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

Paulo Silva de Almeida[1,2], Andrey José de Andrade[3], Alan Sciamarelli[1], Josué Raizer[1], Jaqueline Aparecida Menegatti[4], Sandra Cristina Negreli Moreira Hermes[4], Maria do Socorro Laurentino de Carvalho[5], Rodrigo Gurgel-Gonçalves[3]/+

[1]Faculdade de Ciências Biológicas e Ambientais, Universidade Federal da Grande Dourados, Dourados, MS, Brasil
[2]Laboratório Regional de Entomologia, Núcleo Regional de Saúde, Secretaria de Estado de Saúde, Dourados, MS, Brasil
[3]Laboratório de Parasitologia Médica e Biologia de Vetores, Área de Patologia, Faculdade de Medicina, Universidade de Brasília, Brasília, DF, Brasil [4]Laboratório de Entomologia, Secretaria de Saúde do Estado do Mato Grosso, Cuiabá, MT, Brasil
[5]Diretoria de Vigilância Ambiental em Saúde, Secretaria de Estado da Saúde do Distrito Federal, Brasília, DF, Brasil

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

doi: 10.1590/0074-02760140462
Financial support: CAPES, CNPq
+ Corresponding author: rgurgel@unb.br
Received 5 December 2014
Accepted 27 February 2015

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).

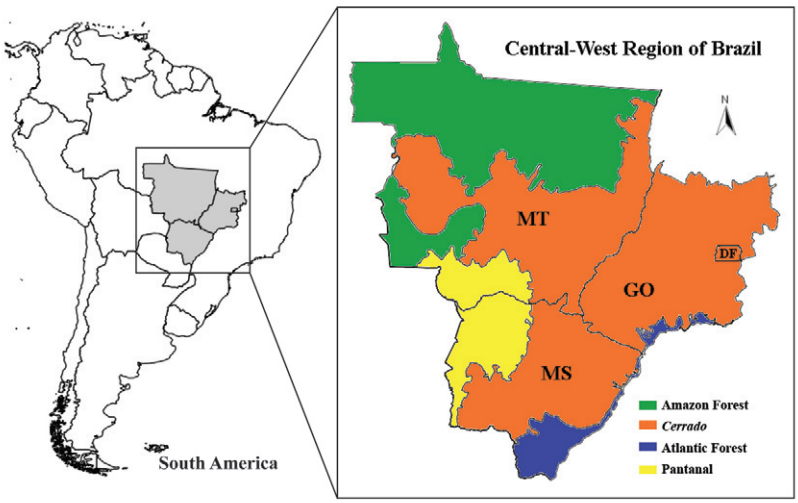

Fig. 1: study area showing the states in Central-West Brazil and the limits of the biomes in this region. DF: Federal District; GO: state of Goiás; MS: state of Mato Grosso do Sul; MT: state of Mato Grosso.

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*

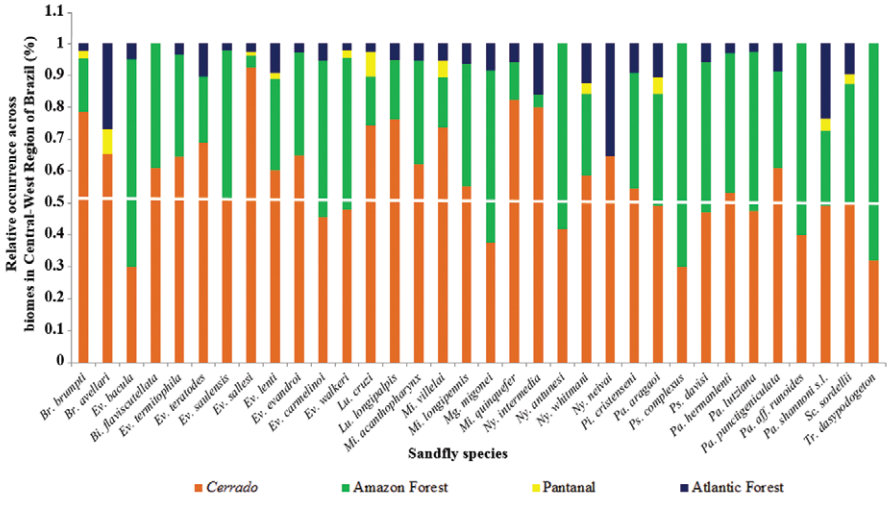

Fig. 2: relative occurrence of 34 phlebotomine species in biomes in Central-West Brazil based on the percentage of known occurrences in each area. The white line indicates a relative frequency of 50%.

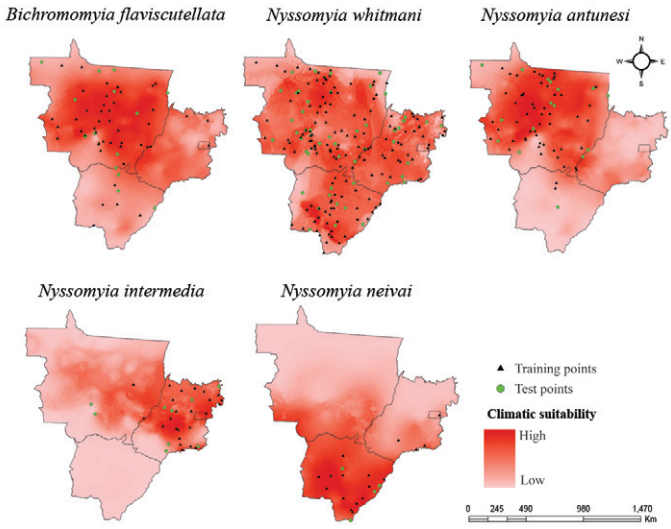

Fig. 3: potential geographic distribution of American tegumentary leishmaniases vectors in Central-West Brazil. The triangles represent the points used to produce the ecological niche model based on eight climate variables. The circles show the points used to evaluate the models. The red scale shows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

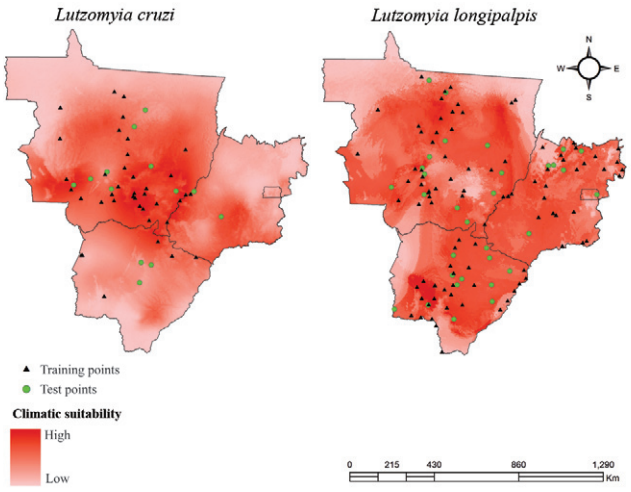

Fig. 4: potential geographic distribution of visceral leishmaniases vectors in Central-West Brazil. The triangles represent the points used to produce the ecological niche model based on eight climate variables. The circles show the points used to evaluate the models. The red scale shows climate suitability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

ACKNOWLEDGEMENTS

To Dr Marcos Takashi Obara (University of Brasilia), for reviewing the paper.

REFERENCES

Aguiar GM, Medeiros WM 2003. Distribuição e habitats. In EF Rangel, R Lainson (orgs.), *Flebotomíneos do Brasil*, Fiocruz, Rio de Janeiro, p. 207-255.

Alvar J, Vélez ID, Bern C, Herrero M, Desjeux P, Cano J, Jannin J, den Boer M, WHO *Leishmaniasis* Control Team 2012. Leishmaniasis worldwide and global estimates of its incidence. *PLoS ONE 7*: e35671.

Alves GB, Oshiro ET, Leite MC, Melão AV, Ribeiro LM, Mateus NLF, Brazil RP, Andrade Filho JD, de Oliveira AG 2012. Phlebotomine sand flies fauna (Diptera: Psychodidae) at rural settlements in the municipality of Cáceres, state of Mato Grosso, Brazil. *Rev Soc Bras Med Trop 45*: 437-443.

Amaral AFS, Varjão JR, Silva GB, Arrais-Silva WW 2011. Phlebotomine fauna (Diptera: Psychodidae: Phlebotominae) in a residential area and in a fragment of savanna vegetation in the municipality of Pontal do Araguaia, Mato Grosso, Brazil. *Rev Bras Parasitol Vet 20*: 165-167.

Anderson RP, Gómez-Laverde M, Peterson AT 2002. Geographical distributions of spiny pocket mice in South America: insights from predictive models. *Global Ecol Biogeogr 11*: 131-141.

Andrade AJ, Shimabukuro PHF, Galati EAB 2013. On the taxonomic status of *Phlebotomus breviductus* Barretto, 1950 (Diptera: Psychodidae: Phlebotominae). *Zootaxa 3734*: 477-484.

Andrade Filho JD, Galati EAB, Falcão AL 2003. Redescription of *Nyssomyia intermedia* (Lutz & Neiva, 1912) and *Nyssomyia neivai* (Pinto, 1926) (Diptera: Psychodidae). *Mem Inst Oswaldo Cruz 98*: 1059-1065.

Andrade Filho JD, Galati EAB, Falcão AL 2007. *Nyssomyia intermedia* (Lutz & Neiva, 1912) and *Nyssomyia neivai* (Pinto, 1926) (Diptera: Psychodidae: Phlebotominae) geographical distribution and epidemiological importance. *Mem Inst Oswaldo Cruz 102*: 481-487.

Andrade ROA, Nunes VLB, Galati EAB, Arruda CCP, Santos MFC, Rocca MLGE, Aquino RB 2009. Estudo epidemiológico das leishmanioses em área de turismo ambiental e ecoturismo, estado de Mato Grosso do Sul, 2006-2007. *Rev Soc Bras Med Trop 42*: 488-493.

Azevedo ACR, Souza NA, Meneses CRV, Costa WA, Costa SM, Lima JB, Rangel EF 2002. Ecology of sand flies (Diptera: Psychodidae: Phlebotominae) in the north of the state of Mato Grosso, Brazil. *Mem Inst Oswaldo Cruz 97*: 459-464.

Braga-Miranda LC, Miranda M, Galati EAB 2006. Phlebotomine fauna in a rural area of the Brazilian Pantanal. *Rev Saude Publica 40*: 324-326.

Carvalho MESD, Heloísa ES, Naves HAM 1989. Contribuição ao conhecimento da fauna flebotomínica do estado de Goiás e Distrito Federal. II - 1986-1987. *Rev Patol Trop 18*: 7-14.

Carvalho MR, Valença HF, Silva FJ, Pita-Pereira D, Pereira TA, Britto C, Brazil RP, Brandão-Filho S 2010. Natural *Leishmania infantum* infection in *Migonemyia migonei* (França, 1920) (Diptera: Psychodidae: Phlebotominae) the putative vector of visceral leishmaniasis in Pernambuco state, Brazil. *Acta Trop 116*: 108-110.

Colacicco-Mayhugh M, Masuoka P, Grieco J 2010. Ecological niche model of *Phlebotomus alexandri* and *P. papatasi* (Diptera: Psychodidae) in the Middle East. *Int J Health Geogr 9*: 1-9.

Condino ML, Sampaio SM, Henriques LF, Galati EAB, Wanderley DMV, Corrêa FMA 1998. Leishmaniose tegumentar americana: flebotomíneos de área de transmissão no município de Teodoro Sampaio, região sudoeste do estado de São Paulo, Brasil. *Rev Soc Bras Med Trop 31*: 355-360.

da Costa SM, Cechinel M, Bandeira V, Zannuncio JC, Lainson R, Rangel EF 2007. *Lutzomyia (Nyssomyia) whitmani s.l.* (Antunes & Coutinho, 1939) (Diptera: Psychodidae: Phlebotominae): geographical distribution and the epidemiology of American cutaneous leishmaniasis in Brazil - Mini-review. *Mem Inst Oswaldo Cruz 102*: 149-153.

de Almeida PS, Leite JA, Araújo AD, Batista MP, Touro RBS, Araújo VS, Souza EJ, Rodrigues JB, Oliveira GA, Santos JV, Faccenda O, Andrade Filho JD 2013a. Fauna of phlebotomine sand flies (Diptera, Psychodidae) in areas with endemic American cutaneous leishmaniasis in the state of Mato Grosso do Sul, Brazil. *Rev Bras Entomol 57*: 105-112.

de Almeida PS, Minzão ER, Minzão L, Silva SR, Ferreira AD, Faccenda O, Andrade Filho JD 2010a. Aspectos ecológicos de flebotomíneos (Diptera: Psychodidae) em área urbana do município de Ponta Porã, estado de Mato Grosso do Sul. *Rev Soc Bras Med Trop 43*: 723-727.

de Almeida PS, Nascimento JC, Ferreira AD, Minzão LD, Portes F, Miranda AM, Faccenda O, Andrade Filho JD 2010b. Espécies de flebotomíneos (Diptera: Psychodidae) coletadas em ambiente urbano em municípios com transmissão de leishmaniose visceral do estado de Mato Grosso do Sul, Brasil. *Rev Bras Entomol 54*: 304-310.

de Almeida PS, Sciamarelli A, Batista PM, Ferreira AD, Nascimento J, Raizer J, Andrade Filho JD, Gurgel-Gonçalves R 2013b. Predicting the geographic distribution of *Lutzomyia longipalpis* (Diptera: Psychodidae) and visceral leishmaniasis in the state of Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz 108*: 992-996.

de Carvalho MSL, Bredt A, Meneghin ERS, de Oliveira C 2010. Flebotomíneos (Diptera: Psychodidae) em áreas de ocorrência de leishmaniose tegumentar americana no Distrito Federal, Brasil, 2006 a 2008. *Epidemiol Serv Saúde 19*: 227-237.

de Oliveira AG, Andrade Filho JD, Falcão AL, Brazil RP 2003. Estudo de flebotomíneos (Diptera, Psychodidae) na zona urbana da Cidade de Campo Grande, Mato Grosso do Sul, Brasil, 1999-2000. *Cad Saude Publica 19*: 933-944.

de Oliveira AG, Galati EAB, de Oliveira O, de Oliveira GR, Espindola IAC, Dorval MEC, Brazil RP 2006. Abundance of *Lutzomyia longipalpis* (Diptera: Psychodidae: Phlebotominae) and urban transmission of visceral leishmaniasis in Campo Grande, state of Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz 101*: 869-874.

de Oliveira EF, Silva EA, Fernandes CES, Paranhos Filho AC, Gamarra RM, Ribeiro AA, Brazil RP, de Oliveira AG 2012. Biotic factors and occurrence of *Lutzomyia longipalpis* in endemic area of visceral leishmaniasis, Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz 107*: 396-401.

Deane LM, Deane MP 1962. Visceral leishmaniasis in Brazil: geographical distribution and transmission, São Paulo. *Rev Inst Med Trop 4*: 198-212.

Dias ES, Michalsky EM, Nascimento JC, Ferreira EC, Valadão JL, Fortes-Dias CL 2013. Detection of *Leishmania infantum*, the etiological agent of visceral leishmaniasis, in *Lutzomyia neivai*, a putative vector of cutaneous leishmaniasis. *J Vector Ecol 38*: 193-196.

Dorval MEC, Alves TP, Cristaldo G, Rocha HC, Alves MA, Oshiro ET, Oliveira AG, Brazil RP, Galati EAB, Cunha RV 2010. Sand fly captures with Disney traps in area of occurrence of *Leishmania (Leishmania) amazonensis* in the state of Mato Grosso do Sul, mid-western Brazil. *Rev Soc Bras Med Trop 43*: 491-495.

Dorval MEC, Cristaldo G, da Rocha HC, Alves TP, Alves MA, Oshiro ET, de Oliveira AG, Brazil RP, Galati EAB, da Cunha RV 2009. Phlebotomine fauna (Diptera: Psychodidae) of an American cutaneous leishmaniasis endemic area in the state of Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz 104*: 695-702.

Dorval MEC, Oshiro ET, Cupollilo E, Castro ACC, Alves TP 2006. Occurrence of American tegumentary leishmaniasis in the Mato Grosso do Sul state associated to the infection for *Leishmania (Leishmania) amazonensis*. *Rev Soc Bras Med Trop 39*: 43-46.

Galati EAB 2003. Classificação de Phlebotominae. In EF Rangel, R Lainson (eds.), *Flebotomíneos do Brasil*, Fiocruz, Rio de Janeiro, p. 23-51.

Galati EAB 2014. Apostila de bioecologia e identificação de Phlebotominae (Diptera, Psychodidae). Available from: fsp.usp.br/egalati/.

Galati EAB, Nunes VLB, Boggiani PC, Dorval MEC, Cristaldo G, Rocha HC, Oshiro ET, Damasceno-Júnior GA 2006. Phlebotomines (Diptera: Psychodidae) in forested areas of the Serra da Bodoquena, state of Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz 101*: 175-193.

Galati EAB, Nunes VLB, Dorval MEC, Cristaldo G, Rocha HC, Gonçalves-Andrade RM, Naufel G 2001. Attractiveness of black Shannon trap for phlebotomines. *Mem Inst Oswaldo Cruz 96*: 641-647.

Galati EAB, Nunes VLB, Oshiro ET, Rego Jr FA 1989. Nova espécie de Phlebotominae, *Lutzomyia corumbaensis*, sp. n. (Diptera, Psychodidae) do complexo *Lutzomyia cortelezzii*. *Rev Bras Entomol 33*: 465-475.

Galati EAB, Nunes VLB, Rêgo-Júnior FA, Oshiro ET, Chang MR 1997. Estudo de flebotomíneos (Diptera: Psychodidae) em foco de leishmaniose visceral no estado de Mato Grosso do Sul, Brasil. *Rev Saude Publica 31*: 378-390.

Galati EAB, Rego Jr FA, Nunes VL, Teruya E 1985. Fauna flebotomínica do município de Corumbá, Mato Grosso do Sul, Brasil, e descrição de *Lutzomyia forattinii*, sp. n. (Diptera, Psychodidae, Phlebotominae). *Rev Bras Entomol 29*: 261-266.

Gebre-Michael T, Malone J, Balkew M, Ali A, Berhe N, Hailu A, Herzi AA 2004. Mapping the potential distribution of *Phlebotomus martini* and *P. orientalis* (Diptera: Psychodidae), vectors of kala-azar in East Africa by use of geographic information systems. *Acta Trop 90*: 73-86.

Guzmán H, Tesh RB 2000. Effects of temperature and diet on the growth and longevity of phlebotomine sand flies (Diptera: Psychodidae). *Biomedica 20*: 190-199.

Hijmans J, Cameron SE, Parra JL, Jones PG, Jarvis A 2005. Very high resolution interpolated climate surfaces for global land areas. *Int J Climatol 25*: 1965-1978.

Ladeia-Andrade S, Fe NF, Sanguinette CC, Andrade Filho JD 2014. Description of *Trichophoromyia uniniensis*, a new phlebotomine species (Diptera: Psychodidae: Phlebotominae) of Amazonas state, Brazil. *Parasit Vectors 7*: 400.

Lainson R, Rangel EF 2003. Ecologia das leishmanioses. In EF Rangel, R Lainson (orgs.), *Flebotomíneos do Brasil*, Fiocruz, Rio de Janeiro, p. 291-309.

Lanzaro GC, Ostrovska K, Herrero MV, Lawyer PG, Warburg A 1993. *Lutzomyia longipalpis* is a species complex: genetic divergence and interspecific hybrid sterility among three populations. *Am J Trop Med Hyg 48*: 839-847.

Marcondes CB 1996. A redescription of *Lutzomyia (Nyssomyia) intermedia* (Lutz & Neiva, 1912) and resurrection of *L. neivai* (Pinto, 1926) (Diptera, Psychodidae, Phlebotominae). *Mem Inst Oswaldo Cruz 91*: 457-462.

Marcondes CB 2007. A proposal of generic and subgeneric abbreviations for phlebotomine sand flies (Diptera: Psychodidae: Phlebotominae) of the world. *Entomol News 118*: 351-356.

Marcondes CB, Bittencourt IA, Stoco PH, Eger I, Grisard EC, Steindel M 2009. Natural infection of *Nyssomyia neivai* (Pinto, 1926) (Diptera: Psychodidae, Phlebotominae) by *Leishmania* (*Viannia*) spp in Brazil. *Trans R Soc Trop Med Hyg 103*: 1093-1097.

Marcondes CB, Conceição MBF, Portes MGT, Simão BP 2005. Phlebotomine sandflies in a focus of dermal leishmaniasis in the eastern region of the Brazilian state of Santa Catarina - preliminary results (Diptera: Psychodidae). *Rev Soc Bras Med Trop 38*: 353-355.

Martins AV, Falcão AL, Silva JE 1962. Nota sobre os flebotomíneos do estado de Goiás com a descrição de duas espécies novas e da fêmea de *Lutzomyia longipennis* (Barreto, 1946) e a redescrição do macho da *L. evandroi* (Costa Lima & Antunes, 1936) (Diptera: Psychodidae). *Rev Bras Malariol Doencas Trop 14*: 379-394.

Martins AV, Willians P, Falcão AL 1978. *American sandflies (Diptera: Psychodidae, Phlebotominae)*, Academia Brasileira de Ciências, Rio de Janeiro, 195 pp.

Martins F, Silva LG, Bezera WA, Maciel IJ, Silva HHG, Lima CG, Cantuária PB, Ramos OS, Ribeiro JB, Santos AS 2002. Diversidade e frequência da fauna flebotomínea (Diptera: Psychodidae) em áreas com transmissão de leishmaniose no estado de Goiás. *Rev Patol Trop 31*: 211-224.

Massafera R, Silva AM, Carvalho AP, Santos DR, Galati EAB, Teodoro U 2005. Fauna de flebotomíneos do município de Bandeirantes, no estado do Paraná. *Rev Saude Publica 39*: 571-577.

Mestre GLC, Ribeiro ALM, Miyazaki RD, Rodrigues JSV, Almeida ABPF, Sousa VRF, Missawa NA 2011. Phlebotomine sand flies and canine infection in areas of human visceral leishmaniasis, Cuiabá, Mato Grosso. *Rev Bras Parasitol Vet 20*: 228-234.

Missawa NA, Dias ES 2007. Phlebotomine sand flies (Diptera: Psychodidae) in the municipality of Várzea Grande: an area of transmission of visceral leishmaniasis in the state of Mato Grosso, Brazil. *Mem Inst Oswaldo Cruz 102*: 913-918.

Missawa NA, Lima GBM 2006. Distribuição espacial de *Lutzomyia longipalpis* (Lutz & Neiva, 1912) e *Lutzomyia cruzi* (Mangabeira, 1938) no estado de Mato Grosso. *Rev Soc Bras Med Trop 39*: 337-340.

Missawa NA, Maciel GB 2007. List of species in the genus *Lutzomyia*, França, 1924 (Psychodidae, Phlebotominae) from the state of Mato Grosso. *Rev Soc Bras Med Trop 40*: 11-14.

Missawa NA, Maciel GBML, Rodrigues H 2008. Distribuição geográfica de *Lutzomyia (Nyssomyia) whitmani* (Antunes & Coutinho, 1939) no estado de Mato Grosso. *Rev Soc Bras Med Trop 41*: 369-373.

Missawa NA, Veloso MAE, Lima GBM, Michalsky EM, Dias ES 2011. Evidência de transmissão de leishmaniose visceral por *Lutzomyia cruzi* no município de Jaciara, estado de Mato Grosso, Brasil. *Rev Soc Bras Med Trop 44*: 76-78.

Moo-Llanes D, Ibarra-Cerdeña CN, Rebollar-Téllez EA, Ibáñez-Bernal S, González C, Ramsey JM 2013. Current and future niche of north and central American sand flies (Diptera: Psychodidae) in climate change scenarios. *PLoS Negl Trop Dis 7*: e2421.

MS - Ministério da Saúde 2006. *Manual de vigilância e controle da leishmaniose visceral*, DVE/SVS/MS, Brasília, 122 pp.

MS - Ministério da Saúde 2010. *Manual de vigilância da leishmaniose tegumentar americana*, SVS/MS, Brasília, 180 pp.

Nieto P, Malone JB, Bavia ME 2006. Ecological niche modeling for visceral leishmaniasis in the state of Bahia, Brazil, using genetic algorithm for rule-set prediction and growing degree day-water budget analysis. *Geospat Health 1*: 115-126.

Oliveira AG, Sanguinette CC, Almeida PS, Andrade Filho JD 2015. Description of *Evandromyia (Aldamyia) orcyi*, a new phlebotomine species (Diptera: Psychodidae: Phlebotominae) from the state of Mato Grosso do Sul, Brazil. *Parasit Vectors 8*: 233.

Paiva BR, Oliveira AG, Dorval MEMC, Galati EAB, Malafronte RS 2010. Species-specific identification of *Leishmania* in naturally infected sand flies captured in Mato Grosso do Sul state, Brazil. *Acta Trop 115*: 126-130.

Pereira JM, de Almeida PS, de Sousa AV, de Paula AM, Machado RB, Gurgel-Gonçalves R 2013. Climatic factors influencing triatomine occurrence in Central-West Brazil. *Mem Inst Oswaldo Cruz 108*: 335-341.

Peterson AT 2006. Ecologic niche modeling and spatial patterns of disease transmission. *Emerg Infect Dis 12*: 1822-1826.

Peterson AT, Nakazawa Y 2008. Environmental data sets matter in ecological niche modelling: an example with *Solenopsis invicta* and *Solenopsis richteri*. *Glob Ecol Biogeogr 17*: 135-144.

Peterson AT, Pereira RS, Neves VFC 2004. Using epidemiological survey data to infer geographic distributions of leishmaniasis vector species. *Rev Soc Bras Med Trop 37*: 10-14.

Peterson AT, Shaw J 2003. *Lutzomyia* vectors for cutaneous leishmaniasis in Southern Brazil: ecological niche models, predicted geographic distributions and climate change effects. *Int J Parasitol 33*: 919-931.

Peterson AT, Soberón J, Pearson RG, Anderson RP, Martínez-Meyer E, Nakamura M, Araújo MB 2011. *Ecological niches and geographic distributions*, Princeton University Press, Princeton, 314 pp.

Phillips SJ, Anderson RP, Schapire RE 2006. Maximum entropy modeling of species geographic distributions. *Ecol Model 190*: 231-259.

Queiroz MFM, Varjão JR, Moraes SC, Salcedo GE 2012. Analysis of sandflies (Diptera: Psychodidae) in Barra do Garças, state of Mato Grosso, Brazil, and the influence of environmental variables on the vector density of *Lutzomyia longipalpis* (Lutz & Neiva, 1912). *Rev Soc Bras Med Trop 45*: 313-317.

Quintana M, Salomón O, Guerra R, de Grosso ML, Fuenzalida A 2013. Phlebotominae of epidemiological importance in cutaneous leishmaniasis in northwestern Argentina: risk maps and ecological niche models. *Med Vet Entomol 27*: 39-48.

Ready PD 2013. Biology of phlebotomine sand flies as vectors of disease agents. *Annu Rev Entomol 58*: 227-250.

Sábio PB, Andrade AJ, Galati EAB 2014. Assessment of the taxonomic status of some species included in the shannoni complex, with the description of a new species of *Psathyromyia* (Diptera: Psychodidae: Phlebotominae). *J Med Entomol 51*: 331-341.

Samy AM, Campbell LP, Peterson AT 2014. Leishmaniasis transmission: distribution and coarse-resolution ecology of two vectors and two parasites in Egypt. *Rev Soc Bras Med Trop 47*: 57-62.

Santos MFC, Ribolla PEM, Alonso DP, Andrade-Filho JD, Casaril AE, Ferreira AMT, Fernandes CES, Brazil RP, Oliveira AG 2013. Genetic structure of *Lutzomyia longipalpis* populations in Mato Grosso do Sul, Brazil, based on microsatellite markers. *PLoS ONE 8*: e74268.

Santos SO, Arias J, Ribeiro AA, Hoffmann MP, Freitas RU, Malacco MAF 1998. Incrimination of *Lutzomyia cruzi* as a vector of American visceral leishmaniasis. *Med Vet Entomol 12*: 315-317.

Saraiva L, Carvalho GML, Quaresma PF, Lima ACVMR, Falcão AL, Andrade Filho JD 2009. Natural infection of *Nyssomyia neivai* (Pinto, 1926) and *Evandromyia sallesi* (Galvao & Coutinho, 1939) (Diptera: Psychodidae) by *Leishmania infantum chagasi* Cunha and Chagas, 1937 in Minas Gerais, Brazil. *J Med Entomol 49*: 1159-1163.

Seo C, Thorne JH, Hannah L, Thuiller W 2009. Scale effects in species distribution models: implications for conservation planning under climate change. *Biol Lett 23*: 39-43.

SES/MT - Secretaria de Estado de Saúde de Mato Grosso 2013. *Relatório das espécies de flebotomíneos detectados em atividades de vigilância entomológica em Mato Grosso no período de 1996 a 2013*, Superintendência de Vigilância em Saúde/Coordenadoria de Vigilância em Saúde Ambiental/Gerência de Núcleos de Apoio em Vigilância em Saúde Ambiental, Cuiabá, 51 pp.

Shaw JJ, Lainson R 1968. *Leishmaniasis* in Brazil: II. Observations on enzootic rodent leishmaniasis in the lower Amazon Region - The feeding habitats of the vector, *Lutzomyia flaviscutellata*, in reference to man, rodents and other animals. *Trans R Soc Trop Med Hyg 62*: 396-405.

Sherlock IA 1996. Ecological interactions of visceral leishmaniasis in the state of Bahia, Brazil. *Mem Inst Oswaldo Cruz 91*: 671-683.

Shimabukuro PHF, Galati EAB 2010. Checklist of Phlebotominae (Diptera, Psychodidae) from São Paulo state, Brazil, with notes on their geographical distribution. *Biota Neotrop 11*: 1-20.

Silva AM, Camargo NJ, Santos DR, Massafera R, Ferreira AC, Postal C, Cristóvão EC, Konolsaisen Jr JJ, Bisetto C, Perinazo R, Teodoro U, Galati EAB 2008. Diversidade, distribuição e abundância de flebotomíneos (Diptera: Psychodidae) no Paraná. *Neotrop Entomol 37*: 209-225.

Silva EA, Andreotti R, Honer MR 2007. Comportamento de *Lutzomyia longipalpis*, vetor principal da leishmaniose visceral americana, em Campo Grande, estado de Mato Grosso do Sul. *Rev Soc Bras Med Trop 40*: 420-425.

Stockwell DRB, Peterson AT 2002. Effects of sample size on accuracy of species distribution models. *Ecol Model 148*: 1-13.

Thies SF, Ribeiro ALM, Michalsky EM, Miyazaki RD, Fortes-Dias CL, Fontes CJF, Dias ES 2013. Phlebotomine sandfly fauna and natural *Leishmania* infection rates in a rural area of *Cerrado* (tropical savannah) in Nova Mutum, state of Mato Grosso in Brazil. *Rev Soc Bras Med Trop 46*: 293-298.

WHO - World Health Organization 2010. *Control of the leishmaniasis. Report of a meeting of the WHO Expert Committee on the control of leishmaniases*, WHO, Geneva, 186 pp.

Vilela ML, Azevedo ACR, Godoy RE 2015. Description of a new phlebotomine species of the Brazilian *Cerrado* from sandstone caves in Tocantins state, Brazil: *Lutzomyia (Lutzomyia) elizabethrangelae* sp. n. (Diptera: Psychodidae). *J Med Entomol* doi: dx.doi.org/10.1093/jme/tjv036.

Wiens JA, Stralberg D, Jongsomjit D, Howell CA, Snyder MA 2009. Niches, models and climate change: assessing the assumptions and uncertainties. *Proc Natl Acad Sci USA 106*: 19729-19736.

Young DG, Duncan MA 1994. *Guide to the identification and geographic distribution of* Lutzomyia *sand flies in México, the West Indies, Central and South America (Diptera: Psychodidae)*, American Entomological Institute, Gainesville, 881 pp.

Zeilhofer P, Kummer OP, dos Santos ES, Ribeiro ALM, Missawa NA 2008. Spatial modelling of *Lutzomyia (Nyssomyia) whitmani s.l.* (Antunes & Coutinho, 1939) (Diptera: Psychodidae: Phlebotominae) habitat suitability in the state of Mato Grosso, Brazil. *Mem Inst Oswaldo Cruz 103*: 653-660.