

Using Geoprocessing Techniques to Analyze the Geographic Distribution of *Lutzomyia* (*Nyssomyia*) *Whitmani* (Diptera: Psychodidae: Phlebotominae) Associated With Vegetation Cover, and the Impacts on the Expansion of American Cutaneous Leishmaniasis (ACL) In Brazil.

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Abstract

Background

In Brazil, due to new and complex epidemiologic scenarios, the focal and dynamic transmissions of American Cutaneous Leishmaniasis (ACL) occur in different patterns, depending on location. An important example of this phenomenon is the widespread distribution and various behavior patterns of *Lutzomyia (Nyssomyia) whitmani*, a vector that transmits three types of dermatropic leishmaniases: *Leishmania (Viannia) braziliensis*, *Leishmania (Viannia) shawi* and *Leishmania (Viannia) guyanensis*. This study aims to correlate different types of Brazilian vegetation with the spatial distribution of *L. (N.) whitmani* in the areas representing Spatial Circuits of Production for American Cutaneous Leishmaniasis (ACL).

Methods

In order to evaluate the ACL vigilance and monitoring model in Brazil, the Ministry of Health has analyzed the Spatial Circuit of the disease until 2013, currently adopting a classification of ACL transmission in municipalities that is based on the composite indicator of tegumentary leishmaniasis (ICLT). For this study, a Geographic Information System (GIS) was used to integrate the layers of *L. (N.) whitmani*'s geographic distribution with vegetation cover and Spatial Circuits of ACL in Brazilian municipalities.

Results

Out of the 5570 Brazilian municipalities here analyzed, information on the *L. (N.) whitmani* was found for 862. The vector occurred in nearly all types of vegetation, with a widespread distribution in: Dense Ombrophilous Forests, Open Ombrophilous Forests (or transition forests), Seasonal Deciduous Forests (or deciduous woods), Seasonal Semideciduous Forests (semideciduous woods) and Steppe. The vector was not found in Oligotrophic Woody Vegetation of the Marshes and of Sand Accumulation.

Conclusions

This ample presence of the vector reinforces the hypothesis that *L. (N.) whitmani* is a notable species, that can easily adapt to different environments.

Background

The focal and dynamic transmissions of American Cutaneous Leishmaniasis (ACL) occur in different ways in different sites, depending on factors related to parasites, vectors, ecosystems, social processes of production and soil use [1, 2] Considering this, the National Program for American Cutaneous Leishmaniasis Vigilance analyzes the disease per Spatial Circuits of Production – which are large, complex and continuous areas, defined by a high concentration of cases in a specific period, composed by several poles and, for the most part, encompassing more than one municipality. These circuits result

from particular, dynamic socio-environmental processes; and they may expand or shrink, depending on the characteristics of their determinants [1,3].

In this context, the *Lutzomyia (Nyssomyia) whitmani* is of key importance, for being considered the main vector of ACL in Brazil, with an ample geographic distribution and a capacity to adapt to different climates and vegetation types. In Brazil, this vector is associated to three different epidemiologic patterns: (1) Wild – here, transmission occurs in areas of primary vegetation. In this case, the disease is characterized as a zoonosis of wild animals, which can affect humans only when they are in contact with wild environments where the disease is circulating; (2) Occupational and Leisure – this pattern is associated to the disorderly occupation of forest environments and processes of deforestation; (3) Rural and peri-urban – in this case, ACL is related to migration processes, where the occupation of hills and conglomerates in urban centers is associated to secondary or residual vegetation [4,5,6,7,8].

In the North region of Brazil, the *L. (N.) whitmani* presents a distinct behavior pattern from other regions in the country: it is characterized as wild, being collected from large tree trunks, with a low tendency to bite men. In the states of Amazonas and Pará, this vector transmits *L. (V.) shawi* (Lainson et al. 1989). In Acre, Rondônia and Roraima, *L. (N.) whitmani* consists in the only species currently known to transmit *L. (V.) braziliensis* [5, 6, 7].

In the Northeast, Southeast, South and Center-west regions, *L. (N.) whitmani* can be found in peridomestic environments, where it practices anthropophilia and transmits *L. (V.) braziliensis* [9, 10,11,12,13]. Important endemic areas are in the states of Maranhão, Ceará, Pernambuco, Bahia, Minas Gerais, Espírito Santo and Paraná, where populations of *L. (N.) whitmani* inhabit domiciliary environments and congregate the main evaluation criteria of phlebotomine vectoral competence: spatial distribution associated with human cases, anthropophilia and natural infection by *L. (V.) braziliensis* [7]. Souza et al. [14] have recently verified, through natural infection studies, the transmission of *L. (V.) guyanensis* by *L. (N.) whitmani* in the French Guiana and in Suriname. This fact brings back a hypothesis raised by Lainson [15] that the *L. (N.) whitmani* would participate in the transmission cycle of the Amazon.

Considering *L. (N.) whitmani's* vast geographic distribution, this study aims to correlate the types of Brazilian vegetation with the spatial distribution of this vector in areas encompassed by the Spatial Circuits of Production of ATL in Brazilian municipalities. This exercise wishes to contribute to a better epidemiologic understanding of this disease in Brazil.

Methods

Study Areas

This study was carried out in areas corresponding to the Spatial Circuits of ACL Production, where these coincided with the geographic delimitation of states and the presence of *L. (N.) whitmani*. Following this logic, out of the 36 Spatial Circuits of ACL Production, 6 were selected: C2 (encompassing the states of

Maranhão and Piauí), C4 (including Pará, Tocantins and Maranhão), C7 (Minas Gerais and Espírito Santo), C11 (Paraná), C12 (Rondônia, Acre and Amazonas), and C21 (Piauí and Ceará) (Figure 1).

Vegetation cover in association with *Lutzomyia (Nyssomyia) whitmani* and the Spatial Circuits of American Cutaneous Leishmaniasis (ACL) Production

The map of the Brazilian vegetation (<https://mapas.ibge.gov.br/tematicos/vegetacao>) was correlated to the presence of *L. (N.) whitmani* in areas covered by Spatial Circuits of ACL Production. The epidemiologic data with information on spatial circuits used in this study (covering the years of 2003 to 2013) was provided by the Working Group on Leishmaniasis of the Brazilian Ministry of Health. The municipalities where *L. (N.) whitmani*'s presence was identified and confirmed were georeferenced, based on the Brazilian municipal division information of 2007. These data were retrieved from scientific papers, book chapters, the CAPES thesis databank, and information was also shared by State Health Secretariats. The information used to generate the databanks of the vector *L. (N.) whitmani* includes records of ACL presence, as well as: vector presence (meaning when more than one year of sampling was carried out, consistently finding vector presence); unconfirmed presence (when more than one year of sampling revealed no confirmation on vector presence); vector absence (when in one year or more of capture there were no records of the vector); and likely absence (when in less than one year no vector presence was registered).

Through the tools available in the Geographic Information System (GIS), the layers of Brazilian vegetation, vector presence and spatial circuits of disease production were overlapped, using the program ArcGis 10.4. The statistical package SPSS was the instrument chosen to calculate the correlations between vegetation and vector presence. A t-test was used to estimate the significance of the average proportions of correlation between vegetation and vector presence.

After these calculations, thematic maps were developed, presenting the most relevant variables of this study. Furthermore, a Kernel interpolator with an adaptation range was generated, aiming to identify hot spots (transmission areas with a high concentration of ACL cases and vector presence).

Results

Spatial Distribution

The analysis of *L. (N.) whitmani*'s spatial distribution throughout Brazilian municipalities has shown a wide spread of the vector. Out of the 5570 municipalities analyzed, 862 had information on the vector, out of which 808 (93.7%) showed presence and only 45 (5.2%) did not. Further, 9 municipalities (1.1%) showed unconfirmed absence of the vector. The study shows that this phlebotomine occurs in twenty-five states of the country, not being found only in Santa Catarina and Rio Grande do Sul (Figure 2).

The selected Spatial Circuits of ACL production were mapped and associated with the presence of the vector *L. (N.) whitmani*, which was predominant in all circuits (Figure 3).

Epidemiology

The pattern of spatial density within municipalities with *L. (N.) whitmani* presence revealed a higher concentration in the following regions: North (Acre, Amazonas, Rondônia, Pará, Tocantins and Amapá), Center-west (Mato-Grosso and Mato Grosso do Sul), Northeast (Ceará, Paraíba and Pernambuco), Southeast (Minas Gerais, Espírito Santo and São Paulo), and the South (Paraná). Coincidentally, these are the areas where important Spatial Circuits of ATL production are located (Figure 4).

Types of vegetation cover in association with *Lutzomyia (Nyssomyia) whitmani*

The *L. (N.) whitmani* is found in almost all types of Brazilian vegetation, except for Oligotrophic Woody Vegetation of the Marshes and of Sand Accumulation (<https://mapas.ibge.gov.br/tematicos/vegetacao>). The *L. (N.) whitmani* was identified in: Pioneer Formation Areas, Ecologic Tension Areas (where there is a contact between different types of vegetation), Steppe, Seasonal Deciduous Forests (deciduous woods), Mixed Ombrophilous Forests, Ecological Refuges (Altitude Fields); and, in a higher concentration, in Dense Ombrophilous Forests, Seasonal Semideciduous Forests (semideciduous woods), and Open Ombrophilous Forests (transition woods) (Figure 5).

The analysis of *L. (N.) whitmani*'s spatial distribution in association with vegetation cover and the six Spatial Circuits of ACL showed a higher density of the vector in Dense Ombrophilous Forests, Seasonal Deciduous Forests, Seasonal Semideciduous Forests, Savanna and Steppe (Figure 6).

Discussion

The thematic maps produced from the data on *L. (N.) whitmani*'s spatial distribution in Spatial Circuits of ACL Production associated to the different types of Brazilian vegetation showed a widespread distribution of the vector. This was mainly true for municipalities where Dense Ombrophilous Forests, Deciduous Ombrophilous Forests, Seasonal Semideciduous Forests, Ecological Tension Areas, Savanna and Steppe vegetation were predominant. The variety of vegetation types where the vector was found indicates its capacity to endure wide environmental variations and to expand to new areas, as described by Costa et al. [16]. These results reinforce the theory of vector presence in all Brazilian biomes, except for the Pampa, as previously suggested by Costa et al. [17] and Rangel et al. [18]. The fact that the vector occurred in all Brazilian states, except for Santa Catarina and Rio Grande Sul, also contributed for this study to conclude that the vector adapts smoothly to different types of vegetation, including environmentally impacted areas, where important Spatial Circuits of ACL are found. This conclusion supports studies performed by Costa et al. [6] on the widespread geographic distribution of *L. (N.) whitmani* in association with forest, cerrado and caatinga areas.

The great region of Tucuruí (C4) encloses areas in the states of Pará, Maranhão and Tocantins and suffers from great environmental impact due to external interventions, containing a high concentration of ACL human cases. In this region, *L. (N.) whitmani* is the predominant vector species, inhabiting both wild and human-occupied spaces [19, 6, 3]. In Tocantins, the applicable Spatial Circuit of ACL did not enclose

the entire state. However, given the percentage of human cases of ACL resulting from human action (the construction of hydroelectric plants, agricultural activities and the establishment of settlements), it can be said that the disease has a powerful impact in the state. These human activities are likely to have enabled or facilitated the spread of *L. (N.) whitmani* to 136 out of the 139 municipalities that compose Tocantins [20, 21].

In the North region, *L. (N.) whitmani* acted within eight Spatial Circuits of ACL production (C3, C4, C12, C13, C15, C16, C17 e C18), but especially in the states of Amazonas and Pará, transmitting *L. (V.) shawi*, and using monkeys (*Cebus apella*, *Chiropotes satanas*), "royal" sloths, "bentinha" (*Choloepus didactylus* e *Bradypus tridactylus*) and quatis (*Nasua nasua*) as hosts. In this region, the vector inhabits tree trunks of primary forests and bites avidly when disturbed [22, 15, 23, 24, 8]. To the north of the Amazon river, in the states of Amazonas, Pará and Roraima – where important ATL Spatial Circuits are located – and in Amapá – where there is no defined Spatial Circuit of ACL - *L. (N.) whitmani* transmits *L. (V.) guyanensis*. In these areas, the vector's hosts are sloths (*Choloepus didactylus*), tamanduás (*Tamandua tetradactyla*), the marsupial *Didelphis* sp. and the rodent *Proechimys* sp. [15, 25, 22, 26]. Recent studies on natural infection have shown the transmission of *L. (V.) guyanensis* by *L. (N.) whitmani* in Monte Dourado (PA), which brings back a discussion proposed by Lainson [27] on the taxonomic status of this vector [14].

Leishmania (V.) braziliensis is the main responsible for ACL in the northeast, southeast, south and center-west regions of Brazil. Important Spatial Circuits are located in the states of Maranhão, Ceará, Pernambuco, Bahia, Minas Gerais, Espírito Santo and Paraná. In these states, the populations of *L. (N.) whitmani* can be found in different environments and possess two fundamental criteria in the evaluation of phlebotomines' vectoral competence: a spatial distribution that coincides with human cases of ACL, and anthrophilia due to the vector's presence in peri-domiciliary environments [28, 29, 26, 5, 7].

Lutzomyia (N.) whitmani is capable of adapting and surviving deforestation in several regions of Brazil. This species' presence has been recorded in Mata Atlântica Reserves, in the Amazon, in Cerrado, Caatinga, and Pantanal. But also in peri-domiciliary environments, where residential areas are close to forests [30, 6, 17]. Recently, Costa et al. [16] have performed a study on climate adequacy, and they indicate the south as the most conducive direction for future presence of *L. (N.) whitmani*. The authors also predict an expansion of the vector to the North region, particularly in the state of Amazonas, in spite of the drought foreseen for this region, with an intensification and expansion of the dry season [31]. The authors sustain that *L. (N.) whitmani* will remain in the North, and will maintain a larger area of climactic adequacy.

Compared to other regions in the country, the *L. (N.) whitmani* presents a distinct behavior in the North. There, the species was considered to be mainly wild, being captured in tree trunks and treetops, with low interest in biting humans [25]. Studies in the following years confirmed these observations, and suggested that, if this species was anthropophilic, this would only be the case in specific situations [29, 28]. According to the results of the present study for the North of Brazil, spatial circuit 12 is present in the region, associated with Open Ombrophilous Forests. This type of vegetation is associated with a

relatively dry climate, predominant in 2 to 4 months per year, with temperatures ranging from 24 to 25°C. Other than the North region, this type of vegetation can also be found in the states of Bahia, Espírito Santo, Alagoas, Pernambuco and Paraíba [32]. Circuit 12 also encompasses an area of Dense Ombrophilous Forests. This vegetation's main ecologic trades are the records of the highest temperatures and most abundant rainfall indexes of the littoral and Amazonic regions. Here, rainfalls are well distributed throughout the year, contributing to a bioecological context where there is barely any dry period (consisting in 0 to 60 days per year) [33]. As evidenced by the dissonant characteristics of these two types of vegetation, the *L. (N.) whitmani* is capable of adapting to very diverse environments. This vector's role in ACL transmission in diverse epidemiologic patterns throughout Brazil has made the *L. (N.) whitmani* the single most important vector of ACL in the country. This vector is associated to three parasites of ACL: *L. (V.) braziliensis*, *L. (V.) shawi* and *L. (V.) guyanensis*.

Costa et al. [16] report that ACL tends to expand to the Northwest of Brazil, and that the disease is linked to recent deforestation areas. In old human occupation areas, the endemic character of the disease is closely related to modified residual forests, and in newer occupation areas, this endemic character is connected to the development of productive activities in contact with woods in their original form [8].

Lutzomyia (N.) whitmani is a species that can transmit ACL in both types of occupied areas: recent and old. This vector is responsible for the circulation of *L. (V.) braziliensis*, a species of parasite with a wider distribution and with a different epidemiology from *L. (V.) shawi* and *L. (V.) gyanensis* [34, 7]. As it transmits *L. (V.) braziliensis*, *L. (V.) shawi* and *L. (V.) guyanensis*; *L. (N.) whitmani* is considered the main vector of ACL in Brazil. It is found in areas with various types of vegetation cover - be they natural or impacted by human action -, and it is associated with important Spatial Circuits of ACL Production.

In order to locate the municipalities with ACL transmission, the Program of Tegumentary Leishmaniasis Vigilance (PV-LT) classifies municipalities into five categories, based on the composite indicator of tegumentary leishmaniasis (ICLT). The categories are: sporadic transmission, moderate transmission, low intense transmission, average intense transmission and high intense transmission [8]. The results obtained through the association of *L. (N.) whitmani* with Brazilian vegetation types, in the states where important Spatial Circuits of ACL Production occur can be converted into ICLT categories, as long as magnitude and incidence of the disease in each municipality is known.

Conclusions

The *L. (N.) whitmani* has a widespread geographic distribution and can be found in all regions of Brazil, which makes it an important vector of ACL in the country. Considering this scenario and the geographic expansion of this vector, the use of geo-technologies serves as a resourceful tool to identify the spatial distribution of *L. (N.) whitmani* and ACL transmission in the areas of important Spatial Circuits of the disease, in association with different vegetation types. The congregation of these factors with deforestation generates relevant environmental impacts, that favor the establishment of outbreaks and endemic areas for ACL. As it is known that environmental changes may impact on the eco-epidemiology

of ACL, the results discussed in this study should be taken into consideration for vigilance initiatives. In that way, they can contribute to health promotion in risk areas where *L. (N.) whitmani* transmits ACL, and strategies can be projected to municipalities, according to epidemiologic situation of the disease.

Declarations

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Availability of data and materials

The data supporting the conclusions of this article are available within the main text.

Authors' contributions

SMdC collected all the data. MdAFMM, RdSdGGC and EFR performed the statistical analyses. The three authors equally participated in writing the manuscript and approved its final version.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they do not have any competing interests.

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Figures

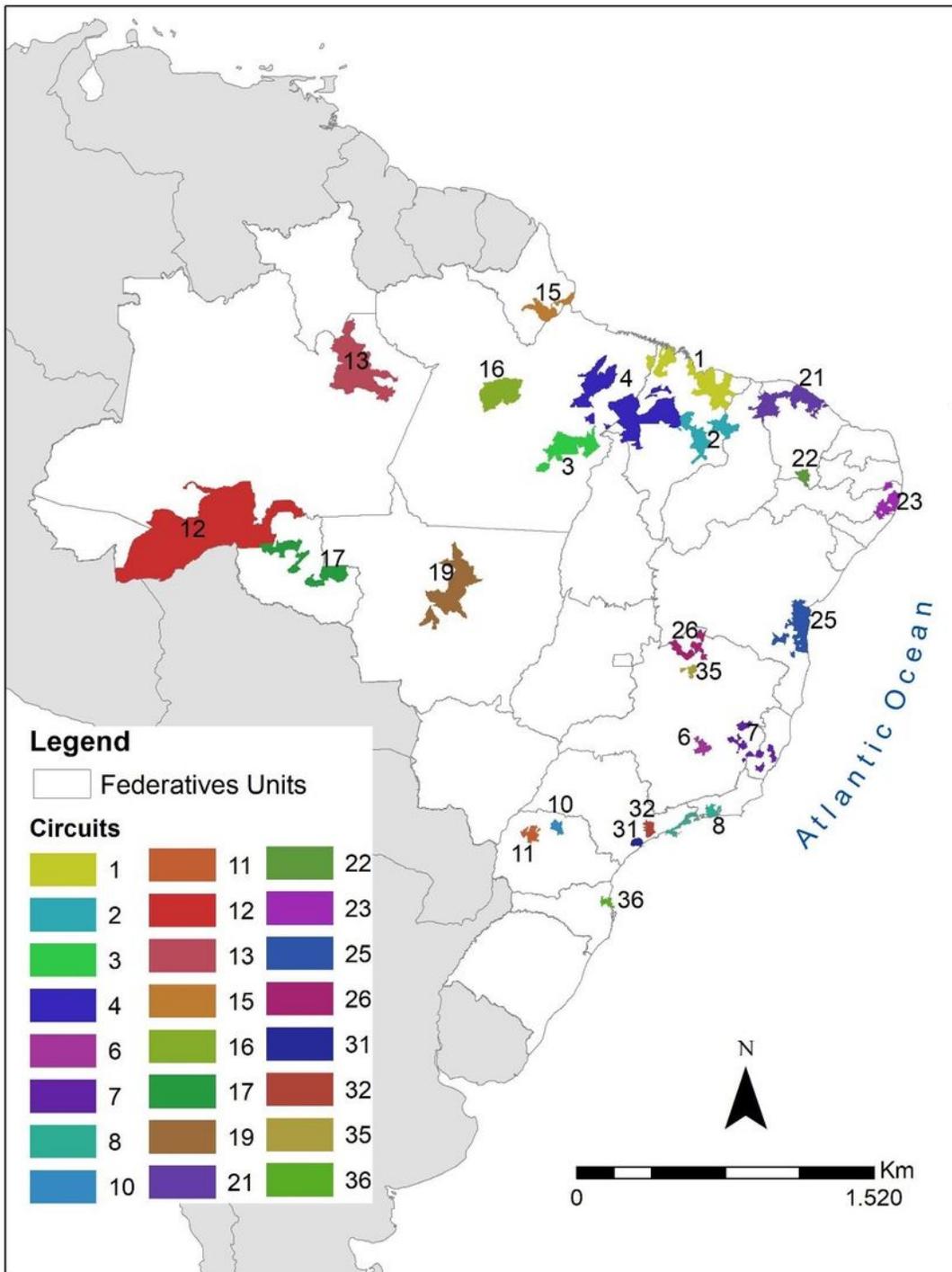


Figure 1

Geographic distribution of the 36 Spatial Circuits of American Tegumentary Leishmaniasis' production. Map developed by: Geoprocessing cluster - LIS/ICICT/FIOCRUZ. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its

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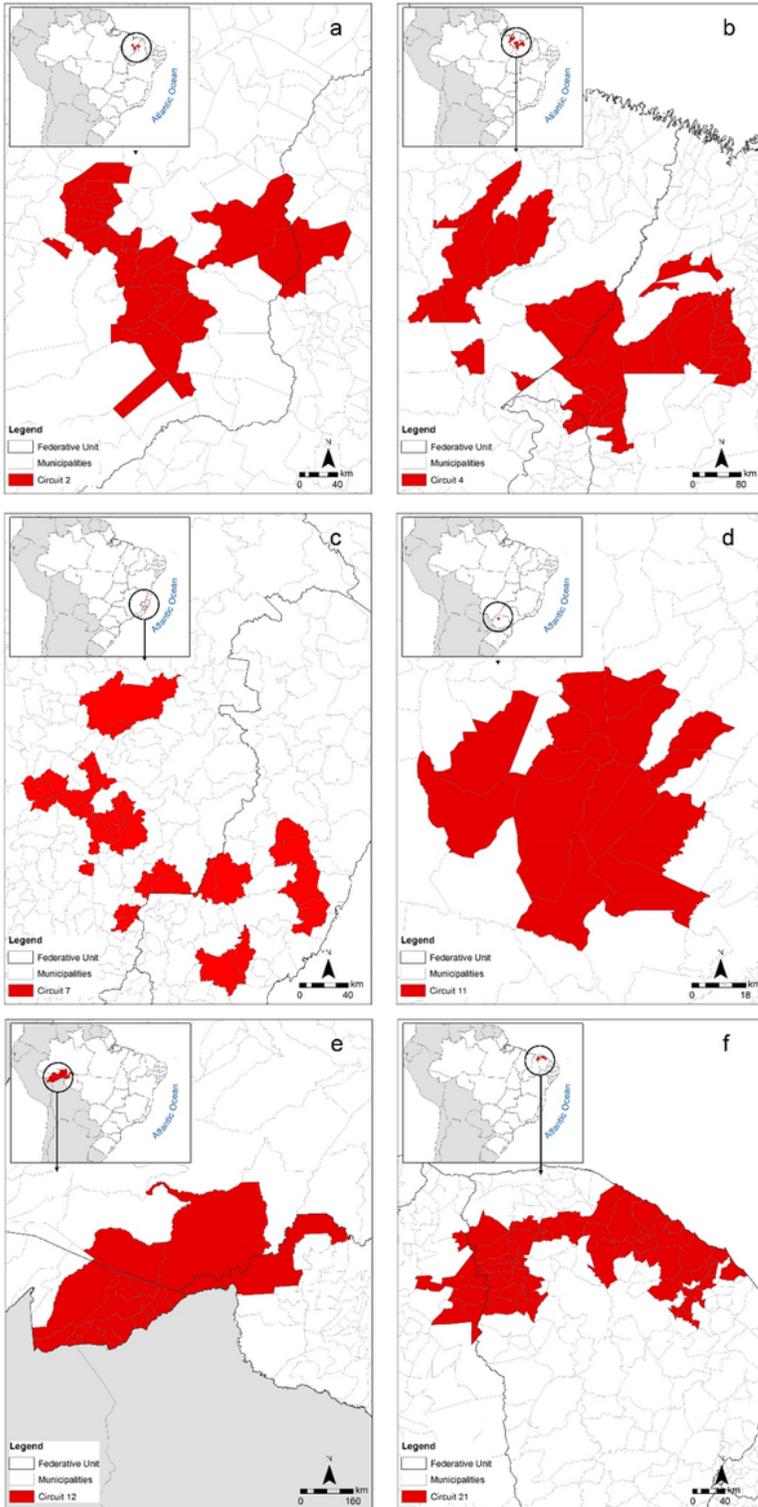


Figure 2

Spatial distribution of *Lutzomyia (N.) whitmani* in Brazilian municipalities. Map developed by: Geoprocessing cluster - LIS/ICICT/FIOCRUZ. 2016. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the

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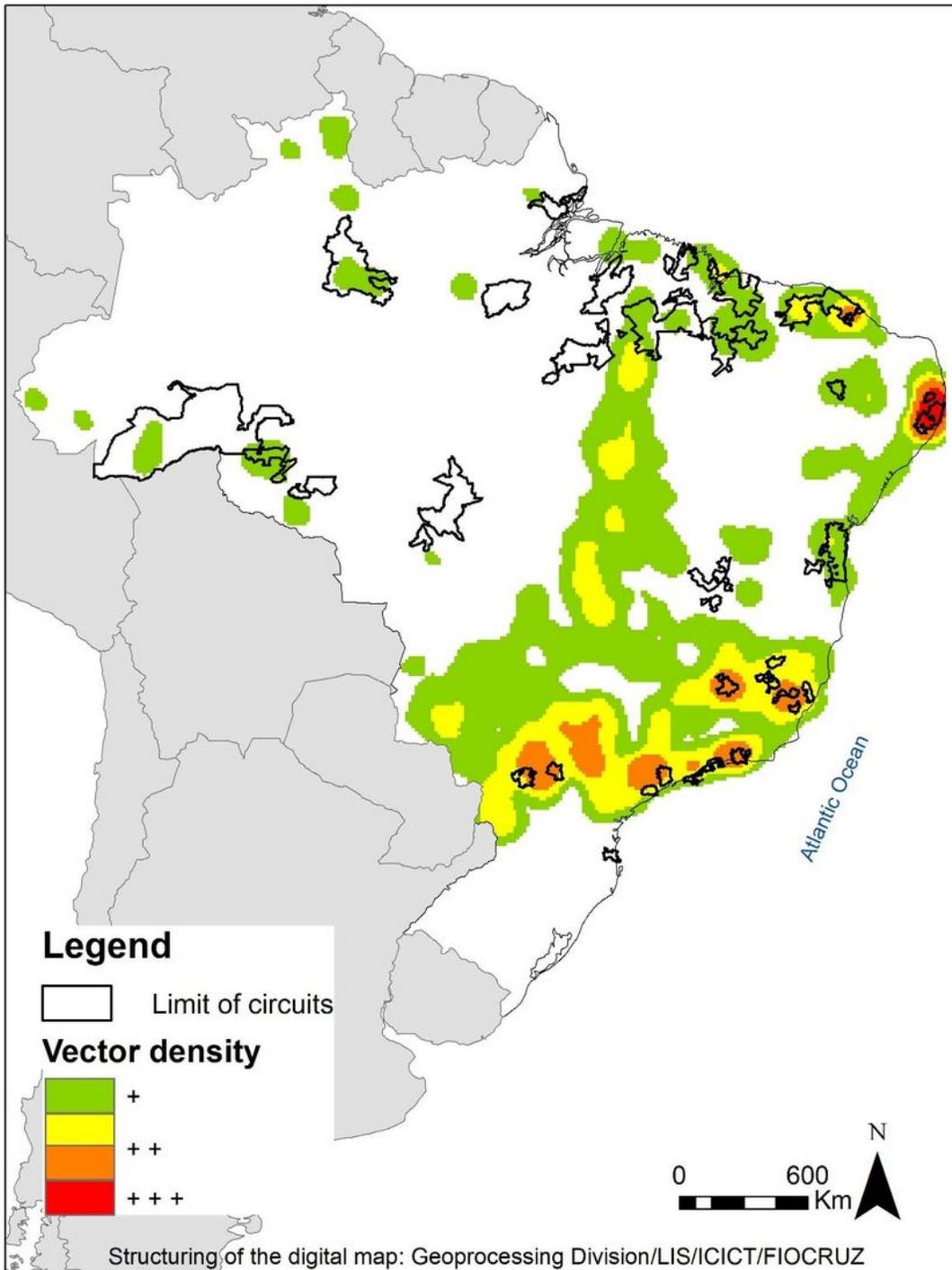


Figure 3

Spatial distribution of *Lutzomyia (N.) whitmani* by ATL Production Spatial Circuits. (a) Circuit 2 (Maranhão and Piauí), (b) Circuit 4 (Pará, Tocantins and Maranhão), (c) Circuit 7 (Minas Gerais and

Espírito Santo), (d) Circuit 11 (Paraná), (e) Circuit 12 (Rondônia, Acre and Amazonas) and (f) Circuit 21 (Piauí and Ceará). Map developed by: Geoprocessing Cluster - LIS/ICICT/FIOCRUZ, 2016. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

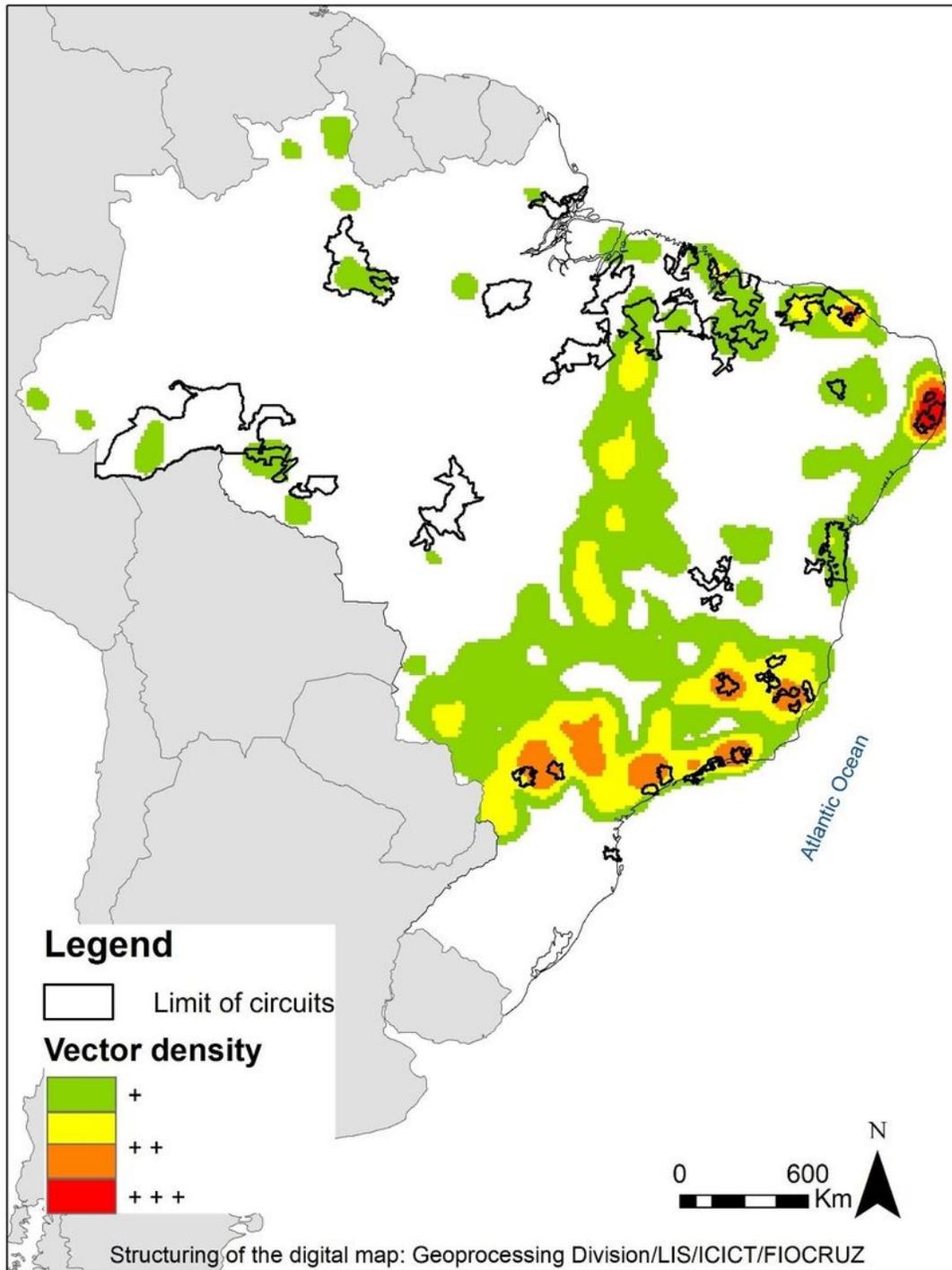


Figure 4

Lutzomyia (N.) whitmani's density, in association with Spatial Circuits of ATL Production in Brazil, according to the Kernel technique. Map developed by: Geoprocessing Cluster - LIS/ICICT/FIOCRUZ, 2016. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

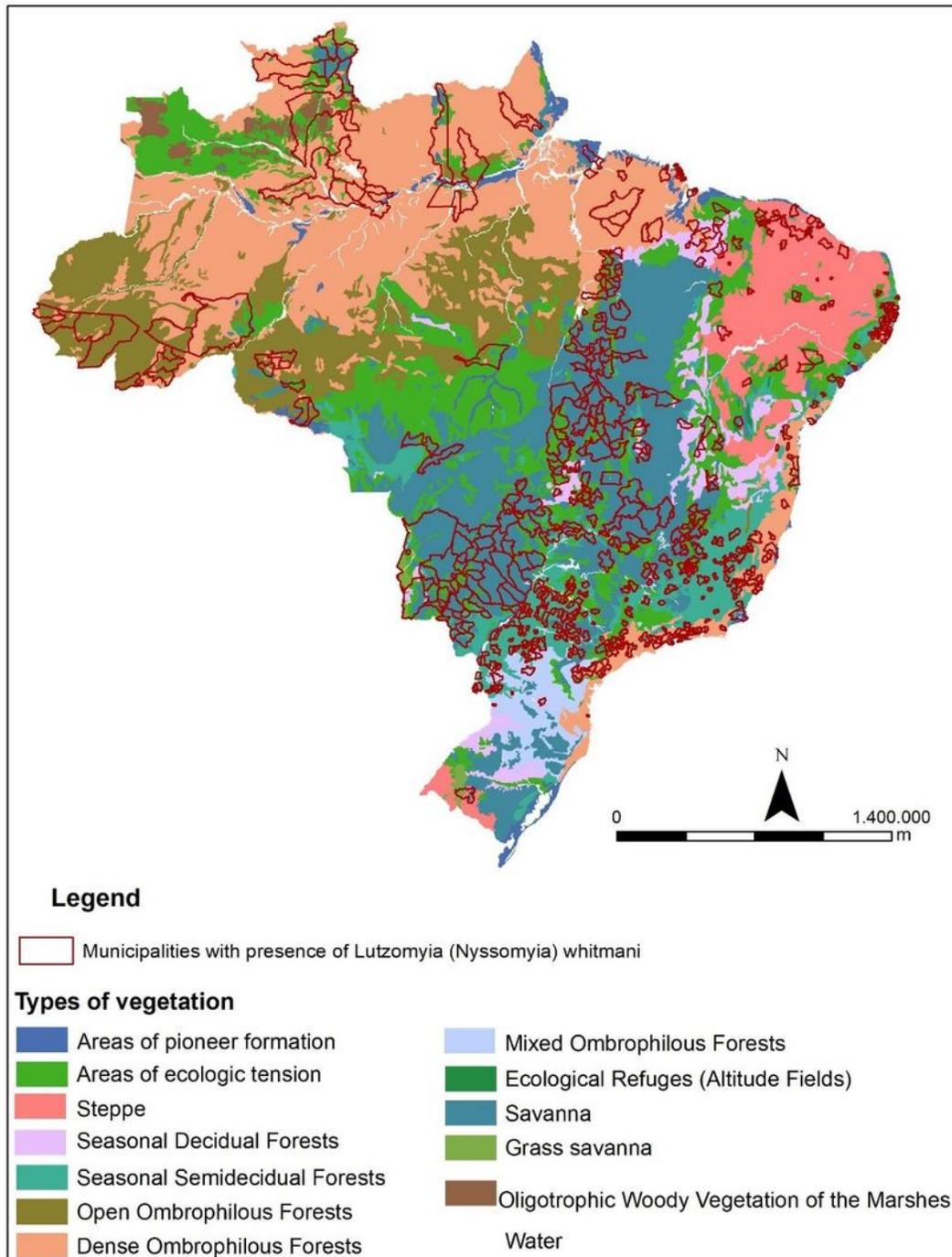


Figure 5

Spatial distribution of *Lutzomyia (N.) whitmani* associated to vegetation types (https://mapas.ibge.gov.br/tematicos/vegetacao). Map developed by: Geoprocessing Cluster LIS/ICICT/FIOCRUZ, 2017. Note: The designations the circuit employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

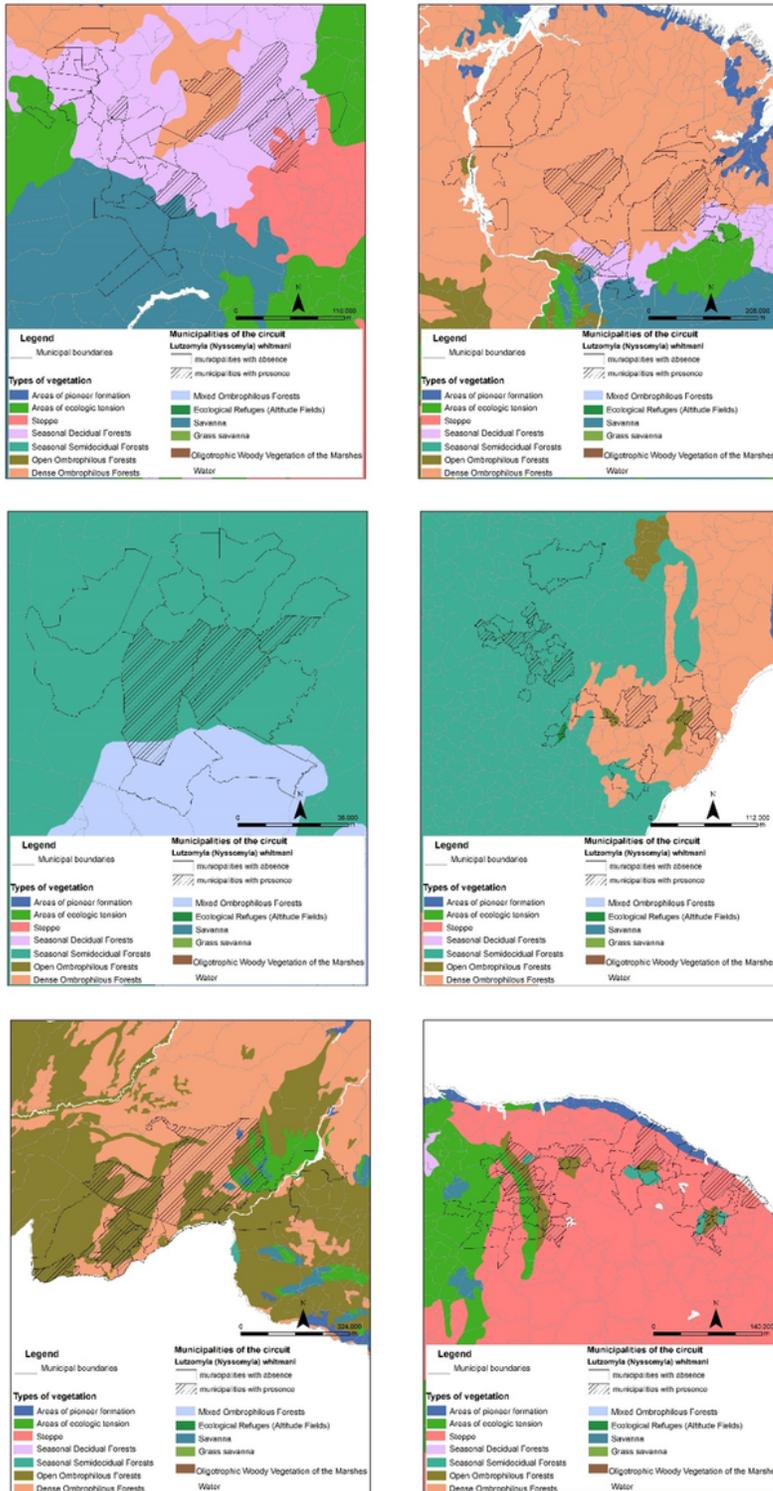


Figure 6

Analysis of the *Lutzomyia* (*Nyssomyia*) *whitmani*'s spatial distribution in association with vegetation types (<https://mapas.ibge.gov.br/tematicos/vegetacao>), within the six Spatial Circuits of American Tegumentary Leishmaniasis: (a) Circuit 2 (Maranhão and Piauí), (b) Circuit 4 (Pará, Tocantins and Maranhão), (c) Circuit 7 (Minas Gerais and Espírito Santo), (d) Circuit 11 (Paraná), (e) Circuit 12 (Rondônia, Acre and Amazonas), and (f) Circuit 21 (Piauí and Ceará). Map developed by: Geoprocessing Cluster - LIS/ICICT/FIOCRUZ, 2016. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.