

Spatial and Temporal Distribution of Rodents During Active and Quiescent Periods in the Plague Focus in Exu, Northeastern Brazil

Diego Leandro Reis da Silva Fernandes^{1¶}, Matheus Filgueira Bezerra^{1¶}, Bruna Mendes Duarte¹, Mayara Paes de França Silva¹, Hadassa de Almeida Souza¹, Elaine Christine de Souza Gomes^{2&} and Alzira Maria Paiva de Almeida^{1&*}

[¶] These authors contributed equally to this work.

[&] These authors also contributed equally to this work.

¹Department of Microbiology, Institute Aggeu Magalhães – Fiocruz PE, Recife, Pernambuco, Brazil.

²Department of Parasitology, Institute Aggeu Magalhães – Fiocruz PE, Recife, Pernambuco, Brazil.

*Correspondence: alzira.almeida@fiocruz.br, Tel 55 81 33612925 or 55 81 999798381

Abstract: The plague caused by the *Yersinia pestis* bacterium is primarily a flea-transmitted zoonosis of rodents that can also be conveyed to humans and other mammals. In this work, we analyzed the spatial and temporal distribution of rodents' populations during active and quiescent periods of the plague in the municipality of Exu, northeastern Brazil. The geospatial analyses had shown that all rodent species occurred through the whole territory of the municipality with different hotspots for the risk of occurrence of the different species. Important fluctuation in the rodent populations was observed with a reduction in the wild rodent fauna following the end of a plague epidemic period, mostly represented by *Necromys lasiurus* and increase of the commensally species *Rattus rattus*. A higher abundance of rats might lead to an increased exposure of humans populations, favoring spillovers of plague and other rodent-borne diseases. Our analysis contributed to further highlight the role of the wild rodent species as the amplifier hosts and of the commensally rats (*Rattus rattus*) as the preserver hosts on the quiescent period on that transmission infection area.

Keywords: Rodentia, Plague, *Yersinia pestis*, Zoonoses, Diseases reservoirs

1. Introduction

The plague caused by the *Yersinia pestis* bacterium is primarily a flea-transmitted zoonosis of rodents their main hosts, that can also be conveyed to humans and other mammals [1]. The rodents constitute the most diverse order (Rodentia) of mammals, with almost 2,600 species, representing 40% of the living mammal species [2]. Out of these, 279 species have already been found naturally infected by *Y. pestis* [3].

The plague caused three worldwide pandemics in the Christian era, claiming numerous lives, with major impact in the course of our history, scientific development and culture [4-5]. The infection reaches Brazil by sea route in 1899, during the third pandemic, through the port of Santos, São Paulo state. The infection afflicted initially the brown rat-population of *Rattus norvegicus* of seaports and in the rural zone of the Northeast, the commensally species (*Rattus rattus*). Finally, it encountered the susceptible autochthonous wild or sylvatic fauna and established several natural foci where the ecological conditions were suitable for its persistence [6-7]. These foci persist until nowadays spreading throughout several mountain ranges and plateaus across the states of Ceará, Piauí, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Bahia, Minas Gerais and Rio de Janeiro [8-9].

By analyzing the records of human plague in the Brazilian plague foci, the municipality of Exu located in the Pernambuco State, Northern Brazil, was considered the epicenter of the focal area of the Chapada do Araripe focus [10]. Based on the concepts of a natural-permanent focus and the telluric conservation of the plague bacillus inside the rodent's burrows, Baltazard [10] hypothesized that the plague activity would persist for longer there and gradually turn quiescent until reappearing in the same regions. Indeed, the Kernel density analysis (KDE) of the number of cases reported in Pernambuco revealed that the municipality of Exu is at higher risk for the occurrence of plague. Exu appeared at the epicenter of the Kernel patch that radiates in decreasing intensity as it moves away from the plateau slope towards the plains and neighboring municipalities [11].

The studies on the Rodentia and Siphonaptera faunas have become an important part of the plague control program activities and several field and laboratory studies have been

carried out to understand the possible role of the different rodent and flea species in the maintenance, epizootization, and epidemization of plague in the Brazilian focal areas. It is worth noting that an important part of this work was the continuous trapping of rodents to detect plague activity among wild species, especially *Necromys lasiurus* [10, 12-17].

Here, we analyzed the spatial and temporal distribution of rodents' populations in the municipality of Exu, northeastern Brazil from 1966 to 2005, during active and quiescent periods of human plague in the region.

2. Materials and Methods

2.1. Study area

The study was performed in the municipality of Exu (Figure 1C), State of Pernambuco (Figure 1B), Northeast Brazil (Figure 1A). This municipality lies in the mesoregion *Sertão*, has an area of 1,336,788 km², an estimated population in 2019 of 31,825 inhabitants, Municipal Human Development Index (2010) of 0.576 and a warm and dry climate with scarcity and irregular rainfall (Biome *Caatinga*). Situated in the ecological complex of Chapada do Araripe, 600-700 m in altitude, about 200 km long and 30 km wide, is limited to the municipalities of Bodocó to the west, Granito to the south, Moreilândia to the east and to the north with Crato in the state of Ceará.

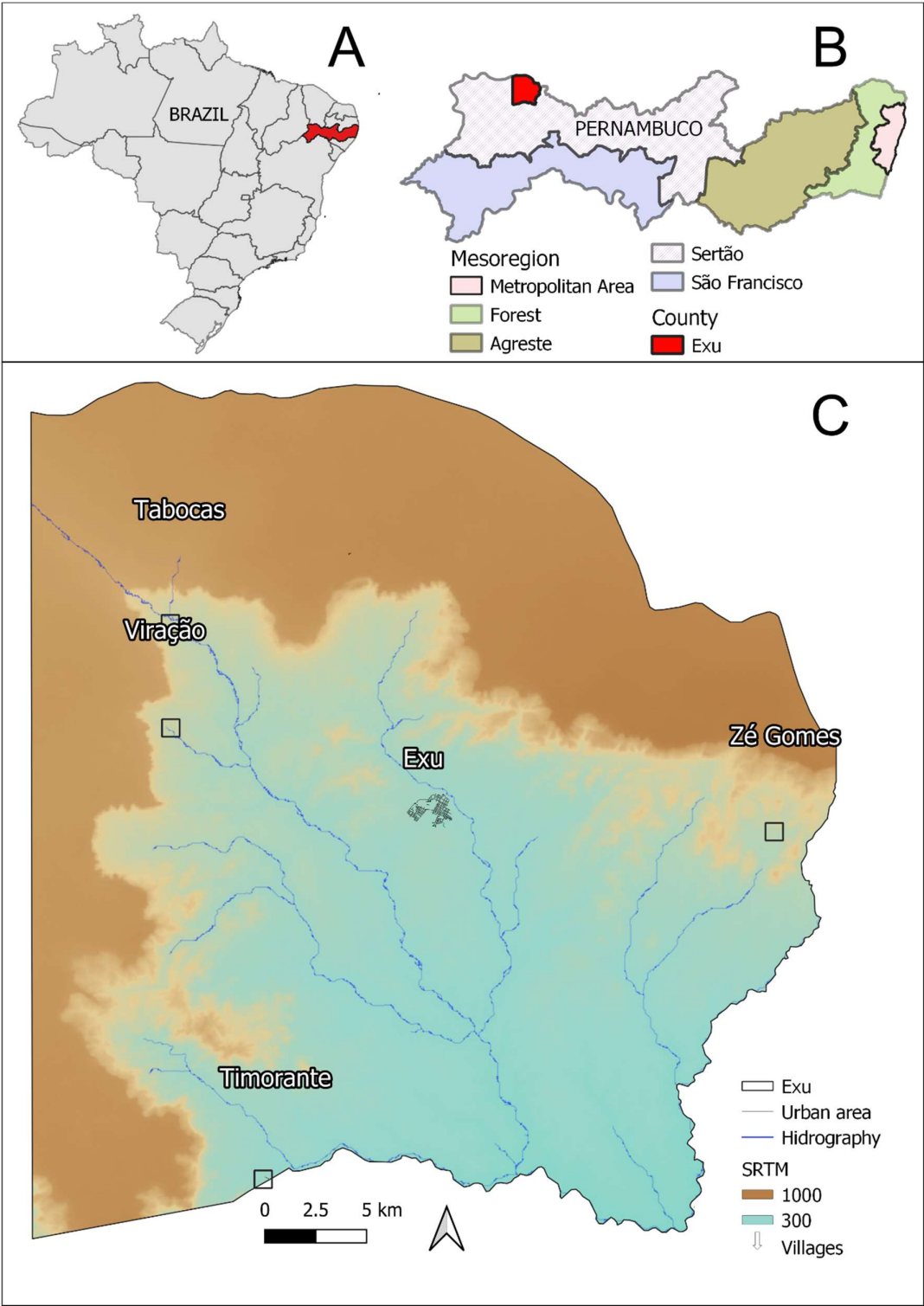


Figure 1. Identification of the study area: Exu, Pernambuco - Brazil.

(A) Map of Brazil showing the state of Pernambuco highlighted in red; (B) Map of Pernambuco showing the mesoregions and the municipality of Exu highlighted in red; (C) Map of the municipality of Exu with hydrography and altitude (m), the urban area of

Exu city (in the center) surrounded by other smaller rural settings the villages: Tabocas, Viração, Timorante and Zé Gomes. Shapefile of Exu was obtained from IBGE; DEM from SRTM (<http://www.dsr.inpe.br/topodata/>); and Hydrography from CPRM. Images were used for illustrative purposes only.

2.2. Data collection

Data on rodent collection was obtained by consulting the original documents available at the Nacional Reference Service of Plague (*Serviço de Referencia Nacional de Peste: SRP*) from the Institute Aggeu Magalhães (IAM), FIOCRUZ PE located at Recife, PE, Brazil. Animal capture and handling methods were performed as previously described [18-23].

In the period between 1966 and 1995, only the data about of the number of animals collected per year in the municipality was available, without specifying the locality. From 1996 onwards, the locality of the collections became available. The localities were georeferenced *in loco*, with a GPS (Global Positioning System) receptor, model eTrex Vista Cx, Garmin (KansasCity, USA), configured in the DatumWGS-84.A landmark (house, church or gate) was standardized for georeferencing each of the localities.

For geospatial analyses, the vector data obtained were municipal limits of Exu (2010) from the Brazilian Institute of Geography and Statistics (IBGE) (<https://www.ibge.gov.br/geociencias/organizacao-do-territorio/15774-malhas.html?=&t=downloads>). The drainage (hydrography) was from the Mineral Resources Research Company (CPRM) (<https://www.cprm.gov.br/en/Hydrology-83>) - Instituto Nacional de Pesquisas Espaciais (INPE). The Digital Elevation Model (DEM) data was obtained from the Shuttle Radar Topography Mission (SRTM) using the script (<https://code.earthengine.google.com/ccf3b9ff46eb845e1b88f68550e9a22a>) on the Google Earth Engine (GEE) platform. All geospatial data were obtained from free access and use platforms.

2.3 Data analysis

The rodent species, the locality and the year of collection were compiled and organized into a database (DB) using Excel software. While the analysis demonstrating the fluctuation of the rodent species from 1966-2005 comprised all samples in DB (Figure

2, n=66,700), only the subset with data available on the location of the captures were included in spatial analysis (Figures 3-4, n=3,724).

The GPS data was transferred to GPS TrackMaker Pro 4.9.603 (Geo Studio Technology, Belo Horizonte, Brazil) and the geographic coordinates were organized and stored in Comma-separated values (CSV) and the shapefile format, that was used to create a spatial database (SDB).

The spatial analyzes performed were: (1) map of spatial distribution and abundance of the rodents to spatially visualize the localities and the number of animals collected in each locality (*sitio*, farm, village) of the municipality of Exu (choropleth maps); (2) Kernel density estimation (KDE) to identify the localization of clusters of animal occurrences. For KDE, the following parameters were used: quadratic function, density calculation, adaptive radius and natural breaks classification. The choroplethic maps of the localization and density of the rodents collected were produced by the software Qgis Desktop 3.16.5 (<https://www.qgis.org>). Kernel maps built with ArcGIS 10 (<http://www.arcgis.com>).

3. Results

3.1. Fluctuation in the abundance of rodent species from 1966 to 2005

Through a long-term monitoring (1966-2005) of the plague activities in the municipality of Exu (Figure 1A-C), 66,700 rodents of eight species were captured: *Necromys lasiurus* (=39,797), *Rattus rattus* (=13,132), *Galea spixii* (=4,581), *Thrichomys laurentius* (=3,195), *Calomys expulsus* (=2,696), *Cerradomys langguthi* (=2,481), *Oligoryzomys nigripes* (=680) and *Wiedomys pyrrhorhinos* (=138). Figure 2 shows the fluctuation in the abundance of rodent species in percentage (2A) and absolute values (2B) per year, over the 40 years' period of from 1966 to 2005.

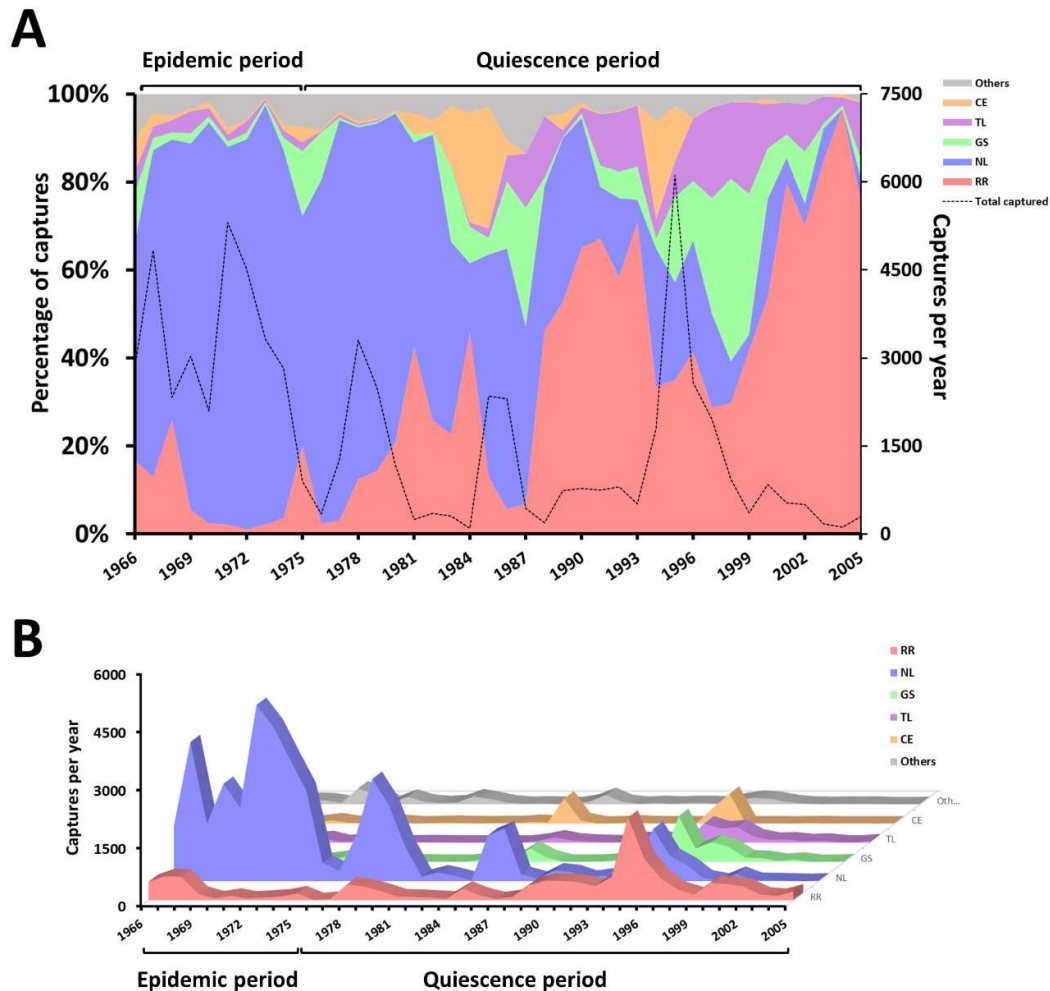


Figure 2. Abundance of rodents captured in Exu, Pernambuco – Brazil, 1966 to 2005. (A) The left axis displays the fluctuations in the proportion of captured rodent species in percentage while the right axis shows the total number of captured animals per year. (B) the absolute number of captured animals per year according to the species.

The species *N. lasiurus* and *R. rattus* were the most abundant throughout the study period (1966 to 2005). Until 1987 the rodent *N. lasiurus* was the predominant species (\cong 40 to 97% of the catches) but from 1988 onwards the rat (*R. rattus*) became predominant (\cong 28 to 96% of the catches) while the number of *N. lasiurus* decreased to 0- 37% of the catches. The species *W. pyrrhorhinos* and *C. expulsus* occurred constantly in basal numbers and from 1990 onwards, no *O. nigripes* was captured (Figure 2A-B).

Due mostly to the reduction in the *N. lasiurus* population, there is a substantial decline in the overall number of captured animals between 1966 and 1981. However, population spikes were observed during the intercalated periods of 1985-1986 and 1994-1997. Of note, with the exception of *W. pyrrhorhinos* and *O. nigripes*, there was an increasing in the total number of most species captured from 1994 to 1997 (Figure 2A-B; Supplementary Table 1).

3.2. Spatial distribution of the rodents' populations in the period analyzed (1996-2005)

Regarding the geographical distribution in the period analyzed (analysis limited to 1996-2005), all species occurred in the same *sitios* or farms scattered through the whole territory of the municipality (Figure 3A and 4A). Figures 3 (B - F) and 4 (B - F) show the spatial distribution and hotspots of the frequency of the species *R. rattus*, *N. lasiurus*, *G. spixii*, *T. laurentius* and *C. langguthi* from 1996 to 2005. Due to the small quantity in this period, the species *C. expulsus* (=15), *W. pyrrhorhinos* (=23) and *O. nigripes* (=0) were not included in the maps.

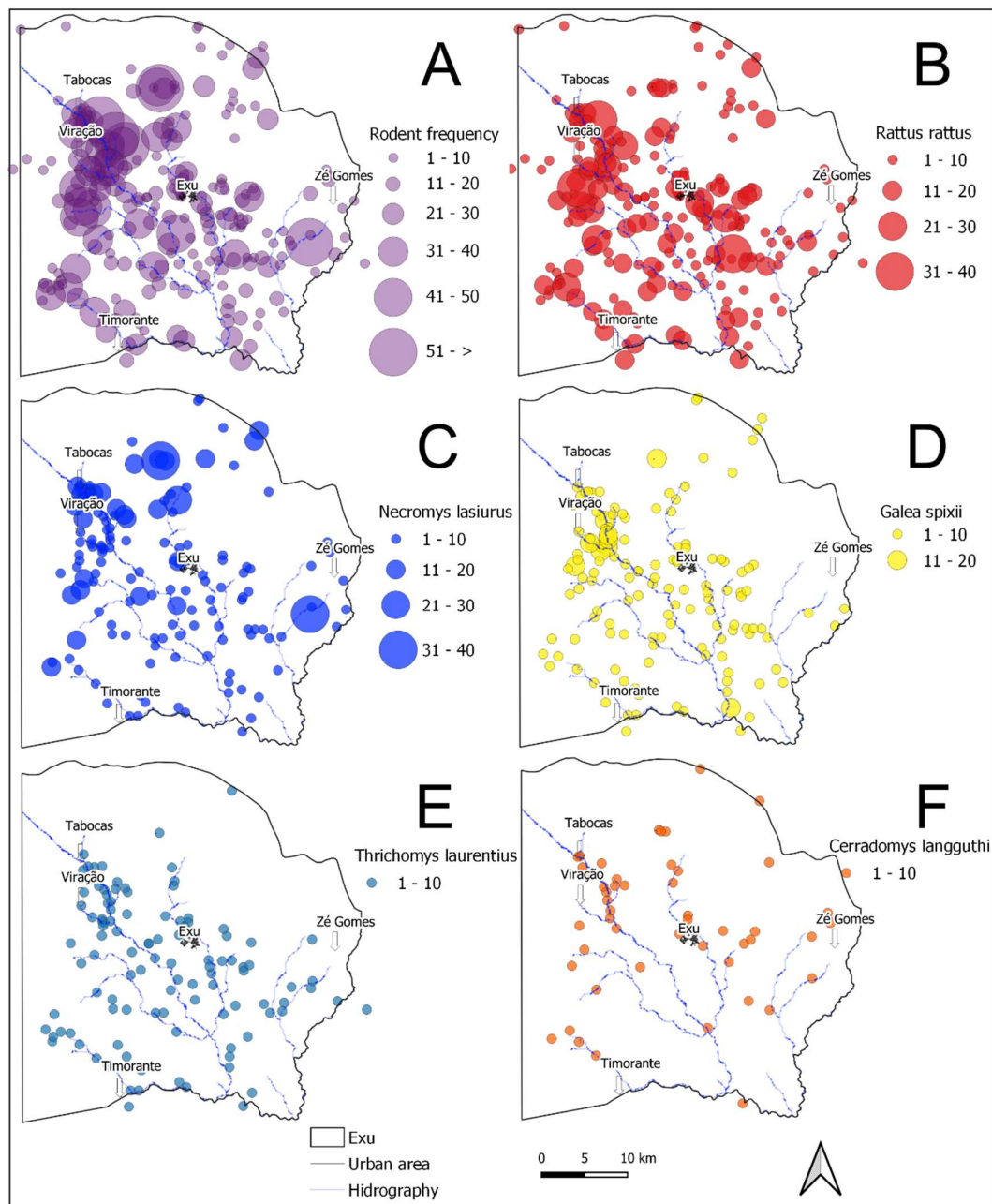
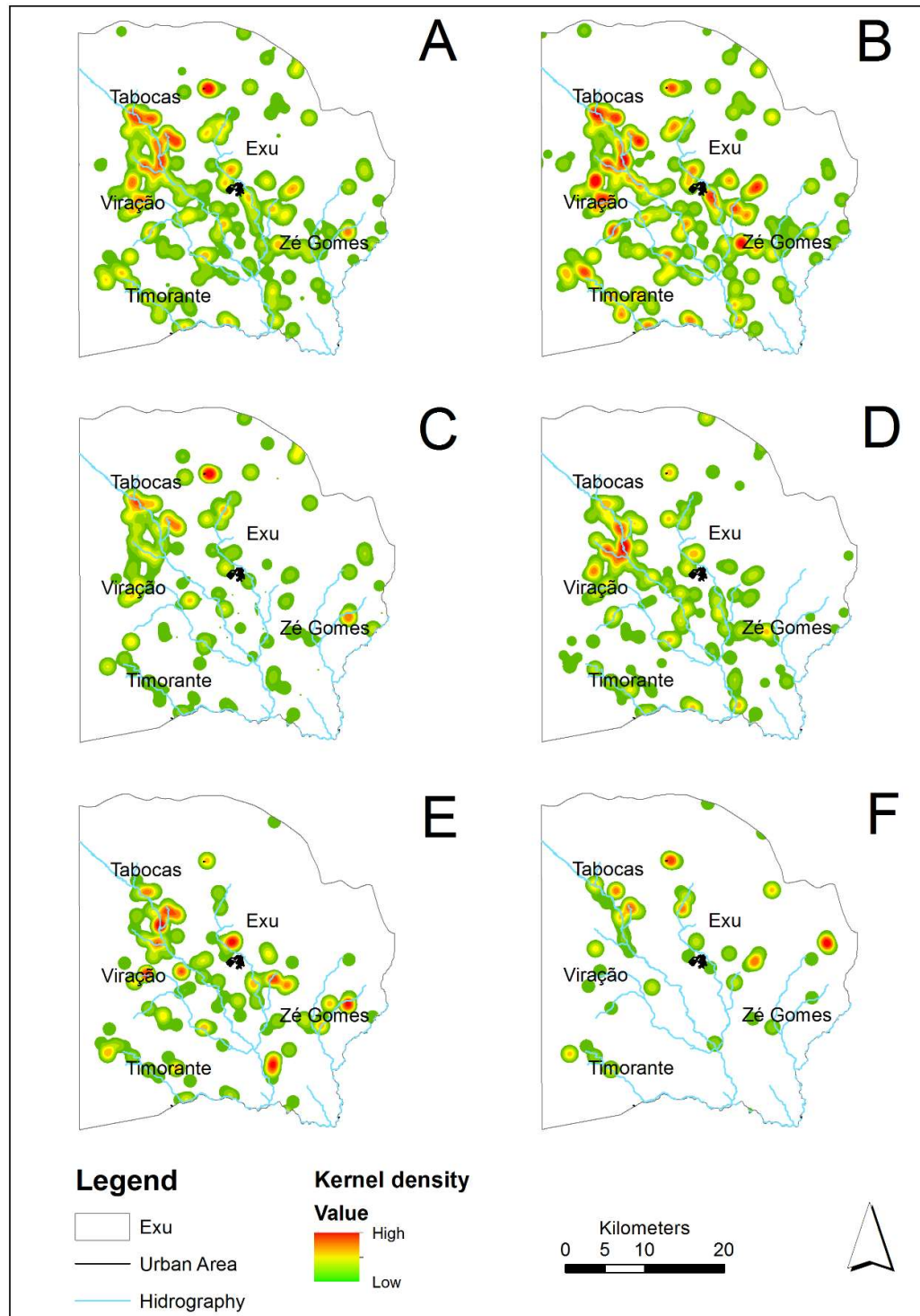


Figure 3. Distribution and abundance maps of the rodent species captured in the localities of Exu, Pernambuco, Brazil, 1996 to 2005.

(A) Total rodents captured, (B) *R. rattus*, (C) *N. lasiurus*, (D) *Galea spixii*, (E) *T. Laurentius*, (F) *C. langguthi*.



The *R. rattus*, the most abundant species in the period, was widely disseminated throughout the territory and occupied a higher number of localities (Figure 3B). However, the areas with the highest density and considered hotspots for the occurrence of this species are in the boundaries of the villages Tabocas, Viração, Timorante and Zé Gomes (Figure 4B). *N. lasiurus* was also found throughout the territory and presented several hotspots near the villages Tabocas and Viração and a hotspot near the village Zé Gomes (Figure 4C). The relatively abundant population of *G. spixii* was also disseminated throughout the territory and presented hotspots in the boundaries of the villages Tabocas and Viração; in the southern part of the municipality and another hotspot on the plateau of the Chapada do Araripe (Figure 4D). *T. laurentius* hotspots occurred in the boundaries of the villages Tabocas and Viração; of the city of Exu and others in the southeast of the municipality (Figure 4E). *C. langguthi*, the least numerous species and with the lowest dispersion (Figure 4F) presented a distribution of hotspots different from the others occurring along the slope of the Chapada do Araripe and in the boundaries of the village Zé Gomes.

Importantly, marked differences were observed in captures from traps set at household or field environments. The proportion of traps set in fields or household environments was standardized in 3:1, respectively. While the proportion of *N. lasiurus* and *R. rattus* in field captures were 44% and 6,5%, respectively, 99% of household captures were *R. rattus* and no *N. lasiurus* was found in this environment (Figure 5).

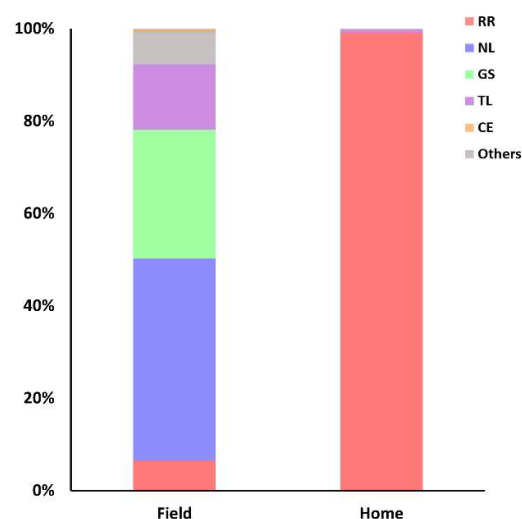


Figure 5. Proportion of species captured in field or household environments.

4. Discussion

Practically since the arrival of the plague in Brazil in 1899, during the third pandemic, a surveillance and control program adjusted to the epidemiological situation, ecological and demographic characteristics and scientific and technological conditions has been carried out [7,10,17]. For several decades, the rodents were trapped for detection of the plague bacillus and/or antiplague antibodies [22-24]. The surveys among the rodents were discontinued in 2007 due to new evidences that serological survey of plague antibodies among roaming-dogs is a more efficient and cost effective tool for plague surveillance [17].

By compiling data from 40 years (1966 to 2005) of monitoring in the plague focus of the Chapada do Araripe, we were able to observe an important fluctuation in the number of captured rodents (Figure 2A-B). It is important to highlight that while the period with predominance of *N. lasiurus* comprises the years with notification of human cases of plague in the region (1966-1976), the period with predominance of *R. rattus* overlaps the period of plague quiescence.

Rodent populations are well known to undergo significant fluctuations over both seasonal and multiannual cycles, which also impact the risk of zoonosis spillovers to humans [25]. Here, we observed 4 to 7 years intervals in the pendular *N. lasiurus* population spikes. However, from the last years of human cases of plague onwards, their abundance peaks were progressively decreasing both in frequency and abundance. From the 1995 peak until the end of the study period (2005) no *N. lasiurus* population growths were observed. The decline of these populations might be due to the important and continuous plague die offs of the susceptible species for many years [17]; climate change and environmental alterations promoted by agriculture [9].

From 1996 to 2005 no *O. nigripes* occurred and the species *C. expulsus* and *W. pyrrhorhinos* were captured in small numbers (Figure 2A-B). The reduction or disappearance of these species does not qualify them as endangered species to extinction risks because this is just a local event [26]. It is noteworthy that some species may eventually show sudden and explosive multiplication popularly known as "ratadas". This phenomenon that are generally correlated with an unusual specific food availability was registered in the State of Bahia involving the species *W. pyrrhorhinos* in 2002 and *C. expulsus* in 2015 [27].

As observed in Figure 3A and 4A, all species occurred in the whole territory of the municipality. The wild species live from agricultural products, which they consume *in situ*. Although occupying the same places (*sítios* or farms) dispersed throughout the territory, the different species do not occupy the same habitats. The species *N. lasiurus*, *C. expulsus*, *C. langguthi*, *O. nigripes* and *W. pyrrhorhinos* usually shelter in sites covered by a low and dense vegetation, where they make their nests. Besides, *C. langguthi*, *O. nigripes* and *W. pyrrhorhinos* can make nests in small trees or rock walls. Others (*G. spixii*, *T. laurentius*) shelter into chinks and crevices of rocks, further away from the humans [10,27].

The main economic activity in practically all the rural land of the municipality of Exu is dedicated to agricultural practiced in the “*sítios*” located mainly along the hydrographic network on the slopes of the Chapada do Araripe (seen in the satellite image - Figure 1C), where remnants of native vegetation (*caatinga*) are also found. The term “*Sítio*” means a rural land division usually including housing, functional buildings (barns, garages, storage areas) and a parcel for cultivating and/or raising stock. The human dwellings are generally unpaved or cemented or with brick floors, clay or brick walls and a roof of tile, zinc, grass or straw. They are often used as both housing and storage for crop products (maize, beans and cotton grains). Unlike the *R. rattus*, the wild rodents only exceptionally enter these dwellings.

The urbanization of some rural communities living with precarious sanitary infrastructure have set the ideal conditions for the expansion of the commensal rat [28]. Therefore, *R. rattus* were more abundant inside household captures (Figure 5) or in the boundaries of the villages Tabocas, Viração, Timorante and Zé Gomes.

The high abundance of rats in those villages might lead to more contact between them and the inhabitants, favoring plague and other rodent-borne diseases [29]. Therefore, some preventive measures should be implemented in these villages including surveillance and rodent and insect control [20].

In a previous study in this same plague area [11], it was observed the transition of the infection from urban to rural areas. The plague reappeared in the rural area after six years of quiescence, and disseminated practically throughout the municipality territory among the wild fauna. According to the figures 3A-F, the dispersal area of the rodents in the present study overlaps the sites of the distribution of the human cases shown by Fernandes et al [11].

The plague disappeared suddenly in this focus since 1975 [11]. Purportedly it could be associated to the rarefaction of the susceptible species, mainly the population of *N. lasiurus*, considered the amplifier host. In spite of the increasing in the *R. rattus* population, plague activity was no longer detected in rodents or humans [17]. The rats are relatively resistant to fatal plague infection and do not suffer from important die-offs that could lead to epizootization in the absence of susceptible species [10, 15, 30-31]. On the other hand, the *R. rattus* might be a preserver host by maintaining the plague dormant until eventual flea re-infection might reactivate the epizootic cycle after restoration of the susceptible wild hosts populations [3, 32].

4. Conclusion

The data presented in this work highlight that *N. lasiurus* might be the responsible for plague epidemics in this focal area of transmission in northeastern Brazil, since the reduction in the abundance of this species over time coincides with the period of disease quiescence. Besides, the increasing in the abundance of *R. rattus* is directly related to the urbanization process of small rural localities. In spite of their abundance they did not drive plague epidemics as could be expected especially considering their proximity to the humans. As the plague infection cycle can reactivate after several years of epidemiological silence a quiescence period must not be misled as extinguished [1,5]. Therefore, continuous surveillance is required and preventive measures focused in driving the rodents away from the houses and protection against flea bites should not be overlooked.

Supplementary Materials: Table 1. Rodents captured in Exu, Pernambuco – Brazil, 1966 to 2005.

Author Contributions: Conceptualization, DLRSF and ECSG; Methodology, DLRSF; MFB and ECSG; Formal Analysis, DLRSF; MFB and AMPA; Investigation, BMD, MPFS, HAS; Data Curation, BMD, MPFS, HAS; Writing – Original Draft Preparation, DLRSF and ECSG; Writing – Review & Editing, MFB, ECSG and AMPA; Supervision, ECSG and AMPA; Project Administration, ECSG and AMPA; All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: The data presented in this study are available in supplementary materials.

Conflicts of Interest: The authors declare no conflict of interest.

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