Geographic distribution of phlebotomine sandfly species (Diptera: Psychodidae) in Central-West Brazil

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This study updates the geographic distributions of phlebotomine species in Central-West Brazil and analyses the climatic factors associated with their occurrence. The data were obtained from the entomology services of the state departments of health in Central-West Brazil, scientific collections and a literature review of articles from 1962-2014. Ecological niche models were produced for sandfly species with more than 20 occurrences using the Maxent algorithm and eight climate variables. In all, 2,803 phlebotomine records for 127 species were analysed. Nyssomyia whitmani, Evandromyia lenti and Lutzomyia longipalpis *were the species with the greatest number of records and were present in all the biomes in Central-West Brazil. The models, which were produced for 34 species, indicated that the* Cerrado *areas in the central and western regions of Central-West Brazil were climatically more suitable to sandflies. The variables with the greatest influence on the models were the temperature in the coldest months and the temperature seasonality. The results show that phlebotomine species in Central-West Brazil have different geographical distribution patterns and that climate conditions in essentially the entire region favour the occurrence of at least one* Leishmania *vector species, highlighting the need to maintain or intensify vector control and surveillance strategies.*

Key words: Phlebotominae - ecological niche modelling - Maxent - *Cerrado*

Leishmaniases primarily affect people living in poverty and they are neglected tropical diseases worldwide. According to the World Health Organization (2010), 350 million people are exposed to leishmaniases and two million cases occur every year. In the Americas, most of the cases occur in Brazil (Alvar et al. 2012). Between 2001-2012, 3,321 confirmed cases of visceral leishmaniasis (VL) were reported in Central-West Brazil. The majority (78%) were reported in Mato Grosso do Sul (MS), followed by Mato Grosso (MT), Goiás (GO) and the Federal District (DF). In the same period, there were 49,932 confirmed cases of American tegumentary leishmaniasis (ATL) in Central-West Brazil, most of which (82%) occurred in MT, followed by GO, MS and DF [Information System on Notifiable Diseases (saude.gov.br/sinanweb)].

In total, 989 phlebotomine species have been identified globally, of which 531 were recorded in the Americas and 277 in Brazil (Shimabukuro & Galati 2010, Andrade et al. 2013, Ladeia-Andrade et al. 2014, Oliveira et al. 2015, Vilela et al. 2015). Various studies have reported a great species richness of sandflies in Central-West Brazil, particularly in MT (106 spp), followed by MS (57 spp), GO (41 spp) and DF (27 spp) (Young & Duncan 1994, Martins et al. 2002, de Oliveira et al. 2006, Galati et al. 2006, Andrade Filho et al. 2007, Missawa & Maciel 2007, de Almeida et al. 2010b, 2013a, de Carvalho et al. 2010, SES/MT 2013). However, only 20 phlebotomine species are associated with the transmission of *Leishmania* in Brazil, including seven species in Central-West Brazil (MS 2006, 2010, Ready 2013).

Lutzomyia longipalpis (Lutz & Neiva 1912) is the main vector of *Leishmania infantum* in Latin America and it has a widespread distribution in Brazil (Deane & Deane 1962, Lanzaro et al. 1993, Sherlock 1996, Aguiar & Medeiros 2003, Galati 2003). *Lutzomyia cruzi* (Mangabeira, 1938) has been implicated as the *L. infantum* vector in some regions of MS (Galati et al. 1997, Santos et al. 1998) and MT (Missawa et al. 2011). *Lutzomyia forattini* Galati, Rego, Nunes & Teruya, 1985, *Lutzomyia almerioi* Galati & Nunes, 1999, *Nyssomyia antunesi* (Coutinho, 1939), *Migonemyia migonei* (França, 1920) and *Nyssomyia neivai* (Pinto, 1926) might be associated with VL transmission in Brazil (Galati et al. 1997, Lainson & Rangel 2003, Saraiva et al. 2009, Carvalho et al. 2010, Dias et al. 2013).

Nyssomyia whitmani (Antunes & Coutinho, 1939) has widespread distribution in Latin America and is the most important ATL vector in Brazil (Young & Duncan 1994, Galati 2003, Peterson & Shaw 2003, da Costa et al. 2007). In addition, *Bichromomyia flaviscutellata* (Mangabeira, 1942), *Ny. neivai* and *Nyssomyia intermedia* (Lutz & Neiva, 1912) have been incriminated as ATL vectors

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in various regions of Brazil (Shaw & Lainson 1968, Condino et al. 1998, Marcondes et al. 2005, 2009, Massafera et al. 2005, Andrade Filho et al. 2007, Silva et al. 2008, Dorval et al. 2010, de Almeida et al. 2013a).

Various studies have analysed the epidemiological importance and ecological aspects of sandflies in Central-West Brazil. However, the geographic distribution and dispersal potential of phlebotomine species must be described and analysed to understand the geographic dimensions of the risk of leishmaniases transmission. Ecological niche modelling (ENM) could be used in this context to estimate the potential geographic distribution of species, based on known occurrence records (Peterson 2006, Peterson et al. 2011). ENM has been used to estimate sandfly distribution and factors related to leishmaniases transmission (Peterson & Shaw 2003, Gebre-Michael et al. 2004, Peterson et al. 2004, Nieto et al. 2006, Zeilhofer et al. 2008, Colacicco-Mayhugh et al. 2010, de Oliveira et al. 2012, de Almeida et al. 2013b, Moo-Llanes et al. 2013, Quintana et al. 2013, Samy et al. 2014). The aim of this study was to analyse the geographic distribution of phlebotomine species in Central-West Brazil as well as the climatic factors associated with their occurrence.

MATERIALS AND METHODS

Study area - Central-West Brazil covers an area of 1,606,371 km² and consists of the following four federal units: MT, MS, GO and DF. The region is divided into 467 municipalities, most of which are in GO [Brazilian Institute of Geography and Statistics (ibge.gov.br/cidades)], which has a population of 14,993,194, found predominantly in urban areas (89%). Geographically, Central-West Brazil is formed by a central and a southern plateau and the Pantanal plain. The *Cerrado*, the predominant biome, covers the greatest area; however, the other biomes include the Pantanal, Atlantic Forest and Amazon Forest (Fig. 1). The climate is tropical with the following two well-defined seasons: a rainy summer between October-March and a dry winter between April-September.

Distribution data - The phlebotomine occurrence data were obtained from the entomology services in the state departments of health (MT, MS, GO and DF) and correspond to captures conducted between 1996-2014. In addition, the literature data between 1962-2014 were reviewed (Martins et al. 1962, 1978, 2002, Galati et al. 1985, 1989, 1997, 2001, 2006, Carvalho et al. 1989, Azevedo et al. 2002, de Oliveira et al. 2003, 2006, Braga-Miranda et al. 2006, Dorval et al. 2006, 2009, 2010, Andrade Filho et al. 2007, Missawa & Dias 2007, Missawa & Maciel 2007, Silva et al. 2007, 2008, Missawa et al. 2008, Andrade et al. 2009, de Almeida et al. 2010a, b, 2013a, b, Paiva et al. 2010, Amaral et al. 2011, Mestre et al. 2011, Alves et al. 2012, Queiroz et al. 2012, Santos et al. 2013, Thies et al. 2013). The records from scientific collections in speciesLink (splink.cria.org.br/), a distributed information system that combines primary data from scientific collections in real time and in the Museum of Zoology of the University of São Paulo were analysed as well. The taxonomic classification used follows Galati (2003) and the abbreviations of the sandfly genera are those proposed by Marcondes (2007).

Species occurrence in the biomes - To analyse the phlebotomine occurrence in the biomes in Central-West Brazil, the species distribution data and the limits of the biomes in the region were superimposed using QGIS 2.6. The relative occurrence (the number of records in the biome/total number of records for the species in Central-West Brazil) was then calculated and represented graphically using Excel.

ENM - The phlebotomine species records were georeferenced with a confidence level of < 5 km and an approximate accuracy of 0.01º. The geographic coordinates of named places were obtained from an online gazetteer (fallingrain.com/world) and the data were organised in spreadsheets. The species occurrence database was reviewed in ArcGIS to avoid duplicate records at the spatial resolution used and obvious errors of georeferencing (e.g., points in the ocean) or identification (out dated taxonomic arrangements).

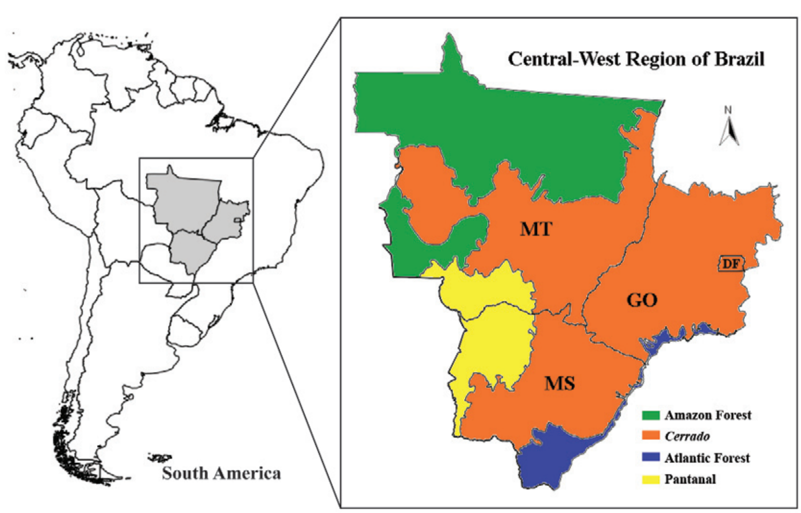

Fig. 1: study area showing the states in Central-West Brazil and the limits of the biomes in this region. DF: Federal District; GO: state of Goiás; MS: state of Mato Grosso do Sul; MT: state of Mato Grosso.

Potential distribution models were produced for the phlebotomine species with more than 20 records to allow for more accurate modelling (Stockwell & Peterson 2002). The models were based on the following eight climatic variables: the mean annual temperature, mean diurnal temperature range, temperature seasonality, maximum temperature in the warmest months, minimum temperature in the coldest months, annual precipitation, precipitation in the wettest months and precipitation in the driest months. These data were obtained from the WorldClim project (worldclim.org) and are the result of interpolation of the mean monthly climatic data from meteorological stations over 30-50 years (1950-2000), depending on the data availability at the stations (Hijmans et al. 2005). The eight variables were selected to avoid confounding effects by producing models in an environmental space with an excess of dimensions (Peterson & Nakazawa 2008). The environmental data used in the analyses had a spatial resolution of 5 x 5 km per pixel. The potential distribution models were produced by the maximum entropy method using Maxent, v.3.2.1. (Phillips et al. 2006). The basic parameters proposed by the program were used with 10 replications by bootstrap sub sampling. The occurrence data for the species were separated into two sets, as follows: one set for the model calibration (75% of the points) and the other set for the model evaluation (25% of the points). The potential geographic distribution models (the median output grids from Maxent) were imported and edited using the ArcGis 9 program (ESRI).

The model accuracy was assessed by analysing the omission rates associated with the test points (Anderson et al. 2002). The jackknife test implemented in Maxent was used to identify which variables had the greatest influence on the distribution of the recorded phlebotomine species (Phillips et al. 2006). This test measures the predictive effect of each variable in the model by determining the quality of the models produced with only the variable being tested and the quality of those produced with this variable being omitted.

RESULTS

In all, 2,803 phlebotomine records for 17 genera and 127 species were analysed in Central-West Brazil, as follows: *Bichromomyia* (2 spp), *Brumptomyia* (7 spp), *Evandromyia* (21 spp), *Expapillata* (1 sp.), *Lutzomyia* (12 spp), *Martinsmyia* (2 spp), *Micropygomyia* (11 spp), *Migonemyia* (2 spp), *Nyssomyia* (8 spp), *Pintomyia* (11 spp), *Pressatia* (3 spp), *Psathyromyia* (19 spp), *Psychodopygus* (13 spp), *Trychopygomyia* (3 spp), *Trichophoromyia* (6 spp), *Sciopemyia* (3 spp) and *Viannamyia* (3 spp). These fauna correspond to approximately 50% of all the known phlebotomine species in Brazil. MT was the state with the greatest species richness (n = 108; 85%), followed by MS (n = 61; 48%), GO (n = 39; 31%) and DF (n = 29; 23%). The *Evandromyia*, *Lutzomyia*, *Psathyromyia* and *Psychodopygus* genera had the greatest species richness.

The *Brumptomyia*, *Evandromyia*, *Lutzomyia*, *Nyssomyia*, *Pintomyia*, *Psathyromyia*, *Micropygomyia* and *Sciopemyia* genera were distributed widely throughout Central-West Brazil. The geographical distributions of most of the phlebotomine species analysed in this study are shown in Supplementary Figure.

All 34 species with more than 20 points have at least one record in the *Cerrado* and 24 (70%) presented a relative occurrence > 50% in this biome (Fig. 2). Ten species were more common in the Amazon, particularly *Evandromyia bacula*, *Psychodopygus complexus* and *Trychopygomyia dasypodogeton*. *Ny. neivai* and *Lu. cruzi* were the species with the highest number of records in the Atlantic Forest and the Pantanal, respectively (Fig. 2).

To study the potential geographic distribution of the phlebotomine species in Central-West Brazil, 2,216 records were analysed, as follows: *Bi. flaviscutellata* (n = 62), *Brumptomyia brumpti* (n = 55), *Brumptomyia avellari* (n = 33), *Ev. bacula* (n = 21), *Evandromyia carmelinoi* (n = 76), *Evandromyia evandroi* (n = 98), *Evandromyia lenti* (n = 143), *Evandromyia saulensis* (n = 62), *Evandromyia termitophila* (n = 116), *Evandromyia teratodes*

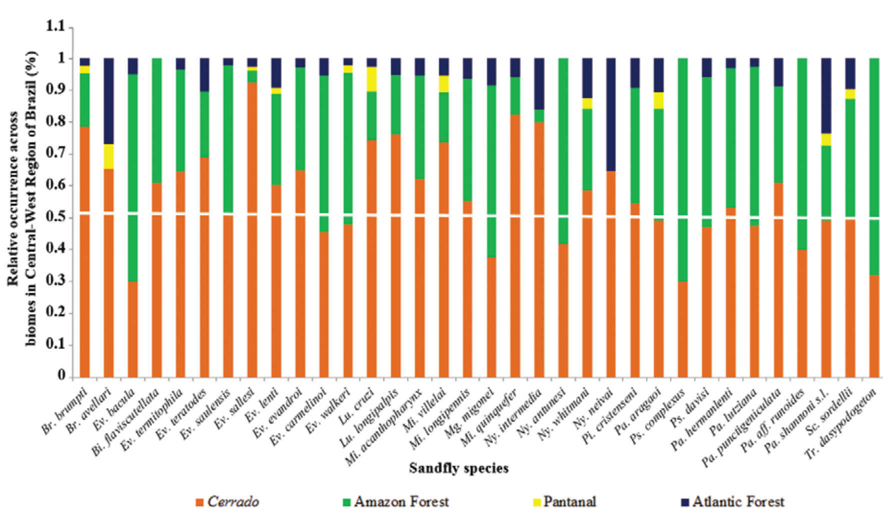

Fig. 2: relative occurrence of 34 phlebotomine species in biomes in Central-West Brazil based on the percentage of known occurrences in each area. The white line indicates a relative frequency of 50%.

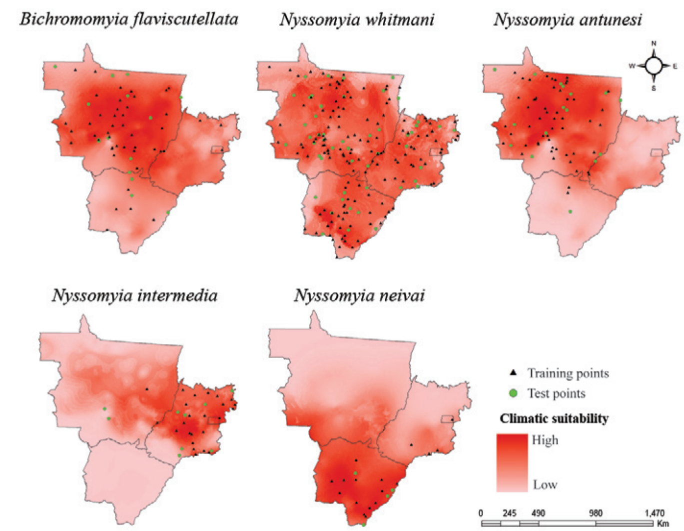

Fig. 3: potential geographic distribution of American tegumentary leishmaniases vectors in Central-West Brazil. The triangles represent the points used to produce the ecological niche model based on eight climate variables. The circles show the points used to evaluate the models. The red scale shows climate suitability for the different species (dark: high; light: low).

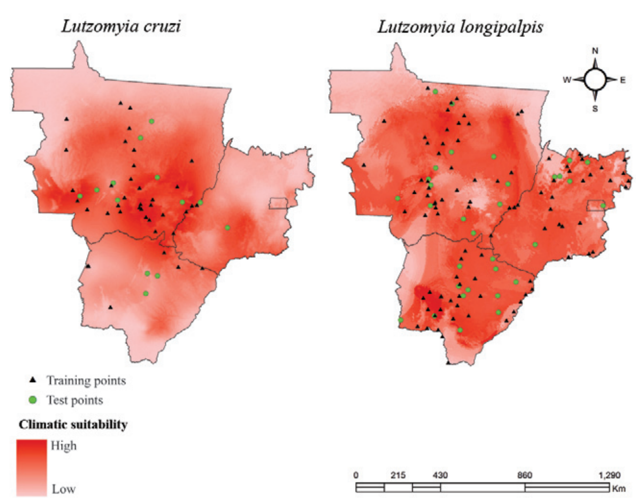

Fig. 4: potential geographic distribution of visceral leishmaniases vectors in Central-West Brazil. The triangles represent the points used to produce the ecological niche model based on eight climate variables. The circles show the points used to evaluate the models. The red scale shows climate suitability for the different species (dark: high; light: low).

(n = 38), *Evandromyia walkeri* (n = 61), *Evandromyia sallesi* (n = 105), *Lu. cruzi* (n = 52), *Lu. longipalpis* (n = 129), *Micropygomyia acanthopharynx* (n = 49), *Micropygomyia villelai* (= *Micropygomyia goiana*) (n = 25), *Micropygomyia longipennis* (n = 62), *Micropygomyia quinquefer* (n = 22), *Mg. migonei* (n = 33), *Ny. antunesi* (n = 71), *Ny. intermedia* (n = 34), *Ny. neivai* (n = 22), *Ny. whitmani* (n = 178), *Psathyromyia aragaoi* (n = 76), *Psathyromyia hermanlenti* (n = 85), *Psathyromyia lutziana* (n = 53), *Psathyromyia* aff. *runoides* (n = 46), *Psathyromyia shannoni* "*sensu lato*" (n = 73), *Psathyromyia punctigeniculata* (n = 61), *Pintomyia christenseni* (n = 29), *Psychodopygus complexus* (n = 27), *Psychodopygus davisi* (n = 68), *Sciopemyia sordellii* (n = 123) and *Ty. dasypodogeton* (n = 28). The ecological niche models of most of these species and their geographic coordinates are shown in the Supplementary Figure and Table, respectively.

Ny. whitmani was distributed widely in all the states and had the potential to occur throughout the entire territory of Central-West Brazil (Fig. 3). *Bi. flaviscutellata* and *Ny. antunesi* were common in MT, where the climate was more suitable to these species. However, *Bi. flaviscutellata* had high potential to occur in southern GO as well. The distributions of *Ny. neivai* and *Ny. intermedia* were more restricted to MS and GO, respectively (Fig. 3). *Lu. longipalpis* had a broader geographic distribution than *Lu. cruzi*. Areas in northern GO, north-western MT and southern MS were not highly suitable for *Lu. cruzi* (Fig. 4).

The temperatures in the coldest months and temperature seasonality were the variables with the greatest influence on the models, according to the jackknife tests. Most of the test points for the species were included in the areas predicted by the ENMs. All the models had omission errors < 1% and could therefore be validated.

DISCUSSION

This study updated the geographic distributions of phlebotomine species in Central-West Brazil, which account for approximately one-half of all the known species recorded in Brazil. The results show that phlebotomine species have different geographic distribution patterns in this region and that nearly all the areas of Central-West Brazil have climate conditions that favour the occurrence of at least one of these species. The distribution patterns show that sandflies are found more frequently in the *Cerrado* areas and that temperature seasonality and temperature in the coldest months are the climate variables that have the greatest influence on the species distribution.

The phlebotomine species list of Central-West Brazil was updated. Missawa & Maciel (2007) and SES/MT (2013) recorded 106 species in MT, which is fewer than the 108 species registered in this study. In MS, de Oliveira et al. (2006), Galati et al. (2006) and de Almeida et al. (2010b) reported 57 species, which is fewer than the 61 species registered here. Martins et al. (2002) detected 41 species in GO, whereas 47 were found in this study. This study did not find new records of sandfly species in Central-West Brazil. The differences between the numbers of species in the previous lists and in this study are in part because the records of the health departments of municipalities are generally unpublished. In addition, we included the lists of Martins et al. (1978), which is sometimes overlooked in the literature and even the latest revision of Galati (2014), which updates the species records in the Brazilian states. The higher species richness in MT is probably related to the size of this state and the variety of the biomes (the *Cerrado*, Amazon Forest and Pantanal) and transition zones, which could favour diversification of phlebotomine fauna, as observed for triatomine species (Pereira et al. 2013). According to Sábio et al. (2014), *Pa. shannoni* do not occur in Brazil and, based on this taxonomic review of the shannoni series, the specimens recorded in Central-West Brazil is *Psathyromyia bigeniculata* (Floch & Abonnenc, 1941). The records of *Lutzomyia cruciata*, *Pintomyia andina*, *Psathyromyia lanei*, *Psathyromyia ruparupa*, *Psychodopygus nigaraguensis* and *Viannamyia caprina* require confirmation. Moreover, *Lutzomyia gomezi*, *Micropygomyia vonatzingeni*, *Evandromyia cortelezzii* and *Pintomyia kuscheli* could be incorrectly registered in the CWB because they are morphologically similar to *Lutzomyia sherlocki*, *Micropygomyia oswaldoi*, *Evandromyia corumbaensis* and *Pintomyia fischeri* or *Pintomyia pessoai*, respectively (EAB Galati, unpublished observations). Specimens identified as *Sciopemyia microps* and *Pa. runoides* can be new species; in the present study they are considered as *Sciopemyia* aff. *microps* and *Pa*. aff. *runoides* (AJ Andrade, unpublished observations). The occurrence records in the present study are according to identified species by health services and formally published. The revision of specimens deposited in scientific collections should elucidate these possible taxonomic problems.

Ny. whitmani showed a widespread geographic distribution in Central-West Brazil, corroborating the findings of other studies (Young & Duncan 1994, Galati 2003, Peterson & Shaw 2003). This species is one of the commonest in artificial environments in Brazil. Its presence in an area is positively correlated with deforestation and it occurs primarily in municipalities with lower economic development indexes (Galati et al. 2006, da Costa et al. 2007, Missawa et al. 2008, Zeilhofer et al. 2008, de Almeida et al. 2013b). *Ny. intermedia* occurs predominantly in GO and DF; however, this study indicated that areas in western MT are climatically suitable and could therefore favour dispersal of this species within this state. This species has a widespread distribution in the Southeast Region of Brazil (Peterson & Shaw 2003). The climatic conditions in southern Central-West Brazil (particularly in MS) were suitable for *Ny. neivai* and not for *Ny. intermedia*. The distribution of *Ny. intermedia* and *Ny. neivai* should be revised in future studies because they are similar species and identification errors could cause it to be difficult to map their geographic distributions correctly (Marcondes 1996, Andrade Filho et al. 2003, 2007). *Bi. flaviscutellata* had great potential to occur in southern GO within the *Cerrado* biome, for which there are few records of this species. According to Young and Duncan (1994), *Bi. flaviscutellata* is found predominantly in the Amazon Region. Our results show that it is frequently found in the *Cerrado* as well and that it probably disperses along the gallery forests in this biome. *Ny. antunesi*, *Ty. dasypodogeton* and *Ps. complexus* were found predominantly in northern MT and had a significant relative occurrence in the Amazon biome, which is in agreement with Young and Duncan (1994).

Lu. longipalpis occurred in all the biomes in Central-West Brazil, confirming its great adaptability to different environments (Deane & Deane 1962, Lanzaro et al. 1993, Sherlock 1996, Aguiar & Medeiros 2003, Galati 2003, de Almeida et al. 2013b). *Lu. cruzi* occurred predominantly in MT and MS, confirming the findings of Missawa and Lima (2006). However, the niche model revealed high climate suitability for *Lu. cruzi* in southern GO. Further studies in these areas are required to confirm the presence of *Lu. cruzi*. Although not involved in the transmission of leishmaniases, *Ev. lenti* was widespread in Central-West Brazil, as previously reported by Young and Duncan (1994) and Galati (2003).

The variables with the greatest influence on the models were the temperatures in the coldest months and temperature seasonality, as in the study of *Lu. longipalpis* in MS by de Almeida et al. (2013b). These results are in agreement with those of Guzmán and Tesh (2000) and highlight the fundamental importance of temperature for the development and occurrence of phlebotomines. However, biotic and socioeconomic variables influence the occurrence of these insects as well (Zeilhofer et al. 2008). Therefore, further studies analysing the geographic distribution of phlebotomines under environmental and climate-change scenarios are required (Moo-Llanes et al. 2013).

Considerable efforts were made in this study to establish a comprehensive, representative, up-to-date database of phlebotomine species in Central-West Brazil. However, although the data were gathered from a variety of sources (e.g., scientific articles, museums and books), some records will inevitably have been overlooked, as an inherent limitation of geographic distribution studies. Furthermore, taxonomic issues might have had an effect on the occurrence data, maps and models described here. The database spatial resolution in this study could limit the accuracy of the ENMs. Models based on low-resolution data tend to overestimate the species distribution limits (Seo et al. 2009). The effects of these uncertainties related to low resolution tend to be smaller in studies on a continental or regional scale (Wiens et al. 2009).

Finally, this study could facilitate the development of surveillance and control strategies for leishmaniases in Central-West Brazil. Areas that are climatically suitable for the species discussed in this study and are without any confirmed occurrence should be investigated in future phlebotomine surveys. The maps produced here could serve as reference to future studies on sandflies and are the first step to developing an Atlas of Phlebotominae in Brazil, with the geographical distribution of all the species, which could be useful in academic studies and health services.

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