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Original Article

Ecoepidemiological approach in an urban community: environmental factors associated with injuries in humans caused by bats

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Abstract
Introduction: The intense urbanization process has resulted in the reduction of forested areas, which poses an additional risk to public health. The aim of this study was to identify environmental variables in an urban community associated with the chances of injuries (bites/scratches) in humans caused by bats.
Methodology: The study community was the Historic Center District of Salvador, Bahia, Brazil. The cases were the official records of households that reported injuries in humans caused by bats along the historical series from 2012 to 2015. Controls were selected from households near the cases without records of injuries involving bats. Univariate analysis was performed for the data using the chi-square and Fisher's exact test. Significant variables ($p < 0.05$) were included in the logistic regression models.
Results: The variable for bats having access to households via defective/broken windows showed an association with the cases in the final model (OR = 45.14, CI = 6.08-335.10). The variables presence of domiciled dogs (OR = 6.04, CI = 1.44-25.92) and exposed fruit (OR = 4.41, CI 95% = 1.15-16.9) were significant factors.
Conclusion: The results shows that access to the residence and supply of food that can be used by bats are factors that increase the chances of injuries in humans caused by these animals possibly increasing the risk of infectious diseases.

Key words: synanthropic bats; eco-epidemiology; infectious diseases prevention.

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Introduction
Bats are related among the main agents that maintain and transmit zoonosis and figure like being recognized as reservoir hosts for viruses which can cross species barriers (*i.e*. spillover) to infect humans and other domestic and wild mammals [1]. The urbanization process intensified in the last decades in the developing countries has an influence on the composition and structure of bat communities because of changes in the natural environment [2–5]. This process leads native species to present synanthropic habits, such as exploring the sources of food and shelter in the urban environment [6–8]. In Brazil, there are known nine families, 68 genera and 178 species of bats, with diverse eating and behavioral habits including the only three hematophagous species in the world and unique in Latin America: *Desmodus rotundus, Diaemus youngi* and *Diphylla ecaudata* [9].

The proximity of bats to humans and domesticated animals can increase the chances of occurrence of injuries and infectious diseases [10–13]. Bats, regardless of their eating habits, may harbor and transmit the virus of rabies directly or indirectly to humans or animals. Of the species of Chiroptera that occur in Brazil, it has found the rabies virus in 41 of them, including hematophagous, frugivorous, insectivorous, nectarivorous and carnivorous [14]. However, with non-hematophagous bats, this transmission occurs accidentally [15]. It's important to cite that the bats are one of the most important reservoirs and vectors of the rabies virus in the world, according to studies of antigenic and genetic characterization. Additionally, the predominant source of infection in humans shifted from terrestrial animals (*e.g.*: dogs and cats) to bats [14]. Synanthropic bats may present population growth because of the process of expansion of urban areas [6]. This may be favored since the conversion of surrounding natural environments to urban areas contributes to the decline of populations of top predator species, which facilitates the proliferation of synanthropic bats, as they can adapt to these adverse conditions [16]. Bat species that adapt to urban environments use artificial shelter structures such as bridges and hidden places in residences, street vegetation, and backyards. Older urban areas are especially sought by bats for establishing their colonies, because of the building, yards and, most times, dilapidated structures [2]. In Brazil, although the decreasing incidence of human rabies shows the effectiveness of control actions, is important to raise public awareness of the potential risk of rabies associated with bats exposures in urban areas. It's identified gaps in relation to basic knowledge, perception, appropriate practices and the importance of bats for public health [17].

In South America, studies on the occurrence of bats in an urban environment are generally devoted to the survey of species of bats [18–21]. However, data on associations between urban/residential environmental factors related to Chiroptera, and the increased chance of an accident, defined as an injury caused by biting or scratching, involving these species are scarce in the scientific literature.

The aim of the present case-control study was to identify environmental variables associated with the increased chance of occurrence of injuries in humans caused by bats in a community that presented the higher incidence of bats injuries along the historical series evaluated.

Methodology

Study type and community definition

During the months of April to July of 2016, a retrospective observational study of the case-control type was carried out in the sanitary district of Historic Center District from Salvador (HCDS). It used the unit of sanitary district because the actions carried out by the Municipal Health Secretary of Salvador use this geographical subdivision of the county, which is composed of 12 sanitary districts (SD). The HCDS has a population of 77,721 inhabitants [22] and is composed of the following neighborhoods: Barris, Centro Histórico, Tororó, Nazaré, Saúde, Barbalho, Macaúbas, Comércio, Santo Antônio Além do Carmo and a portion of the Liberdade.

The HCDS presents a low human population density because of its history of occupation, with a predominance of houses and low buildings, some of which were later modified for use by the public administration and commercial activities. At present, several properties remain closed or in ruins. In the last forty years, the socioeconomic profile of the inhabitants of the HCDS has changed. Currently, in general, the residents present low income, and the area shows substantial dilapidation in the structure of buildings, houses, and a devaluation and loss of quality in the urban infrastructure and cultural equipment [23].

HCDS was chosen as the study community because of the high number of injuries involving bats registered in the national notifiable diseases information system (SINAN) along the historical series from 2012 to 2015. The records in SINAN of the occurrences of bat injuries (bites/scratches) have the compulsory notification because of the actions for rabies prevention and control.

Definition of cases and controls

The cases (n = 31) obtained in SINAN, referring to the period from 2012 to 2015, were defined as the residences with records of injuries caused in humans by bats. These records do not include the identification or description of the species of bats involved in the injuries. The controls selected were households with no record of injuries that were located near (minimum of 50 meters of distance) of the cases. For each case, we selected six controls (n = 178) considering the level of significance (α) of 0.05 calculated in the Epi-Info Program (Centers for Disease Control and Prevention, Atlanta, GA, USA). The number of households for the calculation of the sample size to environmental evaluation was defined by a ratio between the number of inhabitants of the Historic Center of Salvador (77.721 individuals), available in the Superintendence of Economic and Social Studies of Bahia [23] by the mean number of residents per household (3.8 individuals) identified by the Census survey carried out by Brazilian Institute of Geography and Statistics [22].

In this study, the environmental evaluation was carried out only in residences that had no structural modifications along the historical series in the houses and/or peridomiciles communicated by the owner. Structural modifications in this locality are rare because it is a region with historical and artistic value and these changes are not allowed by the National Historical and Artistic Heritage Institute, responsible for the preservation and dissemination of the material and immaterial heritage of the country.

Observation of environmental variables

The same researcher always filled the environmental assessment form of case and control. The form included the following categories: 1)

Demographic characteristics; 2) Definition of the residence; 3) Shelter for bats; 4) access of bats to households; 5) Domiciled animals; 6) Food sources; 7) Water source. The forms also had additional fields for recording information about any non-predefined variables in the study. The variables evaluated were based on the integrated control of synanthropic animals and vectors that considers the importance of the presence of water, food, shelter, and access to the home to intensify the proximity and contact with these animals [24].

Georeferencing and geospatial analysis

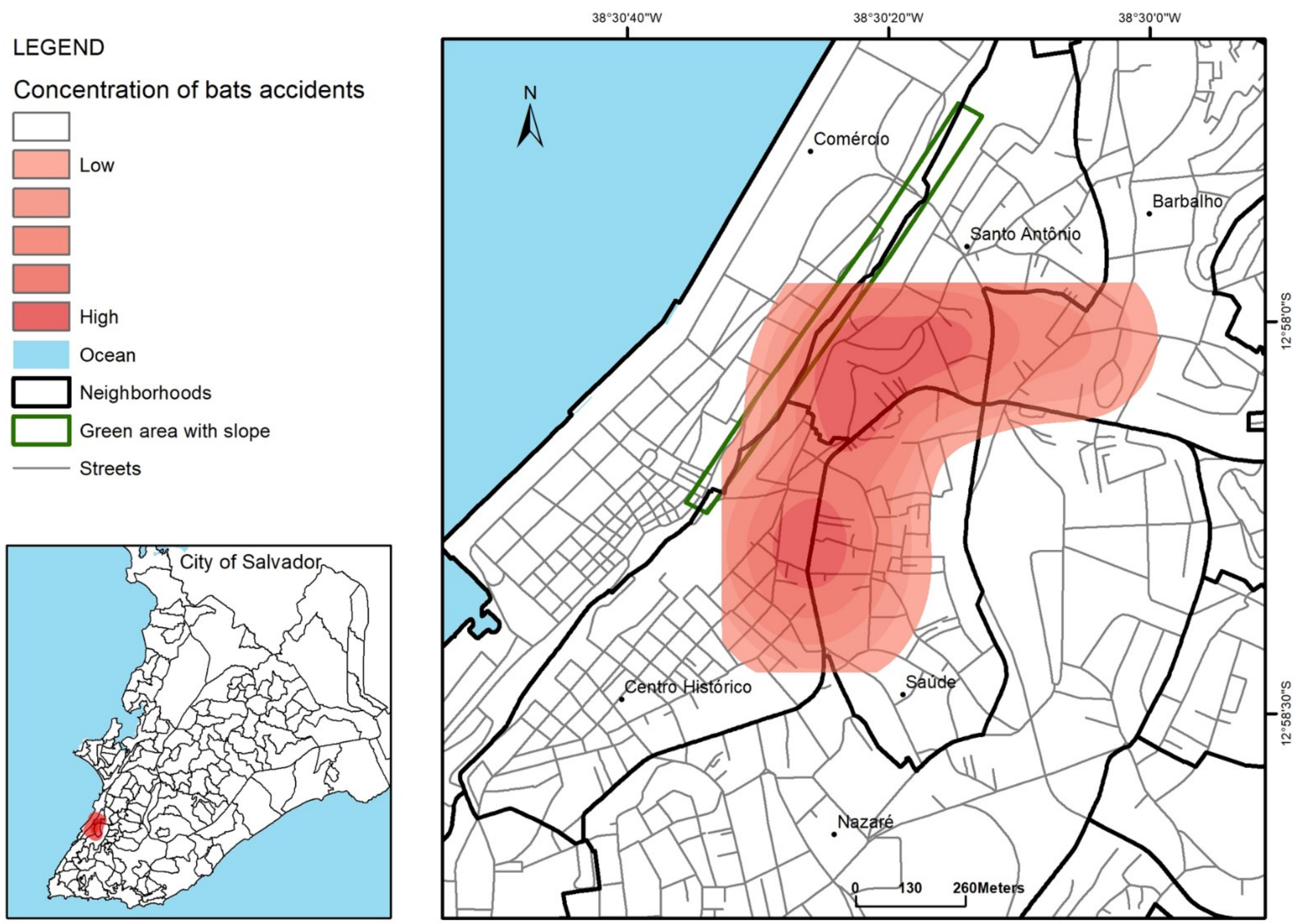
For the applications of the techniques of georeferencing and geospatial analysis, the ArcView v.9.2 was used. Household cases and controls were georeferenced using GPS Garmin, with the coordinates in UTM (Universal Transversa Mercator), using the coordinate system South American Datum 69 (SAD69) to obtain thematic maps of the area. The georeferenced locations of the household cases were used for collecting the estimation statistics of the density curves (Kernel) for the identification of possible spatial associations between the cases. The Kernel estimator analysis produces continuous surface maps from the point information of a geographic event. The continuous surfaces created by the kernel density analysis improve the visualization of the zones of spatial agglomeration (hotspots) of the events.

Statistical analysis

The completed environmental forms were double-typed in the Epi Info program [25]. In addition, the databases were compared (data compare) to identify inconsistencies between the information presented in the databases and in the physical documents (form).

We used the chi-square test and Fisher's exact test to perform the univariate analysis to compare the categorical data, to identify the association between environmental variables and the definition of households (cases or controls). A p value of < 0.05 was significant. The variables that presented a significant

Figure 1. Kernel density estimates of the distribution of injuries involving bats between the years 2012–2015 in the Sanitary District of Historic Center in Salvador, Brazil.



difference (p ≤ 0.05) were included in blocks for a multivariate logistic regression using the backward strategy to identify the variables associated with an increased chance of injuries caused by bats. The first model included variables related to shelters for bats in the urban environment. The second model included variables related to the access of bats to households. The third model included variables associated with food sources for bats. The fourth model included variables related to domiciled animals. The fifth model included variables associated with a water source. The sixth model included variables associated with indicators of bats that remained significant. The final model was composed of variables that remained significant in their respective models.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The protocol was approved by the Research Ethics Committee of the Federal University of Bahia, Salvador, Brazil

Informed consent

All participants were verbally informed of the study's purpose and assured that their responses would be kept anonymous. Oral consent was obtained to ensure anonymity and accommodate illiterate participants.

Results

Of the 31 cases domiciles, twenty-seven households (87%) presented only one report of an accident caused by contact with a bat, three households (10%) had two reports, and one household had five reports. Of the residences evaluated, 29 (93%) of the cases and 114 (64%) of the controls were residential. Kernel analysis identified spatial associations resulting from the higher agglomeration of the number of accident cases. The area inside the community with the highest intensity of injuries was "Rua Direita do Santo Antônio Além do Carmo" followed by "Centro Histórico" (Figure 1).

Data from the univariate analysis revealed associations with variables belonging to the categories of potential bat shelters, types of access to the residence, domiciled animals, food sources and water sources (Table 1).

Table 1. Environmental factors associated with injuries caused by bats in humans between the years 2012–2015 in the Historic Center district of Salvador, Brazil.

Variables	**Case*** **(n = 31)**	**Controls**** **(n = 178)** *No. (%)*	**p**
Definition of the residence			
Residential use only	29 (93)	114 (64)	-
Commercial/residential use	1 (3)	65 (36)	-
Potential shelters for bats			
Attic	12 (38)	26 (14)	0.001
Basement	4 (12)	8 (4)	0.080
Linings	7 (22)	16 (9)	0.056
Hollow trees	1 (3)	2 (1)	0.220
Potential access for bats to the residence			
Openings in the ceiling.	18 (58)	21 (11)	< 0.001
Holes in the wall	13 (41)	6 (3)	< 0.001
Ventilation area	18 (58)	59 (33)	0.005
Defective/broken windows	14 (45)	2 (1)	< 0.001
Open Windows during the night	9 (29)	15 (8)	0.001
Domiciled animals			
Dog	21 (67)	39 (21)	< 0.001
Cat	12 (38)	20 (11)	< 0.001
Bird	10 (32)	14 (7)	< 0.001
Food sources			
Fruit plants	19 (61)	30 (16)	< 0.001
Exposed fruit	8 (25)	14 (7)	< 0.001
Water sources			
Water for animals	21 (67)	55 (30)	< 0.001

* Households that reported bat accidents; ** Households without records of accidents caused by bats.

Of the variables that presented a statistically significant value ($p \leq 0.05$) and were included in the multivariate logistic regression models performed by category (Table 2), only the presence of an attic in the residence was significant ($p = 0.001$) in the category of potential shelters for bats. In the second model, the category of potential access of bats to the residence, the variables openings in the ceiling and defective/broken windows remained significant. In the fourth model, the domiciled animals' category, the variables presence of dogs and presence of cats remained significant.

The last model was composed of the eight variables that remained significant in the logistic regressions by category: attic, ceiling openings, defective/broken windows, fruit plants, exposed fruit, dog and water for animals. Of these, the defective/broken windows variable had the strongest association with cases (OR = 45.14, 95% CI = 6.08-335.10), followed by the variables exposed fruit (OR = 4, 41, 95% CI = 1.15-16.9) and presence of domiciled dog (OR = 6.04, CI = 1.44-25.92).

Discussion

The significant association observed with the access variable broken/defective window demonstrates the vulnerability of households regarding the access of bats to their interiors. In addition, exposed fruit trees and domiciled dogs, also significant in the final model, are related to the availability of food, which, attracts bats of different species (hematophagous or frugivorous) to the proximity of the households, resulting in an increase in the chances of injuries in humans and domiciled animals caused by bats.

The spatial distribution of bat injuries suggests a greater concentration in the region of the Historic Center of Salvador, especially in the "Rua Direita de Santo Antônio" street. Parallel to this street, there is a strip of shrub vegetation permeated by some fruit trees, especially banana trees. It is possible that the proximity of this green area to the households in "Santo Antônio Além do Carmo" neighborhood may have contributed to the greater concentration of occurrences of cases, considering that these areas are important for maintaining the connectivity of the habitat and are used

Table 2. Logistic regression analysis of environmental variables associated with the chance of injuries caused by bats in humans between the years 2012–2015 in the Historic Center district of the city of Salvador, Brazil.

Variables	OR (CI 95%)‡	
	Univariate§	**Logistic regression¶**
Model 1: Potential shelters for bats		
Attic	3.69 (1.60–8.50)	-
Model 2: Potential access for bats to residence		
Openings in the ceiling	10.35 (4.44–24.13)	4.31 (1.34–13.82)
Holes in the wall	20.70 (7.01–61.11)	-
Ventilation area	2.97 (1.28–6.08)	-
Defective/broken windows	72.47 (15.18–345.91)	33.87(4.89–234.57)
Open windows during the night	4.44 (1.73–11.36)	-
Model 3: Food sources		
Fruit tree	7.81 (3.43–17.77)	4.22 (1.24–12.55)
Exposed fruit	4.07 (1.54–10.77)	7.92 (3.39–18.50)
Model 4: Domiciled animals		
Dog	7.48 (3.25–17.20)	5.75 (2.40–13.79)
Cat	4.95 (2.09–11.71)	2.97 (1.11–7.88)
Bird	5.57 (2.20–14.13)	-
Model 5: Water source		
Water for animals	4.69 (2.07–10.63)	-
Model 6: Significant variables from each model		
Attic	3.69 (1.60–8.50)	-
Openings in the ceiling	10.35 (4.44–24.13)	-
Defective/broken windows	72.47 (15.18–345.91)	45.14 (6.08–335.1)
Fruit tree	7.81 (3.43–17.77)	
Exposed fruit	4.07 (1.54–10.77)	4.41 (1.15–16.9)
Dog	7.48 (3.25–17.20)	6.04 (1.44–25.92)
Cat	4.95 (2.09–11.71)	-
Water for animals	4.69 (2.07–10.63)	-

‡Odds ratio (OR) and confidence interval of 95% (CI).

by bats for food because of the existence of fruit trees and natural shelter. Similar results were associated with the presence of forested areas, with the highest frequency of bats present in urban areas [4,5,18,26,27]. Despite the association found in the present study, we encourage the maintenance of these natural areas because we believe that its reduction would intensify the use of the residences by these animals, which can intensify the chances of injuries. At last we point out that more research needs to be done to identify the role of the proximity to trees (or other hypothetical reasons) with the greater concentration of injuries caused by bats showed by the spatial analysis.

In the final model, defective/broken windows were the variable with the greatest increase in the chance of an accident in humans caused by bats. The importance of this variable illustrates the ease with which bats find entry into residences in search of food, which eventually results in injuries to humans. In addition, defective/broken windows are possibly associated with the lower income of the residents and consequent low investment in property maintenance. The presence of this structural failure is aggravated because most of the houses are old. This result is in agreement with studies that determined that structural characteristics in older areas seem to favor the occurrence of bats in view of the diversity of sites for their colonies [2,28]. Previous studies have emphasized the importance of windows as entrances to residences used by bats. The presence of domiciled dogs was shown to be associated with the attraction of species, for instance, hematophagous bats, increasing the chances of contact and injuries caused by them [29] despite reports of predation of bats by dogs in urban areas [12,26]. This association suggests an epidemiological risk for the maintenance and reintroduction of the rabies virus in urban areas, which represents a serious public health problem. In addition, the attraction of bats intensified by dogs associated with the injuries evaluated corroborates the current epidemiological profile of urban rabies transmission in Brazil, which registers growing participation of species of bats in the virus' transmission [30,31].

The variable exposed fruit contributes to an increased chance of injuries inside households via the involvement of frugivorous and generalist species. It is possible that insectivorous species are also attracted by insects in mature fruits [32]. The importance of this variable is reinforced by the existence of ways that enable access of bats to the residence, demonstrated by the variable defective/broken windows. Additionally, it is interesting to highlight the high number of insectivorous bats in urban areas (density of colonies and versatility in the exploitation of human constructions) and their high prevalence of positive diagnoses for rabies [15,33,34]. It is important to cite that we control temporal bias by performing environmental evaluations only in households without structural modifications along the historical series.

Conclusion

The results suggest complementarity between variables that contribute to the attraction of bats (exposed fruit and domiciled dogs) and the existence of ways for bats to gain access to the residence (defective/broken windows), resulting in an increased chance of injuries caused by bats. The concentration of the cases in the "Santo Antônio Além do Carmo" neighborhood suggests that proximity to areas with dense vegetation may contribute to an increased chance of injuries caused by bats, requiring greater attention to the epidemiological surveillance of areas with this configuration. The search for solutions to these factors in urban communities through health campaigns can reduce the chances of injuries in domiciled animals or humans caused by bats. Finally, the identified factors must be the target of changes to contribute to the reduction of infectious diseases associated with bats and the improvement of urban rabies prevention programs.

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Authors' contributions

NJS, AJBC and CRF contributed to the initial design of the manuscript, the acquisition of the data and was responsible for revising the manuscript critically for important intellectual content. NJS, IOC, ESP and CRF performed or/and supported the environmental evaluations and data management: NJS, RLB and CRF was responsible for analyzing data. NJS and CRF wrote the paper.

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