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Article

The coexistence of *Desmodus rotundus* with the human population in San Luis Potosí, Mexico

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Abstract:

Desmodus rotundus is a transmitter of zoonotic and emerging diseases to humans and livestock, such as rabies. Most infectious diseases are spatially limited by the presence of the transmitter, whose abundance and survival are influenced by environmental conditions and the presence of food sources. A tool that facilitates its study is the use of Geographic Information Systems. The objective of this study was to analyze the interaction of populations of hematophagous bats and humans, through the development of a probable model of dispersal of *D. rotundus* based on known shelters and different environmental variables, in addition to analyzing the relationship between shelters identified for three years and their proximity to human settlements, as a process of coexistence. The study was conducted in the state of San Luis Potosí from 2014 to 2016. A total of 180 shelters of *D. rotundus* distributed towards the Huasteca region were identified, 80 % of these were built by man and 57 % were inhabited. A buffer of 5 km around from the location of each shelter was calculated, finding inside a total of 976 rural communities and 15 cities, with 337,836 inhabitants. The average distance from shelters to the first human settlement was 518.65 ± 11.33 m. It is necessary to continue studying the association between urbanization and the emergence of zoonoses, through the understanding of the interactions between wild animals-livestock-humans.

Key words: Vampire bat, Zoonoses, Human population, Coexistence, GIS.

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Introduction

Bats are the mammals that are recognized as reservoirs of potentially zoonotic viruses. They have been associated with different infectious agents such as those of the *Filoviridae* family (*Ebolavirus*, *Marburgrvirus*), coronaviruses (including severe acute respiratory syndrome or SARS coronavirus)(1,2), rabies and other *Lyssaviruses*, a lineage of Influenza A and several of the *Paramyxoviridae* family (*Hendra* [*VHe*] and *Nipah* [*VNi*])(3). These emerging diseases have the potential to cause epidemics, caused by interactions between infected bats, the infectious agent and the host(2). Sometimes there is an intermediate host such as companion animals, wild animals or livestock, these come into contact and infect humans even amplifying the virus(2,3). It is evident that the interactions that occur between wildlife, livestock and humans are not yet well understood, they are likely to occur on different scales of time, space and in a certain ecological organization, where vectors change their distribution mainly due to change in land use (agriculture, urbanization, recreation) or climate changes(1,4). Changes in the environment, mainly those caused by temperature, rainfall and humidity, as well as the height above sea level and those given by interactions influence the frequency and duration of contact between humans and bats, which can favor the transmission of pathogens to the former, which even seems to be increasing(3,5,6). Viruses such as hepatitis C, parainfluenza, canine distemper, among others, which are common in animals and humans, originated in bats(7).

Rabies is the most widely studied viral disease from bats(3). There are three species of hematophagous bats in Latin America, *Diaemus youngi*, *Diphylla ecaudata* and *Desmodus rotundus* (*D. rotundus*)(8).

D. rotundus belongs to the *Phyllostomatidae* family, which is characterized by feeding exclusively on the blood of mammals including humans, it has been considered the main transmitter of rabies in humans and bovine paralytic rabies (BPR) in cattle, from Mexico to South America(9,10,11). The economic impact of vampire bats is difficult to quantify, because they weaken cattle through blood loss, lead to secondary infections, reduce milk and meat production and lead to death if cattle develop BPR(12). In Mexico, this disease occurs endemically in 25 states, from the Pacific through southern Sonora to Chiapas and from the Gulf of Mexico south of Tamaulipas to the Yucatán Peninsula(13,14). Of the 255 cases of BPR reported during 2019, thirty (11.76 %) were reported in San Luis Potosí(14), where despite the prevention and control measures established (treatment with vampiricide and vaccination), they continue to occur, even expanding their geographical coverage. Until 2017 the state of Nuevo León was considered free of BPR, however, in 2018 three cases were reported, demonstrating an increase in the dispersal of the vector(14,15).

Because the transmission of rabies and other infectious diseases can have devastating effects on public health and even wildlife conservation, it is clear that understanding has been limited and it becomes necessary to have different approaches to hematophagous bat-pathogen-human interactions. Knowledge of the ecology of the host is essential for the relationship with the human population in disease transmission and dynamics. It is important that the predictions are reliable to improve the knowledge of the elements that push the dynamics of the space-time infection, to prevent diseases such as rabies in humans, as well as in livestock, the understanding of the dispersal of these vectors is required, since they are recognized as the main transmitters of this virus to these species(3,5,16). Most infectious diseases are considered to be spatially limited by the presence of the transmitter, whose abundance and survival are influenced by environmental conditions and the presence of food sources(17). A tool that facilitates the study of the distribution of vectors and these variables is the use of Geographic Information Systems (GIS)(18,19,20).

Through spatial models, such as those of “Ecological Niche”, the areas of greatest risk of transmission of infectious diseases can be predicted, which allows establishing priorities for their attention through programs such as MaxEnt® or DivaGis®(19,21,22). The maximum entropy (MaxEnt) model is one of the most used methods to study the distribution of different species, predicting the relative suitability of the habitat with functions derived from environmental variables, preventing the model from overfitting the data[22,23]. Like MaxEnt, DivaGis supports the analysis of exploration or occurrence databases to identify ecological and geographic patterns in the distribution of wild species[24]. In this way, it has even been allowed to predict the influence of climate change on the distribution of species and diseases, most models correlate the current occurrence of the species or disease with climatic variables or through the knowledge of the natural history of the disease and the estimation of the physiological response of the species to climate change, estimating its possible redistribution for future climate scenarios[19].

Due to climate change and urbanization patterns and that *D. rotundus* is a species with the potential to transmit diseases such as rabies to humans and livestock, epidemiological surveillance activities and the control of this transmitter become relevant, the objective of this study was to analyze the close relationship between *D. rotundus* and humans, through the development of a probable MaxEnt dispersal model of *D. rotundus* based on known shelters and different environmental variables, and analyze the relationship between the shelters found and their proximity to human settlements, as a process of coexistence with the use of Diva Gis.

Material and methods

The study was carried out in the state of San Luis Potosí, which is located between 98°19'33.6 WL, 102°17'45.6 WL and 21°9'36.72" NL at 24°29'29.4 NL. The climate that predominates is the dry and semi-dry, present in 71 % of the state, the average annual temperature is 21 °C, the average minimum temperature is 8.4 °C in January and the average maximum is around 32 °C in May. Rainfall occurs during the summer from June to September, the average rainfall of the state is around 950 mm per year[25].

Desmodus rotundus dispersal model using MaxEnt

It was carried out through the records of location of shelters notified and visited during the years 2014-2016, obtained by the State Committee for the Promotion and Protection of Livestock of San Luis Potosí (CEFPPSLP, for its acronym in Spanish). Obtaining their longitude, latitude and altitude, in addition to the municipality, the reason for the action, the number of vampires captured and treated.

With the location records of these shelters, 24 environmental variables (EV) were used for the dispersal model, 19 of them were downloaded from the Worldclim database at a 1 km^2 spatial resolution[26,27]. In addition to five other variables of climate[28] obtained from the National Institute of Statistics, Geography and Informatics (INEGI, for its acronym in Spanish), land use[29], soil[30], geology[31] and altitude[32] (Table 1). All were converted to raster format with an equal spatial resolution of the climatic layers. With a total of 181 data sorted in a database and exported to a comma-separated values (CSV) file, for later incorporation into the MaxEnt software.

Table 1: Environmental variables considered for the dispersal model in the state of San Luis Potosí

Code	Environmental variable
EV1	Average annual temperature (°C)
EV2	Diurnal temperature oscillation (°C)
EV3	Isothermality (quotient between parameters EV2 and EV7)
EV4	Temperature seasonality (coefficient of variation, %)
EV5	Average maximum temperature of the warmest period (°C)
EV6	Average minimum temperature of the coldest period (°C)
EV7	Annual temperature oscillation (difference between parameters EV5 and EV6)
EV8	Average temperature of the rainiest quarter (°C)
EV9	Average temperature of the driest quarter (°C),
EV10	Average temperature of the warmest quarter (°C)
EV11	Average temperature of the coldest quarter (°C)
EV12	Annual precipitation (mm)
EV13	Precipitation of the rainiest period (mm)
EV14	Precipitation of the driest period (mm)
EV15	Precipitation seasonality (coefficient of variation, %)
EV16	Precipitation of the rainiest quarter (mm)
EV17	Precipitation of the driest quarter (mm)
EV18	Precipitation of the warmest quarter (mm)
EV19	Precipitation of the coldest quarter (mm)
EV20	Climate map (types of climate)
EV21	Land use (types)
EV22	Soils (type of soil)
EV23	Geology (type of rocks)
EV24	Altitude (m.a.s.l)

Having only presence data, MaxEnt created pseudo-absence points and divided the base into two groups randomly: data for training, which is the spatial model and where 80 % of the location records of the shelters were considered, and validation (test) data of the model, which considers the remaining 20 % and measures predictive capacity. The output model was logistic with predicted presence probabilities among the binary range[33]. The result of the model then expresses the value of the suitability of the habitat for the presence of *D. rotundus* as a function of environmental variables, through a statistical validation test called area under the curve (AUC) that indicated sensitivity, understood as the probability of obtaining a presence result when the species is present, and the closer it is to 1 the more reliable the result. Additionally, the software calculated from iterations the percentage of contribution to the model of each of the environmental variables used for the creation of the model. This analysis marks the climatic similarity between the sites where the shelters are and where the species possibly lives.

Analysis of potential contact or coexistence between *Desmodus rotundus* and human settlements or localities

With the coordinates of the shelters inhabited by *D. rotundus*, the database was exported to a shapefile (shp), where a buffer layer with a radius of 5 km[34] was generated, through the Qgis program. Additionally, another shp layer was added with the information of the location of rural communities, of which only those that were within the created buffer were selected, and another with urban areas, selecting those that touched that same buffer.

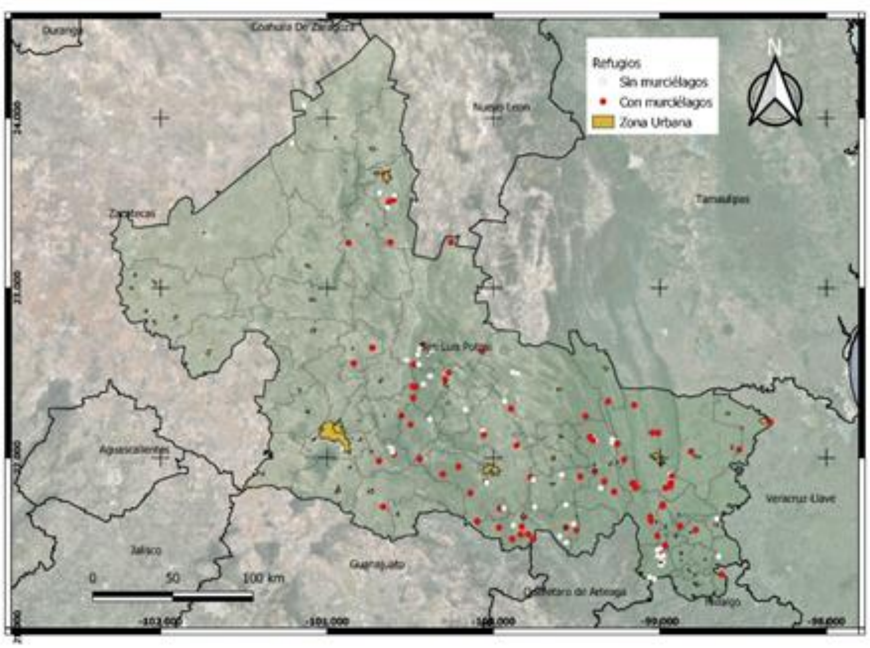
The number of human settlements (rural localities and urban areas) was counted, as well as their population, which are potentially within the buffer and therefore maintain interactions with colonies of *D. rotundus*, in addition, the average distance from the shelter to the nearest dwelling was calculated.

Results

Shelter Information

From 2014 to 2016, a total of 180 shelters were identified, of which 67 were identified during 2014, 46 in 2015 and 67 in 2016. Eighty (80) percent of the shelters were artificial, of these, 3 abandoned houses, 1 school, 1 warehouse, a bus station and a bridge stand out. The remaining 20 % are natural shelters such as caves. The distribution of both natural and artificial shelters is greater towards the Huasteca region in the southeast of the state in various municipalities. Regarding the occupation of the shelters according to the presence of *D. rotundus* of the total identified, in 102 shelters (56.7 %) between 6 and 18 individuals were captured; the rest were found empty despite being visited on average twice in that year (Figure 1).

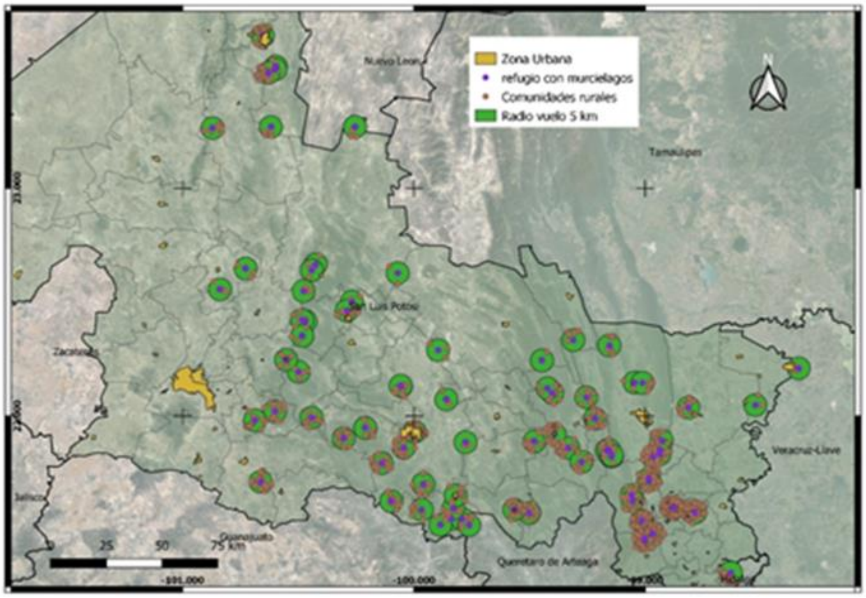
Figure 1: Geographical location of the empty shelters and shelters occupied by *Desmodus rotundus* from 2014 to 2016 by the State Committee for the Promotion and Protection of Livestock of San Luis Potosí (CEFPPSLP)



Analysis of potential contact or coexistence between *Desmodus rotundus* and human settlements or localities

An average flight radius of *D. rotundus* of 5 km from the location of each shelter was considered(34,35,36), and buffers were made, finding within these a total of 976 rural communities, which were inhabited from 1 or up to 3,124 inhabitants, making a total of 124,884 inhabitants. Of these, 375 (38.4 %) had 10 or fewer inhabitants. As well as 15 cities with an estimated population of 212,952, representing a total of 337,836 inhabitants (Figure 2). Since the shelters of *D. rotundus* show connection between them, these can occupy an area of 3 to 6 km on average, giving them the opportunity for short flights to locate prey(37), however, the minimum distance that has been found of the movements in vampire bats in Argentina was 1.5 km(38). As for the average distance from the shelters to the first settlement with a human population was 518.65 ± 11.33 m, this distance can be easily traveled for the search for food, which implies that there is an interaction directly or indirectly at different levels and frequency of contact with humans, who could potentially be exposed to the rabies virus. The coexistence between human population and *D. rotundus* colonies is occurring due to their dispersal, concentration of shelters, and the distance between shelters to human communities.

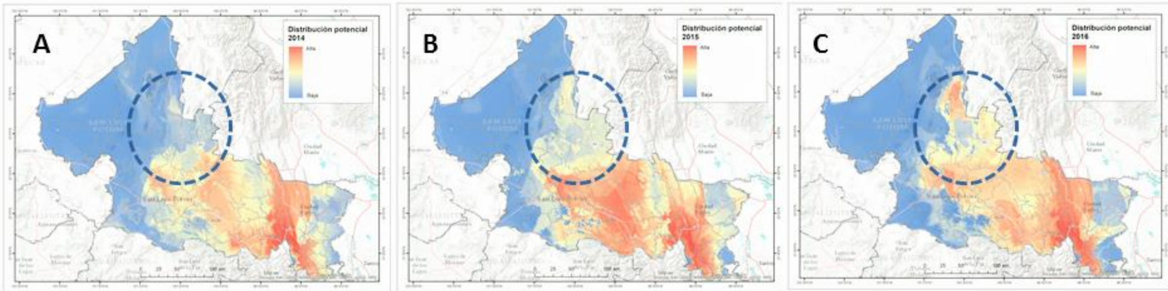
Figure 2: Rural and urban localities within a radius of 5 km from the shelters inhabited in San Luis Potosí during 2014-2016



Desmodus rotundus dispersal prediction model in the state

The prediction model obtained with MaxEnt shows that environmental conditions have changed moderately from 2014 to 2016, generating more sites of environmental suitability towards the northern region of the state for the location of *D. rotundus*, but it is in the southwestern region where there is a greater probability of development of colonies of *D. rotundus*, as shown in Figure 3. Consistently, the climatic variables with the greatest effect on the model were the annual temperature oscillation, temperature seasonality, precipitation of the dry quarter, precipitation seasonality and for 2016 the diurnal temperature oscillation, as can be seen in Table 2. The overall AUC for the model was 0.992 over the entire period under study, specifically for 2014 (AUC 0.992), 2015 (AUC 0.993), and 2016 (AUC 0.992). These results allow making a robust prediction model regarding the dispersal of *D. rotundus*.

Figure 3: The prediction model with MaxEnt for the presence of *Desmodus rotundus*, for 2014 (A), 2015 (B), 2016 (C)



Note the increase in the potential distribution towards the northern region (dotted circle).

Table 2: Percentage of contribution of the variables of the MaxEnt model

Year	Variable	Contribution (%)
2014	Temperature seasonality	30.0
	Precipitation of the driest quarter	16.1
	Annual temperature oscillation	14.9
	Precipitation seasonality	14.3
2015	Annual temperature oscillation	26.8
	Precipitation of the driest quarter	16.7
	Precipitation seasonality	11.8
	Temperature seasonality	11.5
2016	Annual temperature oscillation	22.8
	Temperature seasonality	20.0
	Precipitation of the driest quarter	14.9
	Diurnal temperature oscillation	12.5

Discussion

The importance of the *D. rotundus* bat lies not only in its ability to transmit diseases due to its feeding and social habits, such as rabies to cattle and occasionally to humans, but also because it has managed to adapt to new environments, and to the changes generated in land use, which possibly favors its wide geographical distribution in different regions of Latin America and Mexico[5,36]. This study confirms that the hematophagous bat *D. rotundus* is distributed in large areas of San Luis Potosí, but also, that it has been looking for new niches since cases of BPR have been observed towards the north of the state, where, apparently, the climatic conditions were not suitable for the presence of these bats. The presence of new human settlements, especially rural ones, favors the creation of artificial shelters, where new colonies of these Chiroptera can migrate; in addition, new settlements usually develop livestock activities that in turn facilitate the food source of these vectors[34].

A study in Mexico found that, regardless of environmental characteristics, the distribution of vampire bats increased[39]. In this regard, another study conducted in Mexico using MaxEnt determined through bioclimatic conditions for the period 2050-2070, that 30 % of the Mexican landscape will provide an ideal habitat for *D. rotundus* due to changes in climate regimes. This expansion will occur in northern and central Mexico, where San Luis Potosi is located[13]. Agreeing with the above, another study, using the multi-species distribution model (SDM), estimated the potential distribution of vampire bats in North America under current and future climate scenarios, finding that these can be distributed in various habitats throughout much of southern, central and northern Mexico, including up to the southern region of the United States, the only limitation to reach this latitude being its poor capacity to thermoregulate when they are exposed to temperatures below 10 ºC[12].

Considering studies carried out in Mexico, *D. rotundus* can be in places with temperatures between 21 and 25 ºC, altitude below 2,300 masl and relative humidity of 45 %[13]. The environmental suitability has been changing in the different years of study, increasing the area of dispersal towards the north of the state, in the arid region, however, the variables related to temperature: annual oscillation, seasonality and diurnal oscillation (>11.5 %), together with the precipitation variables: of the driest quarter and precipitation seasonality (>14.3 %) remained as the factors that contribute mostly to detect areas of potential dispersal of *D. rotundus* during the study period. In a study carried out with multivariate geostatistical methods, where the spatial distribution of BPR cases was evaluated from climatic variables and disease frequency, it was found that the greatest risk of the presence of BPR cases is found in the Huasteca region of the state of San Luis Potosí, which agrees with the present work[39].

During the three years studied, shelters of *D. rotundus* were found in abandoned sites, where despite being visited on more than one occasion, no specimen was captured, the percentage of abandonment of 58 % (34 shelters) in 2014 was higher than that found east of Sao Paulo, Brazil, where 260 shelters were identified, of which only 29 (11.2 %) were empty[36]. The abandonment of shelters may be due to factors such as food availability, deforestation, but above all, to the execution of lethal vampire control activities[16,36,40]. Usually, after some time, abandoned shelters can be recolonized, bringing with them new outbreaks of rabies or other emerging diseases[10,16,41].

The change of land use from rural to urbanized favors the shelters of the *D. rotundus* to be artificial(5). In this work some vampire bats were captured in urbanized sites, such as bus stops, schools, uninhabited houses, which is consistent with what was found in Sao Paulo, where 67 % of the shelters used by bats are artificial(42). This situation favors the interaction between humans, companion animals and vampire bats, which increases the risk of spread and persistence of infectious diseases(5,43).

The 337,836 people living within the 5 km flight radius of bats found in shelters would suggest a considerable risk; however, the events of aggression against humans reported by health authorities are few, which suggests a possible stable coexistence between these species. There are no studies that make the degree of interaction evident, so it is considered necessary to establish more precisely the implications of the relationship between these two species. Since the results of a work carried out in the east of Sao Paulo in Brazil shows the presence of a shelter of *D. rotundus* for every six farms, which relates the information with the size of the herd, but not of the human population. It is important to continue with studies such as that of Rocha *et al*(34), which allow establishing values on the potential number of vampire bats per shelter, the frequency of bites to livestock in a region and cases of rabies. With data like the above, the researchers were able to build a model to facilitate the location of shelters and thus be able to identify other vulnerable farms, where surveillance of vampire bat attacks and other control measures must be reinforced(36).

Considering that the presence of livestock is one of the main factors of the presence and proximity of *D. rotundus* to human communities, at the same time it could be a protection to humans, since vampires have more easily accessible food with domestic animals(8,44).

Conclusions and implications

It is common to identify shelters in sites near human populations of San Luis Potosí, which shows a relationship in the ecosystem between people and *D. rotundus*, in which, a higher frequency of aggressions by Chiroptera could be expected; however, that does not happen, which indicates an adaptation of coexistence between both species, especially in the southeast of the state. The fact that 80 % of the shelters have been artificial makes it necessary to study the role that urbanization plays in the distribution of *D. rotundus*, as well as the presence of wild and domestic animals as a buffer against attacks on humans. To date there is not enough information on the distribution of this chiropter and its spatial organization and considering the projections of climate change in the coming years, it is important to be able to predict the sites of environmental suitability for the location of possible shelters associating them with human settlements. This will improve epidemiological surveillance activities for rabies and other zoonotic diseases in the animal and human populations, given the potential of these species to transmit infectious diseases, which may allow serving more vulnerable localities given the close interaction with the species.

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Conflict of interest

The authors declare that they have no conflict of interest.

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