of those techniques. Because of the technical difficulties presented in urban areas, in 1964, the Center for Disease Control and Prevention (CDC), in Atlanta, USA, proposed another methodology to survey the premises infestation to evaluate and manage urban rodent populations (Kaukeinen 1994), which was first published as a manual in 1974 entitled Urban Rat Survey providing more details about the methodology. According to this manual, the calculation of the percentage of infested premises is based on rodent signs observations in internal and external areas. Data on environmental conditions related to food, access, and harbourage are also observed (Davis et al. 1977). In Sao Paulo, the first application of this technique occurred in 2005, first in a pilot study in a few districts and second in the whole city (Masi et al. 2009; Santos et al. 2006). After local adjustments, the CDC manual-based Urban Rodent Survey had been performed on 2006. The results are analyzed in this paper. Conclusions and recommendations will be used in governmental actions for rodent control and management.

Our study aimed to model the effect of environmental (access, harbourage and food availability) and socioeconomic factors (income, education, sanitation services coverage, demographic density) over rodent infestation in Sao Paulo city, regarding the three urban species (*R. norvegicus*, *R. rattus* and *M. musculus*).

The main hypotheses to be tested were:

(a) The rodent infestation in a given urban area (neighbourhood, or district, or census tract) is influenced by socioeconomic factors. Hence, higher infestation rates will be associated with more adverse socioeconomic conditions;

(b) Once the urban neighbourhood is infested, the premises infestation depends on environmental factors. Hence, higher infestation rates will be associated with the availability of the access, harbourage and food sources.

Methods

Study population

The city of Sao Paulo population is 10.4 million people living in 1,509 km^2. More than 3 million dwellings are dispersed in 31 boroughs. Almost 100% of the dwellings are reached by treated water, 70% are served by the sewage collection and disposal system and 99% are served by regular collection of solid residues (Brazilian Institute of Geography and Statistics 2002). The Human Development Index (HDI) is 0.74, ranging between 0.60 and 0.94 for different administrative regions (Pedroso 2003). The HDI was created during the 1990s by the United Nations Development Programme (UNDP). It includes information on life expectancy, literacy, educational attainment and gross domestic product per capita. It ranges between 0.00 and 1.00 and is claimed as a standard means of measuring human development. Hence, higher values of HDI are associated with better life conditions.

Data collection and sample design

Economic data for each census tract came from the national demographic survey, performed by the Brazilian Institute of Geography and Statistics (IBGE), in 2000. The State Data Analysis System Foundation (SEADE) estimated data on HDI, for each administrative region.

Data on rodent infestation and environmental variables were collected in July 2006, by the Urban Rodent Infestation Survey, performed by the Sao Paulo city hall and based on Davis et al. (1977). The survey was based on a probabilistic two-stage cluster sample (Kish 1965). Primary sampling units were census tracts (with demographic density greater than 100 unhabitants/km^2), stratified by 31 city boroughs: 486 census tracts were selected from a total of 13,118 census tracts. The secondary sampling units were blocks: in each selected census tract one block was randomly selected and all the premises in the selected block were visited. Field work was done by zoonosis control personnel, with at least 3 years of experience on rodent control. All the premises in each selected block were visited and as many of them as possible were inspected. When the dweller or owner was absent or refused to authorize the inspection after three attempts, the premise was disregarded from the analysis.

The exterior inspection of premises included any garden, back yard, laundry and other external buildings. The interior inspection of dwellings and buildings included living-rooms, kitchens, bathrooms, ceilings, basements and others. The bedrooms were inspected only by request of the dwellers.

The following variables were observed: premises features (residential or dwelling, commercial, both residential and commercial, unused plot of land); food sources (animal food, available human food, exposed garbage, fruit trees); harbourage (waste material/rubbish, building material, discarded objects, ceiling cracks, wall cracks, dense bush); access sources (by the building structure, by the sewage system); rodent infestation (observed by vestiges of rodents). The rodent species were defined according to the characteristics and the location of their traces. The main characteristics considered in identification were the format and size of the faecal pellets: those of Norway rat are spindle-shaped with very blunt tips, those of roof rat thread-like and with quite thin tips and those of house mouse are smaller than the other two species. The other characteristics observed were: the presence of rub marks at the level of the roof indicates roof rat infestation; the presence of burrows in the garden or back yard indicates the Norway rat infestation. Moreover, the surveyors experience and qualification were crucial for the identification of rodent traces or vestiges. All the variables were categorized as binary (or dichotomous), assuming the values 1 for its presence and 0 for its absence in the premise.

Data analyses

Multiple logistic regression models were estimated for rodent infestation rate as function of the environmental variables (related to access, harbourage and food), the premises features, and socioeconomic factors of where the premises were established. The multiple regressions linking the vector of dependent or response variable Y and the matrix of independent or explanatory variables $\mathbf{X} = (X_1, X_2, \ldots, X_k)$ may be written as

$$p = \Pr[Y|\mathbf{X} = \mathbf{x}] = \frac{1}{1 + e^{-\beta'\mathbf{x}}}$$

The linear logistic model (or logit model) has the form

$$\mathrm{logit}(p) = \ln\left(\frac{p}{1-p}\right) = \beta'\mathbf{x}$$

where $\boldsymbol{\beta}'$ (is the vector of parameters to be estimated (Pino 2007). Models were estimated by LOGISTIC procedure of Statistical Analysis Software (SAS®), version 9.1 for Windows (SAS Institute 2009). The stepwise effect-selection method was used to eliminate the variables not associated with the dependent variable and also to indicate the most interesting variables for the model, i.e., effects or explanatory variables "are entered into and removed from the model in such a way that each forward selection step can be followed by one or more backward elimination steps. The stepwise selection process terminates if no further effect can be added to the model or if the current model is identical to a previously visited model" (SAS Institute 2009). The default value of 0.05 has been used as the significance level of the score chi-square for entering an effect into the model. The odds ratio (OR) and its 95% confidence interval (CI 95%) were used to evaluate the association between the explanatory variables and the dependent variable. Although the models were not used to predict the probability of a given premises to be infested, some indices of rank correlation are also presented in order to help the understanding of the relationship of infestation rate and risk factors (Sommers' *D*, Goodman–Kruskal gamma, Kendall's Tau-*a*, and *c*): the higher they are (until the maximum value of one), the better the model predictive ability.

All the variables are binary (or dichotomous), assuming the values 1 for the presence and 0 for the absence of the effect, except the Human Development Index (HDI), which is a continuous variable in the interval [0;1]. An additional economic variable was created, the income up to two-minimum wages, defined as 1 = more than 50% of the private dwellings in the census tract have the head of the family earning up to two minimum wages monthly, and 0 = otherwise.

Finally, two sets of logistic regression models were considered:

(1) General premises rodent infestation rate depends on all the other variables. Then, the premises rodent infestation rate by species (*R. rattus*, *R. norvegicus* and *M. musculus*) depends on all the other variables.
(2) The same models of the first set, but some independent variables were aggregated as food source, harbourage source and access source.

Results

Sample survey

Although 23,512 premises and dwellings were randomly selected, only 17,375 were effectively inspected and therefore considered in data analysis. Registered non-response percentage was similar to other surveys. As examples, one may mention the 29% registered in 1996 and the 33% in 2001 in the English House Condition Survey (DEFRA 2005). Closed dwellings (22.5%) and refusals (4.3%) were the main reasons for non response (Table 1). Most premises were residential and, residential together with commercial and strict commercial were less represented. Vacant lots were scarce in the studied area. The small values for coefficient of variation, the narrow two standard errors intervals and the small values for estimates standard deviations indicate good statistical estimates from the sample survey (Tables 1, 2).

The most common environmental factor found in the city was harbourage source, mainly waste material and ceiling cracks, followed by building material and wall cracks. The second more important factor was food source, especially exposed garbage and animal food. The least frequent factor was access source, as building structure faults.

The overall premises rodent infestation rate in the city was 23.1 (two standard errors interval from 23.1 to 23.2%). Roof rat (*R. rattus*) was the most frequent species, occurring in 12.7% of the premises, followed by Norway rat (*R. norvegicus*) in 9.4% and house mouse (*M. musculus*) in only 1.7%.

The levels of infestation are also presented by different factors (Table 2), e.g., 6.6% of premises with no access source available were infested by rodents, while 52.8% of the ones with access source available were also infested.

Table 1 Frequency of environmental and infestation variables (% of premises), Sao Paulo city, Brazil, 2006

Variable	Number of premises contributing to the analysis	Weighted according to the sample design		
		Frequency (%)	Two standard errors interval	Coefficient of variation (%)
Inspected premises	17,375	72.9	72.8–73.0	–
Closed premises	5,136	22.5	22.4–22.6	–
Refused premises	1,001	4.3	4.2–4.3	–
Unused plot of land	248	1.3	1.3–1.4	0.8
Strictly residential premises	13,892	78.9	78.8–79.0	0.1
Both residential and commercial premises	750	14.0	13.9–14.1	0.4
Strictly commercial premises	2,197	4.4	4.4–4.5	0.2
Access source	5,254	30.5	30.3–30.7	0.3
Building structure	4,254	25.0	24.8–25.2	0.4
Sewage system	2,273	13.9	13.8–14.1	0.6
Harbourage source	6,650	37.6	37.4–37.8	0.2
Waste material/rubbish/discarded objects	4,231	24.2	24.1–24.4	0.3
Ceiling cracks	2,863	16.7	16.6–16.8	0.2
Building material	2,488	13.9	13.8–14.0	0.3
Wall cracks	2,379	13.3	13.2–13.4	0.4
Dense bush	524	2.9	2.9–2.9	0.5
Food source	5,880	33.9	33.8–34.1	0.3
Accessible garbage	2,976	17.9	17.7–18.1	0.5
Animal food	2,812	16.6	16.6–16.7	0.2
Available human food	2,239	13.3	13.2–13.5	0.6
Fruit trees	1,114	6.1	6.1–6.2	0.3
Rodent infestation	4,146	23.1	23.1–23.2	0.2
Roof rat (*Rattus rattus*) infestation	2,150	12.7	12.6–12.8	0.3
Norway rat (*Rattus norvegicus*) infestation	1,930	9.4	9.4–9.5	0.3
House mouse (*Mus musculus*) infestation	302	1.7	1.7—1.7	0.6
Unknown species infestation	603	3.9	3.8–3.9	0.6

Source: COVISA (2006)

Infestation model

Preliminary model computations showed that some important variables, such as the HDI, were highly correlated with the intercept, resulting bad estimations. Hence, models without intercept were estimated (SAS Institute 2009). Besides, some variable levels were aggregated to allow better predictive properties: commercial premises level is formed by strictly commercial plus residential and commercial premises. Two variables were also aggregated: variable waste material is formed by waste material/rubbish plus discarded objects.

Socio-economical conditions are determinant of the urban rodent infestation in Sao Paulo city, as stated in the first working hypothesis, since the effect of the HDI is very strong (Table 3). As a matter of fact, it has been the first variable to enter the model during the stepwise procedure in all cases. Moreover, it may be observed that the head of the family's income is also a determinant factor for rodent infestation. The rodent infestation was higher in the census tracts where more than 50% of the private dwellings in the census tract have the head of the family earning up to two minimum wages monthly (odd ratio = 1.6). Therefore, the rodent infestation in a given urban area (neighbourhood, or district, or census tract) is influenced by socioeconomic factors, as HDI and income, in the sense that the highest infestation rates are associated with the most adverse socioeconomic conditions.

Once the urban neighbourhood is infested, the premises infestation is expected to depend on environmental factors, i.e., the highest infestation rates are to be associated with the availability of the access, harbourage and food sources. If there are rodents around the premises, for example infesting manholes, vacant lots or the neighbour properties, the premises features will be important to determine if it will be infested or not by rodents. Commercial premises

Table 2 Levels of rodent infestation tabulated by different factors, Sao Paulo city, Brazil, 2006

Variable	Rodents			*Rattus norvegicus*			*Rattus rattus*			*Mus musculus*		
	n	%	SE	*n*	%	SE	*n*	%	SE	*n*	%	SE
Premises features												
Unused plot of land	102	42.0	0.30	53	19.2	0.18	8	4.2	0.07	0	0.0	0.00
Strictly residential premises	3,468	24.2	0.05	1,611	9.9	0.04	1,839	13.7	0.04	258	1.8	0.01
Both residential and commercial	238	30.8	0.09	117	12.5	0.06	140	17.3	0.07	22	2.9	0.02
Strictly commercial premises	305	14.3	0.05	133	5.4	0.03	149	7.1	0.03	17	0.9	0.01
Access availability												
No access source available	1,385	6.6	0.02	554	2.4	0.01	746	3.9	0.01	136	0.7	0.01
Access source available	2,761	52.8	0.17	1,376	22.5	0.11	1,404	28.1	0.14	166	2.9	0.02
Building structure	2,089	48.8	0.18	878	16.3	0.10	1,265	31.1	0.18	131	2.9	0.02
Sewage system	1,307	54.3	0.25	855	32.5	0.25	416	17.0	0.13	67	2.7	0.02
Harbourage availability												
No harbourage source available	972	5.4	0.02	514	2.5	0.01	360	2.2	0.01	74	0.4	0.00
Harbourage source available	3,174	47.2	0.12	1,416	18.4	0.08	1,790	28.1	0.11	228	3.4	0.02
Waste material	1,971	45.0	0.16	899	18.6	0.10	1,088	26.2	0.13	164	4.2	0.03
Ceiling cracks	1,583	55.3	0.11	628	18.9	0.09	1,108	39.9	0.13	99	3.8	0.04
Building material	1,164	46.4	0.10	547	19.2	0.11	620	25.7	0.13	112	5.2	0.05
Wall cracks	1,392	56.7	0.15	719	26.8	0.16	794	33.5	0.16	108	5.0	0.05
Dense bush	292	52.6	0.19	167	25.9	0.19	105	20.1	0.15	17	2.7	0.03
Food availability												
No food source available	1,547	8.3	0.02	684	3.2	0.01	747	4.2	0.01	106	0.5	0.00
Food source available	2,599	43.1	0.11	1,246	18.1	0.09	1,403	24.8	0.11	196	3.5	0.02
Accessible garbage	1,381	44.1	0.20	722	20.8	0.16	716	23.7	0.17	106	3.7	0.04
Animal food	1,292	45.1	0.08	599	18.4	0.07	767	28.2	0.08	114	4.5	0.04
Human food	1,056	43.5	0.22	514	18.8	0.16	552	23.5	0.18	99	4.3	0.03
Fruit trees	567	50.1	0.11	293	21.9	0.08	301	30.4	0.10	38	3.3	0.03

n number of premises contributing to the analysis, % the estimated percentage of premises infested (weighted according to the sample design), *SE* standard error of the estimated percentages

Source: COVISA (2006)

have relative probability 20% higher than strictly residential ones to be infested (OR = 1.2). Unused plots of land are even more suitable (OR = 2.7) to be infested.

The most important environmental factors for rodent infestation are showed to be the access by the building structure (OR = 2.7), followed by access by the sewage system (OR = 2.1). The principal harbourage factors are ceiling cracks (OR = 2.3) and wall cracks (OR = 1.5). These two factors are closely related to the access by the building structure faults, reinforcing its relevance in Sao Paulo. The presence of fruit trees (OR = 1.8) and animal food (OR = 1.6) in the premises are also determinant factors for rodent infestation. The presence of dense bush in premises is uncommon (2.9%) but even though it showed to be a determinant harbourage factor for rodent infestation (OR = 1.4).

The effects of environmental factors may be better seen when these factors are aggregated before modelling (Table 4). The relative probability of premises rodent infestation is 4.5 times higher when there are access facilities in the premises, 3.2 times higher when there are harbourage sources, and 1.6 times higher when there are food sources. In summa, it can be noted a logical sequence: firstly rodents infest the neighbourhood, then enter the premises and take shelter, at last they eat. This also confirms the second hypothesis: the availability of access, harbourage and food allow the premises infestation.

Infestation model by species

Biological peculiarities of each rodent species may lead to different reactions to each environmental factor (Tables 3, 4). Infestation by Norway rat is closely related to the access source (OR = 4.1), particularly by the sewage system (OR = 4.7), then to food source (OR = 1.6), specially accessible garbage (OR = 1.4) and fruit trees (OR = 1.7),

Table 3 Rodent infestation of urban premises, odds ratio (95% confidence interval) of logistic regression models, Sao Paulo city, Brazil, 2006

Effect	Rodents	*Rattus norvegicus*	*Rattus rattus*	*Mus musculus*
HDI	0.035 (0.034–0.035)	0.010 (0.010–0.010)	0.016 (0.016–0.016)	0.001 (0.001–0.001)
Income				
>2 minimum wages	1.000	1.000	1.000	1.000
≤2 minimum wages	1.646 (1.630–1.661)	2.364 (2.338–2.390)	1.036 (1.024–1.048)	0.469 (0.454–0.485)
Premises features				
Strictly residential	1.000	1.000	1.000	1.000
Commercial	1.198 (1.187–1.209)	1.174 (1.159–1.190)	0.969 (0.958–0.980)	1.234 (1.202–1.267)
Unused plot of land	2.676 (2.609–2.744)	2.013 (1.953–2.076)	–	–
Access by the building structure				
No	1.000	–	1.000	–
Yes	2.659 (2.638–2.680)	–	2.487 (2.464–2.510)	–
Access by the sewage system				
No	1.000	1.000	–	–
Yes	2.059 (2.041–2.077)	4.730 (4.683–4.777)	–	–
Harbourage in ceiling cracks				
No	1.000	–	1.000	–
Yes	2.303 (2.284–2.323)	–	3.842 (3.806–3.877)	–
Harbourage in wall cracks				
No	1.000	1.000	1.000	1.000
Yes	1.494 (1.480–1.507)	2.353 (2.328–2.379)	1.548 (1.533–1.564)	1.849 (1.810–1.889)
Harbourage in waste material/rubbish/discarded objects				
No	1.000	1.000	1.000	1.000
Yes	1.445 (1.434–1.457)	1.148 (1.136–1.161)	1.327 (1.314–1.339)	1.995 (1.950–2.040)
Harbourage in dense bush				
No	1.000	1.000	1.000	–
Yes	1.411 (1.385–1.437)	1.436 (1.407–1.466)	0.686 (0.671–0.700)	–
Harbourage in building material				
No	1.000	1.000	1.000	1.000
Yes	1.226 (1.214–1.237)	1.088 (1.075–1.101)	1.035 (1.024–1.045)	2.201 (2.155–2.249)
Available fruit trees				
No	1.000	1.000	1.000	–
Yes	1.792 (1.770–1.814)	1.721 (1.696–1.747)	1.588 (1.568–1.610)	–
Available animal food				
No	1.000	1.000	1.000	1.000
Yes	1.627 (1.614–1.640)	1.374 (1.359–1.388)	1.660 (1.645–1.675)	2.032 (1.991–2.073)
Available human food				
No	–	–	–	1.000
Yes	–	–	–	1.345 (1.314–1.376)
Accessible garbage				
No	–	1.000	–	1.000
Yes	–	1.415 (1.400–1.431)	–	1.122 (1.097–1.148)
Indices of rank correlation				
Sommers' *D*	0.653	0.643	0.641	0.508
Goodman–Kruskal gamma	0.655	0.648	0.645	0.532
Kendall's Tau-*a*	0.226	0.127	0.139	0.017
c	0.826	0.821	0.821	0.754

Table 4 Rodent infestation of urban premises, odds ratio (95% confidence interval) of logistic regression models, aggregated environmental factors, Sao Paulo city, Brazil, 2006

Effect	Rodents	*Rattus norvegicus*	*Rattus rattus*	*Mus musculus*
HDI	0.020 (0.020–0.020)	0.007 (0.007–0.007)	0.009 (0.009–0.009)	0.001 (0.001–0.001)
Income				
>2 minimum wages	1.000	1.000	1.000	1.000
≤2 minimum wages	1.426 (1.412–1.439)	2.417 (2.391–2.443)	0.868 (0.858–0.877)	0.475 (0.460–0.490)
Premises features				
Strictly residential	1.000	1.000	1.000	1.000
Commercial	1.271 (1.259–1.284)	1.131 (1.116–1.145)	1.062 (1.050–1.074)	1.219 (1.188–1.252)
Unused plot of land	2.182 (2.129–2.236)	2.427 (2.358–2.498)	0.236 (0.226–0.248)	0.293 (0.264–0.326)
Access source				
No	1.000	1.000	1.000	1.000
Yes	4.520 (4.485–4.556)	4.142 (4.096–4.187)	2.046 (2.027–2.065)	0.914 (0.894–0.933)
Harbourage source				
No	1.000	1.000	1.000	1.000
Yes	3.184 (3.157–3.211)	1.555 (1.537–1.573)	5.623 (5.561–5.685)	3.412 (3.323–3.512)
Food source				
No	1.000	1.000	1.000	1.000
Yes	1.558 (1.546–1.571)	1.609 (1.592–1.626)	1.513 (1.500–1.527)	2.352 (2.297–2.408)
Indices of rank correlation				
Sommers' *D*	0.667	0.623	0.616	0.506
Goodman–Kruskal gamma	0.671	0.628	0.621	0.526
Kendall's Tau-*a*	0.231	0.123	0.134	0.017
c	0.833	0.812	0.808	0.753

and then to harbourage source (OR = 1.6), mainly by the wall cracks (OR = 2.4). Contrariwise, the infestation by roof rat is strongly related to the harbourage source (OR = 5.6), particularly by the ceiling cracks (OR = 3.8), then to access source (OR = 2.0), by the building structure (OR = 2.5), and then to food source (OR = 1.5), specially animal food (OR = 1.7) and fruit trees (OR 1.6). The infestation by house mouse is negatively related to access source (OR = 0.9) but positively related to harbourage source (OR = 3.4), mainly to building material (OR = 2.2), waste material (OR = 2.0) and wall cracks (OR = 1.8), and to food source (OR = 2.5), particularly to available animal food (OR = 2.0) and human food (OR = 1.3).

All models (Tables 3, 4) fitted well, since R^2 and max-rescaled R^2 equal to 1.000 (Shtatland et al. 2000), with P value < 0.0001 for all estimates.

Discussion

In Sao Paulo, the overall infestation rate (all the species) was 23.1%, where 12.7% of the premises were infested by roof rat, followed by Norway rat (9.4%) and house mouse (1.7%), including inside, outside and non-specified infestation local. The predominance of roof rat in Sao Paulo is recent; in 1943–1944 Moojen (1952) captured 90.448 rodents, from which 53.7% were house mouse, 33.6% Norway rat and 12.8% roof rat. In 1987, a study in the Aricanduva River valley found only Norway rat infesting the dwellings (10.9% of 9.381 dwellings inspected), according to Silva et al. (1992). The recent predominance of roof rats may be attributed firstly to the changes in land use and occupation patterns occurred in the late 1980s. By that time industrial activities were substituted by commercial and services activities. Consequently, the number of small food stores increased in town. The structural and sanitary precariousness of the buildings where these stores were located is also an important factor. Second, since the early 1970s, the rodent control program in Sao Paulo focused the elimination of Norway rat due to its zoonotic importance. Consequently, as a result of the interspecific competition, this may have favoured the rise of roof rat infestation (Amarasekare 2003; Leung and Clark 2005). Third, the natural partition of ecological niches among the urban rodent species may have lessened interspecific competition. The results of this article as well as those obtained by Russel and Clout (2004) and by Masi et al. (2009) showed that roof rat has more successfully explored the remaining places and consequently increased its distribution (Schoener 1974; Amarasekare 2003). A positive correlation between the real rodent population size and the premises infestation is assumed, although there are not scientific evidences on this point yet. Nevertheless, empirical observations of the first author seems to indicate that roof rat population is indeed larger than those of Norway rat and house mouse in Sao Paulo, but deeper studies will be necessary to understand the population dynamic of these animals.

Methodological diversities can introduce serious difficulties in comparing infestation rates from different studies. A study with similar methodology to the present one is The England House Conditions Survey (EHCS), in which: (a) "the overall levels of infestation found in 2001 were 1.4% for mice inside, 0.3% for rats inside and 2.9% for rats outside" and (b) "in 1996 the levels were reported to be 1.8%, 0.4% and 1.7%, respectively" (DEFRA 2005). The corresponding data for Sao Paulo, in 2006, were 0.72% for mice inside, 2.17% for *R. norvegicus* inside and 5.60% for *R. norvegicus* outside; besides, the infestation rate were 7.17% for *R. rattus* outside and 4.14% for *R. rattus* inside. EHCS was based on properties in all regions of England, whereas the survey in Sao Paulo was based on properties in only one city. This is probably one of the major reasons why the infestation rates found in Sao Paulo for rats were so much higher than those reported by the ECHS. The former surveyed a city only, which due to the higher population density would be expected to support more commensal rodent, whereas the latter included rural and urban areas. Other reasons may be the differences in climates and urban concepts, as well as socio-economical, cultural and educational patterns. On the other hand, in EHCS, the main rodent species is the Norway rat, which infests rather external than internal areas, such as farms, parks and gardens (DEFRA 2005), but the main species in Sao Paulo is the roof rat, which prefers dwellings (Alves 1990; Masi et al. 2009).

According to our results, roof rat was probably the most commons species in Sao Paulo, like in Buenos Aires (Argentina), in Rio de Janeiro (Brazil), in Luang Prabang town (Lao), in the province of Zambezia (Mozambique), in India, in Madagascar and in New Zealand (Cavia et al. 2009; Alves 1989; Promkerd et al. 2008; Belmain et al. 2002; Parshad 2004; Duplantier et al. 2003; Russel and Clout 2004). Nevertheless, the Norway rat was the predominant species in Europe (Austria, Denmark and United Kingdom) and in USA (Leirs et al. 2004; Traweger et al. 2006; DEFRA 2005; Easterbrook et al. 2007). This difference may be due to several factors: roof rat seems to be the predominant species in developing countries, maybe due to precariousness of habitations and environmental sanitation, and the Norway rat in developed countries, where it lives mainly in natural places, such as stream banks, sewer system, vacant lots, parks, gardens, and farms (DEFRA 2005; Traweger and Slotta-Bachmayr 2005; Channon et al. 2006; Traweger et al. 2006); on the other hand, roof rat seems to be related to warm climates, while Norway rat may dominate in cities with cold climates, as pointed out by Cavia et al. (2009). Although these are attractive hypotheses, they still need supporting evidence studies, since there are some conflicting results: in Durban (South Africa), the main species is the Norway rat (Taylor et al. 2008) and, even in Sao Paulo city, different boroughs present different infestation patterns by species.

The results of infestation modelling agree with biological knowledge of urban rodents and enable us to measure the relative importance of each socioeconomic and environmental factor through the analysis of odds ratios and, therefore, lead the governmental actions to each specific situation. The fact that HDI is so important agrees with several studies emphasizing that the most precarious areas are the most susceptible to rodent infestation (Childs et al. 1998; Lambropoulos et al. 1999; Langton et al. 2001; Barttersby et al. 2002; Bradman et al. 2005; Traweger et al. 2006; DEFRA 2005; Promkerd et al. 2008; Taylor et al. 2008). The latter variable is even more important for dwellings infestation by Norway rat, almost irrelevant for roof rat, but negatively correlated for the house mouse. Therefore, the poorest areas of town are more susceptible to infestation by Norway rat and less susceptible to infestation by house mouse, while roof rat occur equally in both areas. The fact that the rodent infestation decreases as income and literacy of dwellers increase is probably associated with the access to information on the sanitary risks of the animal and how to manage the rodent problem, civilized cleanliness and tidiness habits and adequate housing maintenance. Moreover, streets and public areas in these census tracts may be better maintained by both dwellers and municipal departments (Lambropoulos et al. 1999; Traweger et al. 2006; Masi et al. 2009).

The higher odds ratios of commercial premises and vacant lots infestation in relation to the strictly residential ones confirms the results of other studies (Langton et al. 2001; Camero et al. 2004; Promkerd et al. 2008; Battersby et al. 2002; Traweger et al. 2006). The Norway rat is the only species associated with unused plots of land probably due to its peridomestic habits. House mouse showed the highest association with commercial premises, and roof rat occurs equally in commercial and residential premises. Results presented in this article suggest that the presence or absence of distinct environmental factors makes different premises features to be more or less probable of being infested by different rodent species.

A strong association of rodent infestation mainly with the existence of access sources in the dwellings (OR = 4.5) and with harbourage source suggests that neglected and older buildings seem to be more susceptible to such infestations, a similar result to that obtained in England (DEFRA 2005). Besides, the existence of harbourage sources and access sources by structural deficiencies seem to be an indirect indicator of low income dwellers. Among the three major environmental factors studied, the one with the most difficult intervention is the access source, since it depends on high financial investments from both owners and public administration. Building maintenance may be too expensive for some dwellers, increasing the risk of harbourage by ceiling and wall cracks, as the infestation model showed, especially by roof rat. An example of the positive impact of interventions on access source was presented by McGuire et al. (2006) that verified the Norway rat population infesting the barn at the University of Illinois Biological Research, in USA, declined after reinforcing the barn structure to obstruct rodent access to food sources. The high presence of dwellings with harbourage sources (37.6%) may be due the habit of maintaining waste material, rubbish, discarded objects and building material, even when they are not being used, seems to be necessary, due to the difficulty of new acquisitions or disposal of such wastes. The enhancement of the actual municipal services of waste and rubbish collection, giving priority to the most infected areas, should play an important role on a rodent control program.

Due to peridomestic habits of Norway rat, infestation by this species is more strongly associated with unused plots of land and with the access source, especially by the sewage system, as well as to harbourage in wall cracks and in dense bush as pointed out by Langton et al. 2001; Traweger et al. 2006; Promkerd et al. 2008 and Taylor et al. 2008. Similar results were found by Bajomi and Sasvari (1986) who showed that in Budapest an important micro-habitat explored by Norway rat is the sewerage system, because it provides runways and food to the animals. On other hand, strong association between the roof rat infestation and the harbourage source, mainly in ceiling cracks, and access by the building structure imperfections, accords with its intradomestic and scansorial habits. The house mouse infestation present strong association to food and harbourage sources, particularly to building material, waste material, wall cracks, animal food and human food, according to intradomestic habits of this rodent (Meehan 1984). Similar result is presented by Murphy and Marshall (2003) in a study on the house mouse infestation in Manchester, UK, suggests that infestation is "more likely to occur where there is poor structural maintenance, poor hygiene and ample internal harbourage".

The Norway rat and roof rat association with fruit trees makes evident the natural partition of the resources between these two rodent species in Sao Paulo. Animal food is an important risk factor of infestation by the three rodent species studied and is accessible in 17% of the city premises, showing to be an important factor for intervention by dwellers. However, in according to Paranhos (2002), 98.7% of dogs and 92.5% of cats in Sao Paulo eat in their own dwelling, with average of 1.9 and 2.4 meals per day, respectively. A matter of great concern, however, is that 12.4% of dogs and 30.1% of cats receive food at ease from their owners. This show that people are not well aware that correct pet feeding is important and that any animal food leftover or excess has to be avoided. The exposure of pet food for long periods has been reported to be related to rodent infestation (Bevillacqua et al. 2004). The presence of pets was also shown to be important for rodent infestation in England (Langton et al. 2001).

Food sources occurred in one-third of the premises in Sao Paulo city and the main one is garbage, accessible in 18% of the premises. Moreover, this variable is strongly associated with Norway rat and house mouse infestations, as well as waste material/rubbish/discarded objects, the most frequent harbourage source in the city (24%), associated with roof rat. Besides, annually, 9.7 million tons of garbage is produced in this city (Pedroso 2003), an average of 930 kg per inhabitant, and other million tons of waste material are discarded in many public areas. Hence, public policies aiming at solid residues reduction should be an indirect action in controlling rodents.

The results obtained in this article add some knowledge on the biology and behaviour of commensal rats, especially roof rat, the least studied of the three species in urban areas. Summarizing, the factors that favour the presence of Norway or roof rats may exclude the presence of mice. Analogously, the factors that favour the presence of Norway rat make difficult the presence of roof rat. Therefore, access by the building structure favours only roof rat, but access by the sewage system favours only Norway rat. Harbourage in ceiling cracks are determinant for roof rat, harbourage in wall cracks and in dense bush are determinant for Norway rat, and harbourage in waste material or in building material is determinant for house mouse infestations. Available animal food favour all the three species, fruit trees favour Norway and roof rats, human food and garbage are important only for house mouse, showing the existence of a natural partition of the environmental resources among the species.

Conclusions

In Sao Paulo city, 23.1% of the premises were infested by rodents. Moreover, in Sao Paulo:

- Socio-economical conditions, represented by the HDI and an income variable, are determinant of rodent infestation in a given urban area (neighbourhood, or district, or census tract), as stated in the first working hypothesis. The first hypothesis is indirectly confirmed by the behaviour of these two factors, since the infestation by rodents depend on the neighbourhood socioeconomic conditions;

- Once the urban neighbourhood is infested, the premises infestation depends on environmental factors, mainly the availability of access, harbourage and food sources, as stated in the second working hypothesis;
- The main environmental factors leading premises rodent infestation are premises features, access by sewage system or by building structure, harbourage by ceiling cracks, wall cracks, waste material, building material, bushes, and food sources, as animal food and fruit trees;
- The three species studied, namely *R. norvegicus*, *R. rattus*, and *M. musculus*, are differently affected by the environmental factors. The first species is strongly affected by the access source, then food source and harbourage source; the second one is strongly associated with the harbourage source, then access source and food source; the third one is associated with harbourage and then to food source, but not to access source;

Interventions on socio-economical conditions are very difficult to accomplish and they depend almost exclusively on public policies, so the results of such actions will be obtained in a long term. On the other hand, the availability of access, harbourage and food sources for rodents and the influence of these factors on the urban rodent infestation show the necessity and the urgency of a behavioural change of human population, respecting to ecological and sanitary aspects of premises in order to make them less susceptible to that infestation. The feasibility of environmental management of rodents, known as integrated pest management (IPM), is suggested by the article results, including human behaviour changes and public policies, complemented by chemical control by rodenticides in the most infested areas or in those with high diseases risk.

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