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Short communication

SPATIAL FEATURING OF ANIMAL RABIES OUTBREAKS IN MARANHÃO STATE, BRAZIL (FROM 1992 TO 2022)

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The aim of the current study is featuring animal rabies outbreaks in Maranhão State, Brazil, from 1992 to 2022. The official database of the Ministry of Agriculture and Livestock of Brazil (MAPA) was used for this purpose. The investigated timeframe was split into two different periods: P1, from 1992 to 2006 and P2, from 2007 to 2022. In total, 310 animal rabies outbreaks were reported in the investigated state. Cattle were the most affected animals (260 cases), followed by horses (28 cases), vampire bats (12 cases), foxes (6 cases), goats (1 case), sheep (1 case), donkeys (1 case) and swine (1 case). Ninety-six (96) of the 217 municipalities in the state of Maranhão have recorded one or more rabies outbreaks. Mangroves, flooded fields and areas close to the Equatorial Forest were the most affected ones. The lowest rabies outbreak frequencies were observed in *restinga* and drier climate areas. In total, 78.8 % (n=41) of municipalities had a recurrence at intervals ranging from 2 to 8 years. Thus, it was possible to conclude that rabies is a recurring problem and that environmental areas have endemic outbreaks of the disease.

Keywords: Prevention; Epidemiology; Geo-temporal Analysis

INTRODUCTION

Rabies is an anthropozoonosis featured by acute fatal encephalitis in animals and humans [1]. The virus is mainly transmitted through contact with infected animal saliva, as well as through bites, scratches and licking open wounds or mucous membranes [2].

The rabies virus lingers in nature through different carnivore and bat species [3,4]. This virus presents seven antigenic variations (AgV) associated with specific reservoir-hosts, which were isolated according to criteria set by the Center for Disease Control

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(CDC) and by the Pan American Health Organization (PAHO) [5], namely: AgV1 and AgV2 (isolated from dogs); AgV3 (isolated from hematophagous bats like *Desmodus rotundus*); and AgV4 and AgV6 (isolated from insectivorous bats like *Tadaria Brasiliensis* and *Lasiurus Cinereus*), two variants (called AgV2) found in Brazilian faunal species like forest fox (*Cerdocyon thous*) and hoary fox (*Lycalopex vetulus*); and the AgVCN variant found in white-tufted marmoset (*Callithrix jacchus*) [6].

Rabies affecting herbivores has been reported in all Brazilian states. In total, 41,919 cases were recorded in the country from 1999 to July 2022. It is one of the most relevant zoonoses in global Public Health due to its high social and economic costs [7]. Silva et al. [8] reported 16.63 % rabies prevalence in samples collected from domestic and wild animals that were analyzed from 2010 to 2018 in Maranhão State [8].

Desmodus rotundus plays a significant role in rabies transmission processes. Based on the technical manual on herbivore rabies issued by the Ministry of Agriculture, Livestock and Supply (MAPA), male and single bats are expelled from their colony and they can move 15 km away from their refuges, although their action range can reach 100 km. According to Trajano [9], *D. rotundus* uses multiple shelters often located in a 2-3 km radius from its shelter.

According to Freitas [10], each female *D. rotundus* individual gives birth to one offspring per year, and colonies often reach their "peak" between eight and ten years. Therefore, this balance interval only changes when new rabies virus exacerbations randomly take place [10].

In the Peruvian Amazon was observed that vampire bats are physiologically capable of performing long-distance flights, although their typical dispersal distance reaches 10 km and long-distance flights are rare. According to the aforementioned authors, rabies in *D. rotundus* advances in slow dissemination waves in comparison to other reservoir-hosts or transmitters, such as raccoons (*Procyon cancrivorus*), whose long-distance moves range from 30 to 100 km/year [11].

Therefore, the aims of the present study were to show the spatial data of herbivore rabies cases reported in Maranhão State from 1992 to 2022, to assess both the absolute frequency and the evolution of rabies outbreaks, and to feature this disease's transmission cycle.

MATERIAL AND METHODS

Sampling design

Data on herbivore rabies cases reported from 1992 to 2022 were collected from files belonging to the Input and Animal Health and Inspection Service of Maranhão State (SISA/SFA-MA/MAPA), under Consent Form n. 001/24. Data on herds and cartographic grids were collected from IBGE's (Brazilian Institute of Geography and Statistics) website [12,13].

Study site

The study was carried out in Maranhão State, Northeastern Brazil, which holds a 640 km coastline bathed by the Atlantic Ocean. Due to its area (approximately 329 thousand km²), Maranhão is the eighth largest state in Brazil. Its population comprises approximately 7.1 million people who account for the lowest income *per capita* in the country, a fact that leads to economic and social challenges. A large area in the state is used for cattle breeding purposes (approximately 9.4 million animals). It holds the second largest cattle herd in Northeastern Brazil [12]. Livestock farming in Maranhão State benefits from 1.1 millions ha of natural pastures out of a total area of 33 millions ha and it plays key role in the state's economy [14].

The prevalent tropical climate is featured by temperatures higher than 26 °C and by annual rainfall ranging from 700 mm (in its Central region) to more than 2,200 mm (in its Northern region), on average. Maranhão State's coastal zone and Northern region present humid tropical climate featured by abundant rainfall events in the rainy season (from January to June). Its Southern region, in its turn, presents drier climate and lesser rainfall events [15].

Maranhão State comprises 217 municipalities grouped into 21 micro-regions, which were considered geographic units of analysis (Figure 1).

Figure 1. Maps depicting the study site. South America is depicted in the smaller map. The largest map depicts Maranhão State split into 21 micro-regions. Maranhão State. Brazil, 2024. Base cartography: IBGE, 2024; SCG Datum: SIRGAS 2000. Elaborated by the authors.

Geographic micro-regions were defined based on specificities associated with the agricultural, industrial, mineral extraction and fishing production structures, as well as on their natural framework and specific social and economic relations [13]. The state's topography also changes, given its coastal plains featured by beaches, dunes and mangroves, mainly in Lençóis Maranhenses National Park. The terrain rises towards the South, with emphasis on Gurupi and Balsas Plateaus. Maranhão State has a rich waterway network comprising important rivers, such as Parnaíba River, which forms the state's Eastern border, and Gurupi River, which separates Maranhão from Pará State. Itapecuru and Mearim, as well as their different tributaries, are other important rivers in this region [13].

Data analysis

The database, graphs and tables were built in MS Excel software, version 2013. Rabies case-distribution maps were plotted in QGIS geographical information system software, version 3.32. Choropleth maps, as well as dispersion and correlation-calculation charts, were plotted in Geoda free software, version 1.20.0.36.

RESULTS AND DISCUSSION

In total, 310 rabies outbreaks were reported in animals within the analyzed timeframe (Figure 2). This figure does no comply cases affecting canines and felines. Of this total, 291 cases were reported for herbivores. Rabies recorded 10.3 outbreaks/year, on average – 2006 was the year recording the largest number of cases (n = 28). Bovines were the most affected animals (260 cases); they were followed by horses (28 cases), hematophagous bats – HB (12 cases) and foxes (6 cases).

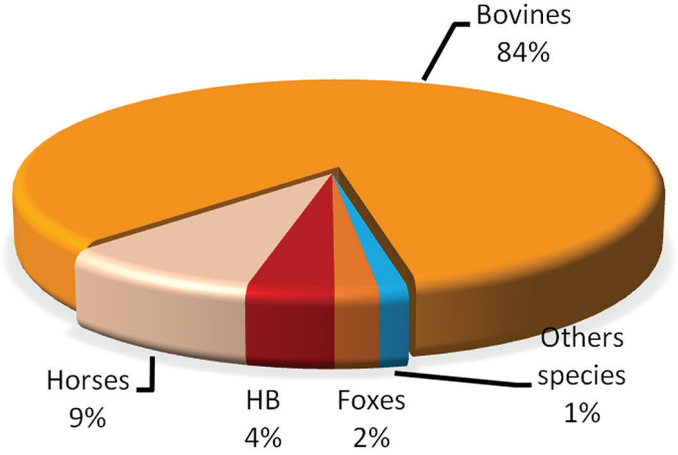

Figure 2. Species affected by rabies in Maranhão State from 1992 to 2022. The other affected species comprised caprine (1 case), asinine (1 case), sheep (1 case) and swine (1 case). Source: Animal Health Information System of MAPA and Maranhão State Agency of Agricultural Defense (AGED-MA), 2023.

Evolution of rabies outbreaks in herbivores in Maranhão State and Brazil

Maranhão State recorded increased number of rabies cases from 1999 to 2000, and it was followed by a downwards trend stage. However, unlike the national trend of continuous and significant decrease in the number of cases, this state has shown fluctuations and increased number of cases after 2004, which reached their peak in 2006. This peak was followed by oscillation with downward trend until 2022, as shown in Figure 3 and Table 1.

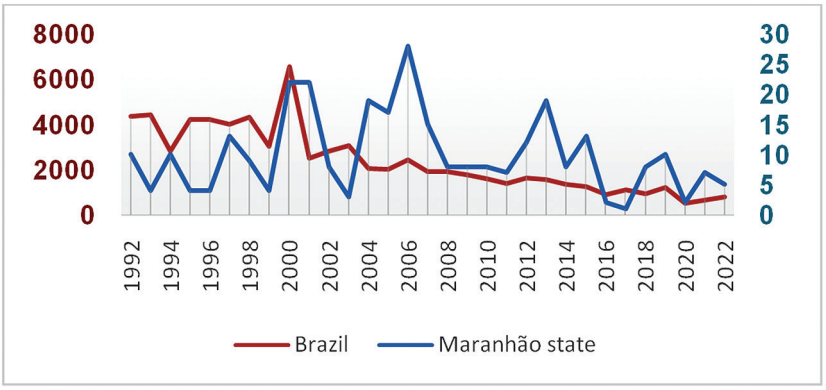

Figure 3. Evolution of animal rabies outbreaks in Maranhão State and in Brazil, from 1992 to 2022. Source. MAPA and AGED-MA, 2023.

Table 1. Temporal distribution of animal rabies cases in Maranhão and Brazil (1992-2022)

Period	Maranhão State	Brazil
1992-1996	32	20129
1997-2001	70	9106
2002-2006	75	12390
2007-2011	46	8586
2012-2016	54	6689
2017-2022	33	5148
Total	310	41919

Source. Animal Health Information System of MAPA and Maranhão State Agency of Agricultural Defense (AGED-MA), 2023.

On the other hand, most municipalities did not present rabies cases over the investigated period. These municipalities are mainly located in Northeastern and Southeastern Maranhão State (Figure 4). Balsas was the municipality in the Southern region recording a high occurrence frequency of rabies cases; the other municipalities recorded less than 2 cases.

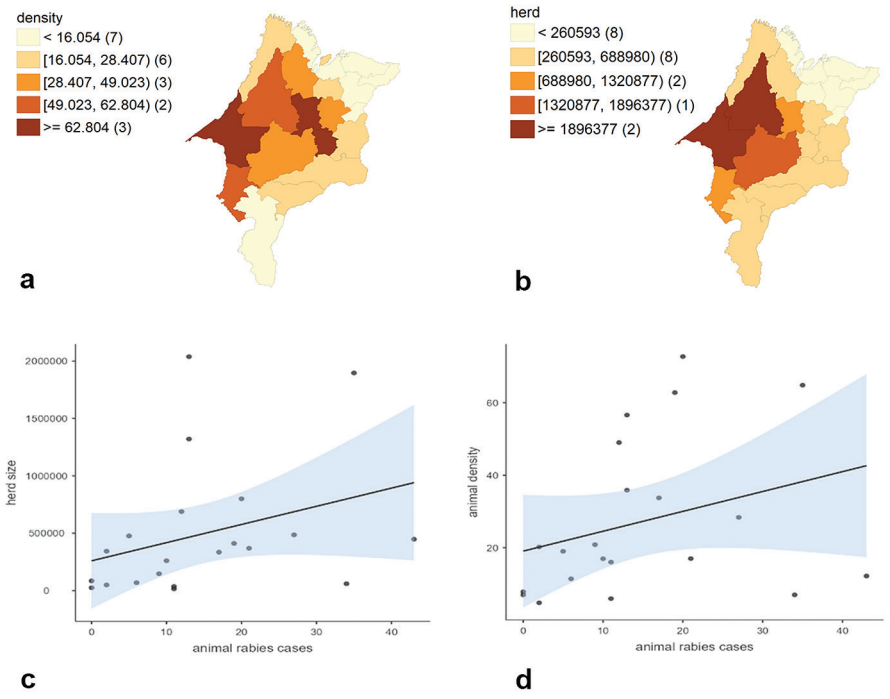

Figure 4. Maps depicting animal density distribution **(a)** and cattle herd size **(b)** per micro-regions, in 2022. Scatter plots of variables "herd" **(c)** and "animal density" **(d)** in comparison to variable "animal rabies cases". Maranhão State, Brazil, 2023. Source. MAPA and AGED, 2023.

Souza [21] explains the dynamics of rabies in the *D. rotundus* population in an outbreak of rabies in herbivores. For the aforementioned author, first there is mortality in the colony, then there is the mortality of attacked herbivores, and another portion of surviving bats will spread the outbreak to new areas. This would also explain the observations of Itou et al. [22], who visited a typical distribution range of *D. rotundus* activity in an outbreak in Rio Grande do Sul was approximately 80 km^2 due to limitations of the river and colony size, and the focus ended suddenly over a period of one month and there have been no rabies outbreaks in the last three years.

In this context, the evolution of rabies outbreaks, Arruda et al. [23], when analyzing the captures of *D. rotundus* in forest and mangrove regions of the State of Maranhão, they concluded that the absence of new attacks, after effective control of the vampire bat population, occurs within three years. According to Ferrari & Marrelli [24], the recolonization time of daytime shelters by *D. rotundus* was on average 12.5 months, with a variation between three and 25 months.

Effect of animal density and herd size on animal rabies occurrence frequency

Based on Figure 4, the largest cattle herds in Maranhão State are located in its Midwestern and Southeastern regions. Regions close to the coast present smaller cattle herds (Figure 4. a, b).

There was no correlation between rabies occurrence frequency and herd size in the assessed micro-regions (R de Pearson 0,324, p=0.152), based on Figure 4d. Although animal density is seen as determining receptivity factor for vampire bats due to food availability [25, 26], it did not show correlation to rabies prevalence (R de Pearson 0,303, p = 0.182), as shown in Figure 4c. This finding suggests that factors associated with animal care, such as vaccination practices, the quality of the official defense service and environmental changes, such as deforestation [27] and highway construction, may have stronger effects on rabies occurrence than the food availability represented by the number of bovine animals.

Environmental impacts have changed the habitat of both bats and other rabies virus-transmission mammals, and it forced them to migrate to unprotected areas. Anthropogenic climate change, drought, fire suppression and changes in land use have led to increased frequency and severity of fire events worldwide [27] and they may be associated with the rabies virus outspread.

Evolution of rabies outbreaks from 1992 to 2005 and from 2006 to 2022

The analysis applied to the evolution of herbivore rabies cases in Maranhão State, from 1992 to 2022, has evidenced variations pointing towards successful disease control and highlighting challenges to be faced. Maps in Figure 5 show rabies cases in 21 Maranhão State micro-regions, in two different periods: a) 1992-2006 and b) 2007-2022), as well as highlight changes in rabies outbreaks distribution in this state.

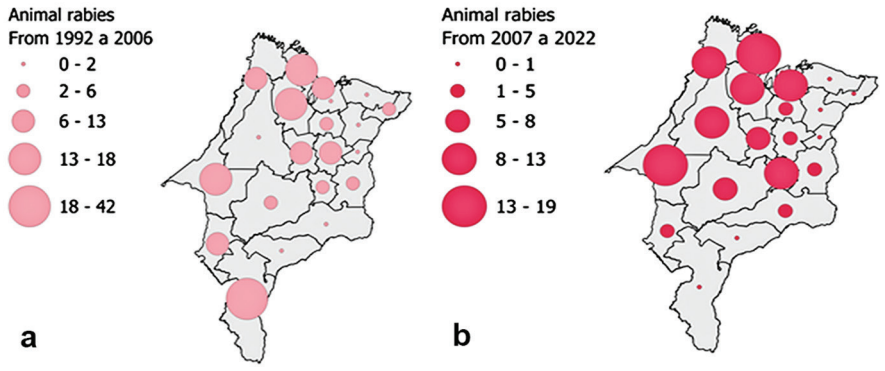

Figure 5. Animal rabies outbreaks in two different periods: **a)** from 1992 to 2006 and **b)** from 2007 to 2022. Maranhão State, Brazil, 2023. Source: MAPA and AGED-MA

The first analyzed period recorded 177 rabies cases, and it resulted in occurrence frequency rate of 11 cases / year. The second period, in its turn, recorded 133 cases, and it resulted in occurrence frequency rate of 8.9 cases / year.

The number of outbreaks recorded from 2007 to 2022 reached a range of values lower than that of the previous period (from 33 to 42 outbreaks). This finding points out overall decrease in the maximum number of outbreaks recorded from the first to the second period.

Based on Figure 5a, which represents period I, rabies outbreaks seem to be better distributed in the state. The highest values were observed in the state's Southern, Southeastern and Northwestern regions, whereas the lowest values were recorded in its Eastern region, along Parnaíba River, as well as in Lençóis Maranhenses and Itapecuru Mirim Microregions. Figure 5b, which covers the period from 2007 to 2022, presents significantly smaller number of outbreaks in Southern Maranhão State, as well as increased frequency of rabies cases in its Northern region, with emphasis on the Western Coast region. These observations suggest a pattern in rabies outbreak displacements from South to North Maranhão State, over time.

Results have evidenced that Balsas micro-region stood out for significant decrease in these outbreaks (from 42 to just 1 rabies outbreak), which also corresponded to a decrease by approximately 97.6 % in the number of rabies outbreak records. Although São Luís and Lower Parnaíba micro-regions recorded 11 and five rabies cases, respectively, in the initial period, they did not report any new rabies outbreak in the following period. Micro-regions, such as Codó and Porto Franco, also recorded significant drop in the number of rabies outbreaks. Codó recorded decrease from 13 to 4 cases, whereas Porto Franco recorded decrease from 9 to 3 cases – both micro-regions recorded rabies outbreak reduction rate higher than 66 %.

Unlike this scenario, the state's Western Coast recorded increased number of rabies outbreaks, from 15 to 19. Presidente Dutra micro-region also experienced substantial increase in the number of rabies outbreaks, from 6 to 13. Pindaré micro-region recorded a significant increase in the number of rabies outbreaks, which jumped from 1 to 12. Alto Mearim and Grajaú micro-regions recorded increase in the number of rabies outbreaks from 5 to 8. Rosário and Chapadas do Alto Itapecuru micro-regions, which did not register any case in P1, recorded 11 and 5 cases in P2, respectively. Such an increase suggests that these regions may have had a hard time adopting rabies control measures or that new risk factors for rabies transmission may have emerged during P2, or even lack of diagnosis of rabies cases in P1.

Gurupi and Imperatriz micro-regions recorded moderate variations: Gurupi recorded an increase in the number of outbreaks, from 8 to 12 cases, whereas Imperatriz recorded a slight reduction in the number of outbreaks, from 18 to 17 cases. It is worth emphasizing that the displacement of rabies outbreak clusters may be linked to factors, such as vaccination coverage and variations in the occurrence frequency

and migration of wild reservoir-hosts of this virus. Furthermore, environmental or socioeconomic changes may also have influenced these patterns [28] [29].

On the other hand, rabies outbreak displacements from Southern to Northern Maranhão State, from 2007 onwards, may be associated with agricultural development in MATOPIBA region (area comprising 336 municipalities in Maranhão, Tocantins, Piauí and Bahia states), which focuses on grain production systems [31]. This process has been observed in the last 15 years and it is associated with native vegetation replacement and, consequently, with reduced number of natural areas, lower food availability and less shelters for wild mammals that transmit rabies viruses to production animals.

Thus, the significant decrease in rabies ocurrence frequency in Maranhão State can be partly explained by the Official Veterinary Service (SVO – Serviço Veterinário Oficial) structure after the Maranhão State Agency of Agricultural Defense (AGED-MA) was launched in 2002. From 2005 onwards, AGED-MA implemented intense hematophagous bat (*Desmodus rotundus*) population control, besides monitoring rabies outbreaks and encouraging herd immunization practices.

Lack of correlation between rabies occurrence frequency and animal density has suggested that food abundance for hematophagous bats, which are pointed out as the main rabies transmitter in rural environments, may not be the only important factor in the rabies cases, as well as that other factors, such as animal management practices and effectiveness of vaccination campaigns, can play highly significant role in its dynamics.

CONCLUSION

According to the spatial feature of herbivore rabies cases reported in Maranhão State, from 1992 to 2022, it is possible concluding that rabies is a cyclical issue and that the investigated areas have experienced endemic outbreaks. In addition, animal rabies cases have shown a downward trend in Maranhão State, and it highlight the need of strategic planning based on local conditions and on continuous monitoring and surveillance procedures to be performed by Official Veterinary Service teams.

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Authors' contributions

RCNA conceived and designed the study and wrote the manuscript, with IRN and VCSC participating in sample collection and analysis. HMP, FBC, and HPS critically reviewed the manuscript and made substantial contributions to data interpretation. JWAS performed the statistical analysis. All authors read and approved the final manuscript.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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PROSTORNI PRIKAZ ŽARIŠTA BESNILA KOD ŽIVOTINJA U BRAZILU (DRŽAVA MARANHÃO, 1992. - 2022.)

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Cilj ove studije je da prikaže izbijanje žarišta besnila kod životinja u državi Maranhão, Brazil, od 1992. do 2022. godine. U tu svrhu je korišćena zvanična baza podataka Ministarstva poljoprivrede i stočarstva Brazila (MAPA). Istraženi vremenski okvir je podeljen na dva različita perioda: P1, od 1992. do 2006. i P2, od 2007. do 2022. godine. Ukupno je prijavljeno 310 slučajeva besnila kod životinja u ovoj državi. Najčeešće su obolela goveda (260 slučajeva), zatim konji (28 slučajeva), slepi miševi (12 slučajeva), lisice (6 slučajeva), koze (1 slučaj), ovce (1 slučaj), magarci (1 slučaj) i svinje (1 slučaj). Devedeset šest (96) od 217 opština u državi Maranhão zabeležilo je jednu ili više epidemija besnila. Ističu se najviše pogođene oblasti, one gde rastu mangrove, poplavljena polja i područja u blizini ekvatorijalne šume. Najmanja učestalost izbijanja besnila zabeležena je u sušnijim klimatskim područjima. Ukupno, 78,8 % (n=41) opština imalo je recidiv u intervalima od 2 do 8 godina. Može se zaključiti da je besnilo problem koji se ponavlja i posebno da posmatrana prirodna područja imaju endemsku pojavu žarišta.