

Climatic factors influencing triatomine occurrence in Central-West Brazil

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We estimated the geographic distributions of triatomine species in Central-West Region of Brazil (CW) and analysed the climatic factors influencing their occurrence. A total of 3,396 records of 27 triatomine species were analysed. Using the maximum entropy method, ecological niche models were produced for eight species occurring in at least 20 municipalities based on 13 climatic variables and elevation. Triatoma sordida and Rhodnius neglectus were the species with the broadest geographic distributions in CW Brazil. The Cerrado areas in the state of Goiás were found to be more suitable for the occurrence of synanthropic triatomines than the Amazon forest areas in the northern part of the state of Mato Grosso. The variable that best explains the evaluated models is temperature seasonality. The results indicate that almost the entire region presents climatic conditions that are appropriate for at least one triatomine species. Therefore, it is recommended that entomological surveillance be reinforced in CW Brazil.

Key words: Triatominae - ecological niches - Central-West Brazil - entomological surveillance - Chagas disease

Chagas disease (CD) is a chronic and potentially fatal infection caused by the protozoan *Trypanosoma cruzi* (Chagas 1909). The principal mode of transmission for this parasite is via haematophagous insects of the subfamily Triatominae (Lent & Wygodzinsky 1979) and control of synanthropic triatomines is the main strategy for preventing human infection (Coura & Dias 2009, Coura & Viñas 2010).

At present, there are 143 known species of triatomines and one fossil specimen has been described (Galvão et al. 2003, Costa et al. 2006, Costa & Felix 2007, Schofield & Galvão 2009, Frías-Lasserre 2010, Rosa et al. 2012). In Brazil, 63 species have been documented, but only a few of these are relevant in terms of their synanthropic potential (Silveira et al. 1984, Costa et al. 2003, Gurgel-Gonçalves et al. 2012b, Rosa et al. 2012). In 2006, Brazil was declared free of CD transmission by the domestic vector *Triatoma infestans* (Schofield et al. 2006, Silveira & Dias 2011). Nevertheless, acute cases of human disease caused by transmission via native triatomine species are still being registered (MS/SVS 2012). Triatomines continue to infest homes in a number of states in Brazil (Oliveira & Silva 2007, Almeida et al. 2008, Villela et al. 2009, Gurgel-Gonçalves et al. 2010, Silva et al. 2011, 2012, Maeda et al. 2012).

Studies addressing the geographic distributions of triatomines and underlying factors are of fundamental importance for understanding the risk of CD transmission. Specific climatic conditions can influence the occurrence of triatomines (Bustamante et al. 2007). Ecological niche modelling (ENM) is an approach that permits the exploration of geographic and ecologic phenomena based on known occurrences of species (Peterson 2011). In recent years, ENM has been widely applied in research addressing the geographic distribution of triatomines (Costa & Peterson 2012, Gurgel-Gonçalves et al. 2012b).

Acute CD cases have been observed less frequently in the Central-West Region of Brazil (CW) than in other parts of the country: a total of 32 cases were registered in this region from 2007-2011, mainly in the state of Goiás (GO) (MS/SVS 2012). However, the risk of vectorial transmission of *T. cruzi* to humans persists, given the continuing presence of triatomines in domiciliary and peridomiciliary environments. Up-to-date knowledge of the geographic distributions of triatomines and the factors influencing their occurrence can aid in planning vectorial surveillance and control measures to be undertaken in the region. The objective of the present study was to estimate the geographic distributions of triatomine species in CW and analyse the climatic factors influencing their occurrence.

MATERIALS AND METHODS

Study area - CW comprises the states of Mato Grosso (MT), Mato Grosso do Sul (MS) and GO, as well as the Federal District (DF) of Brazil, Brasília. According to the 2010 census conducted by the Brazilian Institute of Geography and Statistics, the region occupies an area of 1,606,372 km² distributed among 466 municipalities, the

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majority of which are located in GO. The total population of CW is 14,050,340 people, most of whom (89%) reside in urban areas. Geographically, CW is formed by the central and meridional plateaus and the Pantanal plains. *Cerrado* is the prevailing biome in terms of its areal extent, but the region also includes areas of Pantanal, remnants of Atlantic forest, Amazon rain forest and enclaves of dry forests (WWF 2012). Its tropical climate is characterised by two well-defined periods: a rainy summer, between October-March and a dry winter, from April-September.

Distributional data - Information regarding the occurrence of triatomine species was provided by the Program for Chagas Disease Control (PCDCh) based on captures in domiciliary environments between 2000-2010. PCDCh conducts both active research (a household survey conducted by community health workers at least once per year) and entomological surveillance with community participation (reports by residents of triatomine occurrence to health workers), in accordance with the classification of risk among municipalities (Silveira 2004). At present, most municipalities in CW give priority to surveillance with community participation.

Data on the occurrence of triatomine species in domiciliary environments between 1975-1983 were also taken into account (Silveira et al. 1984), as were data from other studies (Silva & Lustosa 1993, Carcavallo et al. 1999, 2002, Carcavallo & Jurberg 2000, Oliveira & Silva 2007, Almeida et al. 2008, Gurgel-Gonçalves & Silva 2009, Gurgel-Gonçalves et al. 2012b, Maeda et al. 2012, Obara et al. 2012). In addition, records of triatomines in the collections of Rodolfo Carcavallo and Herman Lent at the National and International Reference Laboratory on Triatomine Taxonomy at the Oswaldo Cruz Institute, Oswaldo Cruz Foundation, were analysed.

Predictor variables - To build ecological niche models for triatomine species, data on climate and elevation were obtained from the WorldClim project (worldclim.org). These variables are obtained through the interpolation of mean monthly climatic data obtained from meteorological stations over a period of 30 (1960-1990) to 50 (1950-2000) years, depending on their availability at the stations (Hijmans et al. 2005). The environmental data used in the analyses cover Central and South America at a spatial resolution of 2.5' (5 x 5 km per pixel). Only variables that were not strongly correlated ($r < 0.8$) were used in building the models (Table).

ENM - Data on a total of 3,396 occurrences of 27 triatomine species were assembled. These occurrences were referenced to geographic coordinates with an uncertainty of ≤ 5 km and precision of 0.01° , which is a degree of error that should not dramatically influence the results. Records of triatomine species presenting georeferencing or identification errors were eliminated. The records were georeferenced based on data available from fallingrain.com/world and ibge.gov.br. We only analysed species for which 20 unique occurrence points were available (Stockwell & Peterson 2002, Wisz et al. 2008), resulting in eight total species: *Triatoma pseudomaculata*, *Triatoma sordida*, *Triatoma williami*, *Triatoma costalimai*, *Panstrongylus megistus*, *Panstrongylus diasi*, *Panstrongylus geniculatus* and *Rhodnius neglectus*.

TABLE
Uncorrelated ($r < 0.8$) environmental variables utilized in ecological niche modelling ENM for eight synanthropic triatomine species in Central-West Region of Brazil

Variables	Description	<i>Triatoma williami</i>	<i>Triatoma costalimai</i>	<i>Rhodnius neglectus</i>	<i>Panstrongylus diasi</i>	<i>Triatoma pseudomaculata</i>	<i>Panstrongylus geniculatus</i>	<i>Panstrongylus megistus</i>	<i>Triatoma sordida</i>
Bio 1	Annual mean temperature	X	X	X	X	X	X	X	X
Bio 2	Mean diurnal range	X	X	X	X	X	X	X	X
Bio 3	Isothermality	-	X	X	X	X	X	-	X
Bio 4	Temperature seasonality	-	X	X	-	X	X	X	X
Bio 6	Minimum temperature of coldest month	-	-	X	-	-	-	-	-
Bio 11	Mean temperature of coldest quarter	X	-	-	-	-	-	X	-
Bio 12	Annual precipitation	X	-	-	-	-	-	-	-
Bio 14	Precipitation of driest month	X	-	-	-	-	-	-	-
Bio 15	Precipitation seasonality	-	X	-	-	-	-	-	-
Bio 16	Precipitation of wettest quarter	-	X	X	X	X	X	X	X
Bio 17	Precipitation of driest quarter	-	X	-	X	X	X	X	X
Bio 18	Precipitation of warmest quarter	X	X	X	X	X	X	X	X
Bio 19	Precipitation of coldest quarter	X	X	X	X	X	X	X	X
-	Altitude	-	-	-	-	-	-	-	-

the variables highlighted in bold face made the greatest contribution to explaining the ENM, as shown by the Jackknife test.

Maps of potential species distributions were produced using Maxent version 3.2.1 (Phillips et al. 2006) applying the default parameters, which are considered appropriate for most situations. The choice of methodology took into consideration the particular characteristics of the study area, i.e., the area of interest is the area sampled, with no need for transferring models over broader or other landscapes (Elith et al. 2006, Peterson et al. 2007).

Occurrence data were separated into two sets: one for model calibration (80% of points) and the other for model evaluation (20% of points). Subsequently, raw maxent outputs were converted into binary maps showing the presence or absence of each species based on a threshold that includes 90% of the records of each species used in model calibration (Pearson et al. 2007, Peterson et al. 2008). The analyses were focused on the species diversity of broadly distributed triatomines. Thus, we summed the final, thresholded map for each of the eight species using the Spatial Analyst extension of ArcView 3.3 (Environment System Research Institute Inc - Geographical Information System, Redlands, CA). Given the binary nature of each map, the sums yield a hypothesis regarding the numbers of species (triatomine species richness) present across the study region.

With respect to the occurrence maps for the remaining triatomine species, only point maps were generated, using TerraView version 4.0.0. The digital mesh network (in shape file format) for Brazil was obtained from siscom.ibama.gov.br/ and subsequently edited for CW.

Model validation - The quality of the models generated was evaluated using the receiver operating characteristic (ROC) curve, which correlates the sensitivity and specificity of model predictions across multiple thresholds (Phillips et al. 2006). The area under the ROC curve (AUC) provides a measure of model performance across many thresholds. AUC values close to one indicate high performance, while readings below 0.5 indicate poor performance of the model (Elith et al. 2006).

To test the models' significance, we compared the predictive power of the models against a random null hypothesis. After developing a model, we checked whether test points fell into areas predicted to be present more often than expected at random, given the overall proportion of pixels showing predicted presence vs. predicted absence for that species. In addition to the model significance (departure from random predictions), we assessed model accuracy by examining the proportion of test points falling into regions of predicted presence (Anderson et al. 2002). Using Maxent's internal Jackknife test, the variables that most influence the distribution of triatomine species were identified.

RESULTS

A total of 27 triatomine species were recorded in the CW region: *T. sordida*, *T. pseudomaculata*, *T. williamsi*, *T. infestans*, *T. costalimai*, *Triatoma baratai*, *Triatoma matogrossensis*, *Triatoma lenti*, *Triatoma jurbergi*, *Triatoma guazu*, *Triatoma deaneorum*, *Triatoma vanda*, *P. megistus*, *P. diasi*, *P. geniculatus*, *Panstrongylus guentheri*, *Panstrongylus lenti*, *R. neglectus*, *Rhodnius picti-*

pes, *Rhodnius robustus*, *Rhodnius stali*, *Psammolestes tertius*, *Psammolestes coreodes*, *Microtriatoma trinidadensis*, *Microtriatoma borbai*, *Eratyrus mucronatus* and *Cavernicola pilosa*. This set of species accounts for 42.8% of the 63 known species in Brazil. MT was the state with the greatest number of triatomine species (n = 17, 63%), followed by MS (n = 15, 55.5%), GO (n = 14, 52%) and the DF (n = 7, 26%).

The genus *Triatoma* presented the greatest species richness (n = 12 species). *T. sordida* was the most widely distributed species (Figs. 1, 2). The genus *Panstrongylus* was represented by five species, among which *P. geniculatus* was the most widespread (Fig. 2). Four species of the genus *Rhodnius* were registered, of which *R. neglectus* was the most widespread (Fig. 2). Other genera, such as *Psammolestes*, *Microtriatoma*, *Eratyrus* and *Cavernicola*, exhibited few species and very limited distributions (Fig. 1). Only one occurrence of *T. infestans* was recorded in the year 2000 (in GO). The species *T. jurbergi*, *T. guazu*, *R. robustus*, *M. trinidadensis*, *M. borbai*, *E. mucronatus* and *C. pilosa* (Fig. 1) presented very restricted geographical distributions, with occurrences registered in just one municipality.

All of the models derived from the analysis performed well (AUC > 0.90), summarising the necessary ecological conditions for the occurrence of the species. All models showed sensitivities greater than 98%. The binomial probabilities were statistically significant for the species (p < 0.01). The map aggregating the ecological niche models for eight species (Fig. 3) indicated greater climatic suitability for the occurrence of triatomines in *Cerrado* areas in GO in comparison to Amazon forest areas in northern MT. The Jackknife tests showed that temperature seasonality was the variable that best explained the models (Table).

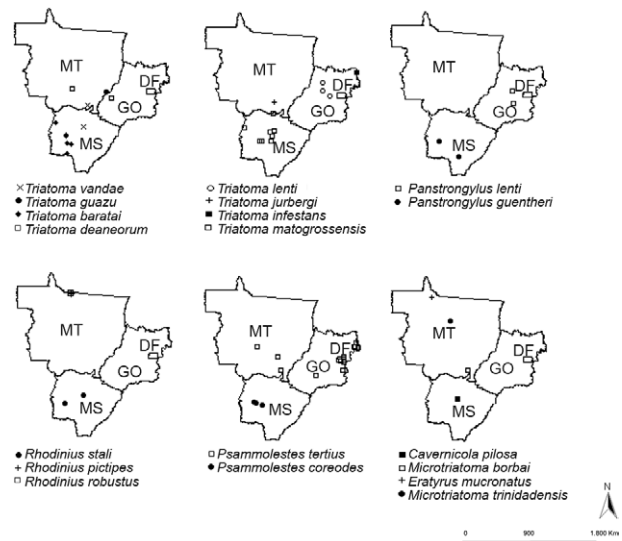


Fig 1: geographic distribution of triatomine species with < 20 known occurrences in Central-West Region of Brazil. DF: Federal District; GO: state of Goiás; MS: state of Mato Grosso do Sul; MT: state of Mato Grosso.

DISCUSSION

This study indicates that there is a rich triatomine fauna in CW. Almost half of all known species in Brazil are represented in the region. Indeed, nearly the entire region offers favourable conditions for the occurrence of at least one triatomine species. Furthermore, our results show that the triatomine occurrence is greater in the *Cerrado* biome, where there are major seasonal temperature variations. The results of this study serve to update the list of triatomine species in CW. Oliveira & Silva (2007) registered nine species in GO, which is fewer than the 14 species registered in the present study. Almeida et al. (2008) reported 12 species in MS, also fewer than the 15 recorded in our list. Finally, Figueiredo et al. (2007) reported five species from MT, while we registered 17 species. The greater triatomine diversity observed in MT is most likely a function of the size of this state and of the diversity of its biomes (*Cerrado*, Amazon rainforest and Pantanal). Analysis of the ENM maps showed less climatic suitability for the occurrence of synanthropic triatomines in northern MT, where Amazon rainforest predominates. The lower diversity of synanthropic triatomines in rainforest areas reinforces the hypothesis that the chances of domiciliary infestation by triatomines are greater in drier regions (Abad-Franch & Monteiro 2007).

T. sordida and *R. neglectus* were the species showing the broadest geographic distributions in CW. Both species are capable of adapting to different ecosystems, as has been noted by other authors (Lent & Wygodzinsky 1979, Forattini 1980, Gurgel-Gonçalves & Cuba 2009, Gurgel-Gonçalves et al. 2011, 2012b). Although it is the most frequently encountered species in Brazil, *T. sordida* occurs mainly in peridomicile areas and generally feeds on birds, which reduces the probability of vectorial transmission of *T. cruzi* to humans (Diotaiuti et al. 1993). *R. neglectus* frequently inhabits palm trees in CW (Barretto et al. 1969, Gurgel-Gonçalves et al. 2004, Abad-Franch et al. 2009, Gurgel-Gonçalves & Cuba 2009), where it participates actively in the enzootic transmission of *T. cruzi* and *Trypanosoma rangeli* (Gurgel-Gonçalves et al. 2012a); this species has been documented in domiciliary environments in recent years (Oliveira & Silva 2007, Almeida et al. 2008, Gurgel-Gonçalves et al. 2008), which may be related to ecological processes that stimulate the invasion of artificial ecotopes by potentially infected individuals (Abad-Franch et al. 2009).

T. costalimai appears to be endemic to the *Cerrado*. This species has been frequently collected on limestone outcrops in peridomiciliary environments in northeastern GO (Mello 1982, Lorosa et al. 1999, Machiner et al.

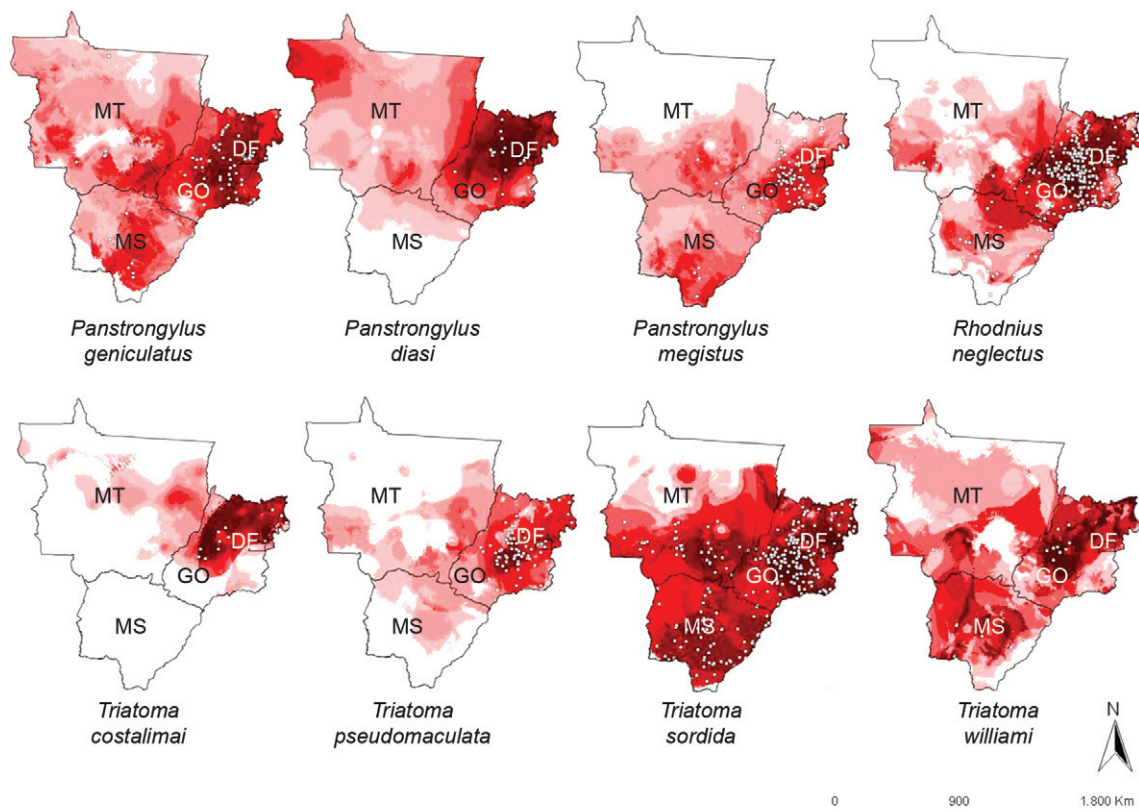


Fig 2: maps of potential distribution derived from ecological niche models for triatomine species with > 20 occurrences in Central-West Region of Brazil. Blank areas represent triatomine absence predicted by the model. Areas identified as suitable based on climatic variables are shown in red scale: light red (low suitability) to dark red (high suitability). Dots represent known occurrences of the triatomine species. DF: Federal District; GO: state of Goiás; MS: state of Mato Grosso do Sul; MT: state of Mato Grosso.

2012). However, our findings point to areas that are propitious for this species in eastern GO and even in MT, where *T. williami*, a similar species (Obara et al. 2012), has been reported. Thus, the co-occurrence of these species in GO may be likely. More detailed studies of the ecological niches of these species are needed to understand their distributional limits. Our results indicate that *T. williami* also occurs in areas of the Pantanal in the northwest of MS. Although individuals of this species have been found to be infected in domiciliary environments (Arrais-Silva et al. 2011), little is known about their biology and their natural habitat is still unknown.

T. pseudomaculata, a species that is widespread in northeastern Brazil with a known ability to infest artificial ecotopes (Carcavallo et al. 1999, Assis et al. 2007), occurs only in GO and the DF. Our results show lower climatic suitability for *T. pseudomaculata* in MT and MS, in agreement with the findings of Carbajal de la Fuente et al. (2009), who used different environmental variables to produce potential distribution maps. The historical occurrence of *T. infestans* in the municipality of Posse in GO was recorded in 2000; this population was also observed by Oliveira and Silva (2007). Additionally, Gurgel-Gonçalves et al. (2012c) reported residual foci of *T. infestans* in Bahia (BA). Thus, the areas along the border line between GO and BA should be monitored to prevent re-infestations by *T. infestans* in GO.

Among the *Panstrongylus*, *P. geniculatus* showed the greatest potential for occurrence in CW. In contrast, *P. megistus* was indicated as absent from northern MT and *P. diasi* was predicted to be absent in southern MS. *P. geniculatus* occurs in at least 16 countries in the Americas. In contrast, *P. diasi* appears to be endemic to the Brazilian *Cerrado* (Carcavallo et al. 1999), while

the distribution of *P. megistus* is centred in the Atlantic forest (Forattini 1980) and its occurrence in the *Cerrado* seems to be greater in humid areas (gallery forests).

Among the analysed climatic variables, temperature seasonality was found to best explain the models of triatomine occurrence in CW. A greater number of synanthropic triatomine species was observed in areas with greater seasonal temperature variation. Other studies have shown temperature to be an important determinant of the distribution of triatomines on a regional or continental scale (Gorla 2002, Rodriguero & Gorla 2004, Batista & Gurgel-Gonçalves 2009, Gurgel-Gonçalves & Silva 2009, Gurgel-Gonçalves et al. 2011). However, other environmental variables, such as the slope of the terrain (Leite et al. 2011) and humidity (Arboleda et al. 2009), have also been identified as principal determinants of the occurrence of certain species.

The basic strategies for CD vector surveillance in CW are as follows: monitoring the possible re-infestation of *T. infestans* and reducing the domiciliary infestation of native triatomines with widespread geographic distributions, as described in this paper. Therefore, it is recommended that entomological surveillance be reinforced in CW.

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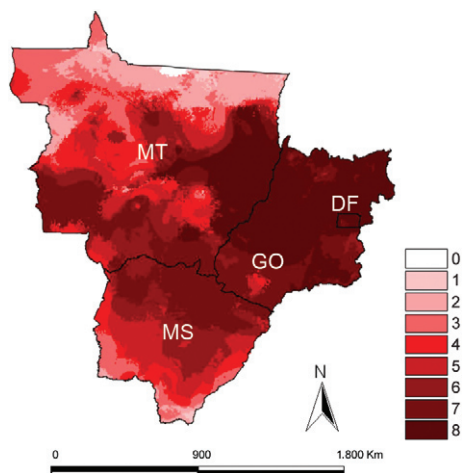


Fig 3: final model of climatic suitability for eight triatomine species in Central-West Region of Brazil, summing binary models versions of potential distributions derived from ecological niche. Blank areas represent zero species diversity predicted; the red scale indicates numbers of species expected, with light red indicating few species and dark red indicating many. DF: Federal District; GO: state of Goiás; MS: state of Mato Grosso do Sul; MT: state of Mato Grosso.

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