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ECOSYSTEMS

Modelling the effect of density vegetation coverage and the occurrence of peridomestic infestation by *Triatoma infestans* in rural houses of northwest of Córdoba, Argentina

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Abstract: To better understand the dispersion strategies of *Triatoma infestans* (Klug) (Hemiptera: Reduviidae, Triatominae), we evaluated the spatial effect of infested peridomicile and density vegetation cover in a historically endemic area for Chagas disease**.** The study was conducted in rural houses of the northwest of Córdoba province, Argentine, during 2012-2013. Active search of triatomines were made in domicile and peridomicile habitats. To characterize vegetation coverage, a thematic map was obtained considering five types of vegetation cover (closed/open forest, closed/open shrubland and cultural land). From each house we extracted the area of vegetation coverage, housing density and infested peridomiciles density. We used generalized linear models to evaluate the effect of these variables on the occurrence of infested peridomicile. According to our results, the probability of a peridomicile to be infested increases by 1.34 (95%CI [0.98; 1.90]) times more when peridomicile structures are in environments with higher housing density and by 1.25 (95%CI [0.84; 1.88]) more times when houses are surrounded by open shrublands. Among the multiple ecological determinants of peridomestic infestation, the influence of vegetation cover has been poorly studied. In this study we discussed the effect of the vegetation as a potential modulator of the dispersion strategies of *T. infestans*.

Key words: Dispersion, infestation, peridomicile, ***Triatoma infestans***, vegetation.

INTRODUCTION

Chagas is one of the most important endemic diseases in Latin America. It is caused by the protozoan *Trypanosoma cruzi*, which is transmitted to humans and other mammals mainly via blood-sucking insects from the Reduviidae family, Triatominae subfamily (OMS 2007).

In South America, *Triatoma infestans* is the vector of greatest epidemiological importance, characterized by its high adaptive capacity to human dwellings (Rabinovich 1972, Lent & Wygodzinsky 1979). They are found almost exclusively in domestic environments and peridomestic habitats such as chicken coops, goat pens, pig corrals and storerooms, which show optimum conditions for the establishment of colonies (OMS 2007).

The Southern Cone Initiative to Control Chagas Disease (INCOSUR), launched in 1991, succeeded in reducing the distribution area of *T. infestans* to less than 1 million km^2 through insecticide-based vector control, health education and house improvement program (Schofield et al. 2006). The interruption of vector transmission of *T. cruzi* was achieved in Uruguay (2012), Chile (1999), two Departments of Bolivia (2011 – 2013), eastern region of Paraguay (2008) and Alto Paraguay (2013) as well as in eight provinces of Argentina between 2001 and 2013 (PAHO 2012).

Nevertheless, in arid Gran Chaco areas of Argentina, Paraguay and Bolivia, reinfestations of human dwellings continue to occur in several provinces or departments (Gürtler 2009). Many authors agree that the persistence of triatomine infestation in the Chaco region is due to the difficulty of eliminating the vector population in peridomestic habitats (Cecere et al. 1997). After the residual application of pyrethroid insecticides, chicken coops, goat pens, pig corrals and other potential habitat in the peridomicile are the first to be recolonized (Canale et al. 2000), because their complex structure not only prevent good penetration of insecticides (Gürtler 2009) but also provide optimal conditions for sustaining near domiciles abundant triatomines population (Cecere et al. 2006). Hence, the active dispersal of *T. infestans* (flying and walking) plays an important role in the local propagation of triatomines within and between neighboring households (Vazquez-Prokopec et al. 2004, Abrahan et al. 2011).

Several studies conducted in semiarid regions of Argentina determine that at local scales, the spatial patterns of reinfestation of peridomicile and domicile habitats are determined by flight dispersal capacity, local abundance of triatomines and hosts, the spatial configuration of households and vegetation cover (Vazquez-Prokopec et al. 2004, McGwire et al. 2006, Abrahan et al. 2011). However, little is known about how vegetation cover surrounding houses affect the spatial distribution of infestations. Some authors mentioned that dense vegetation cover and high trees may act as a barrier for triatomine dispersal (Vazquez Prokopec et al. 2004).

The northwest region of Córdoba Province, located in the south of the Gran Chaco region of Argentina, shows a heterogeneous scenario of *T. cruzi* transmission related with differences in vector control interventions, land use changes and socioeconomic factors in the last decades (Moreno et al. 2010, 2012). Previous reports on the area (Crocco et al. 2019), showed a high peridomiciliar infestation, strongly associated with the presence of chicken coops. This peridomestic habitat is the most frequent in the area and the most vulnerable to infestation because the materials of construction (sticks, wood, or cardboard) provide excellent refuge sites for triatomines. Soria et al. (2019) report within the same area a high percentage of combined blood meals (goat, chicken, dog and human) on feeding profiles of *T. infestans* collected in peridomicile. This record does not seem to be related to host-feeding source choice nor to the main host residing in the peridomicile, since most of the triatomines that recorded mixed blood ingestion were found in peridomiciles with only one type of host present. Hence, this study evidence a high dispersion of adult *T. infestans* between peridomiciles in natural conditions, which reinforces the importance of better understanding how environmental and spatial factors may modulate the dispersal strategy of triatomines.

The aim of our study was to evaluate the spatial effect of peridomestic infestation and density vegetation cover in a historically endemic area for Chagas disease, in order to add understanding on the dynamics of dispersion of *T. infestans*. We hypothesize that the density of the vegetation cover influences the dispersion of triatomines between nearby peridomicile by facilitating or preventing the transmission of physical and chemical signals from the peridomiciliary area. Infrared radiation, thermal signals emitted by domestic hosts as well as the mixture of odor cues and lights can be perceived in a range of meters by *T. infestans,* and may influence the appetitive searching and long-range orientation (Guerensten & Lazzari 2009, Catalá 2011).

MATERIALS AND METHODS

Study area

The field work was conducted in six rural communities of Cruz del Eje and Ischilín departments, at northwest Cordoba province, Argentina, between latitudes -30° and -31° S and longitudes -64° and -65° O (Figure 1a-b). This region belongs to the Chaco phytogeographical province (Cabrera 1976), characterized by a subtropical dry climate with a summer season from October to March. The average monthly temperature is 26 °C, with absolute maximum temperatures that exceed 45 °C (Karlin et al. 2013).

Entomological data

The study was carried out in sixty-six rural houses that were visited between December 2012 - November 2013 and were georeferenced in the field using GPS (Garmin Etrex 20). The communities and the houses visited were selected according to the recommendations of the National and Provincial Program of Chagas. The last insecticide spraying campaign by vector control personnel was carried out in these communities three years before this study.

The man-hour technique was carried out in domicile and peridomicile -chicken coops, goat and pig corrals- for the active search of triatomines (Chuit et al. 1992). The captured triatomines were identified taxonomically according to the identification keys of Lent & Wygodzinsky (1979) and Brewer et al. (1983).

Estimation of vegetation cover and spatial variables

To identify the landscape coverage classes, it was used a Landsat 8 image generated by the OLI sensor, corresponding to scene 230-81, with an acquisition date of May 8, 2013, provided by the US Geological Survey (USGS) (http://earthexplorer.usgs.gov/). The vegetation cover

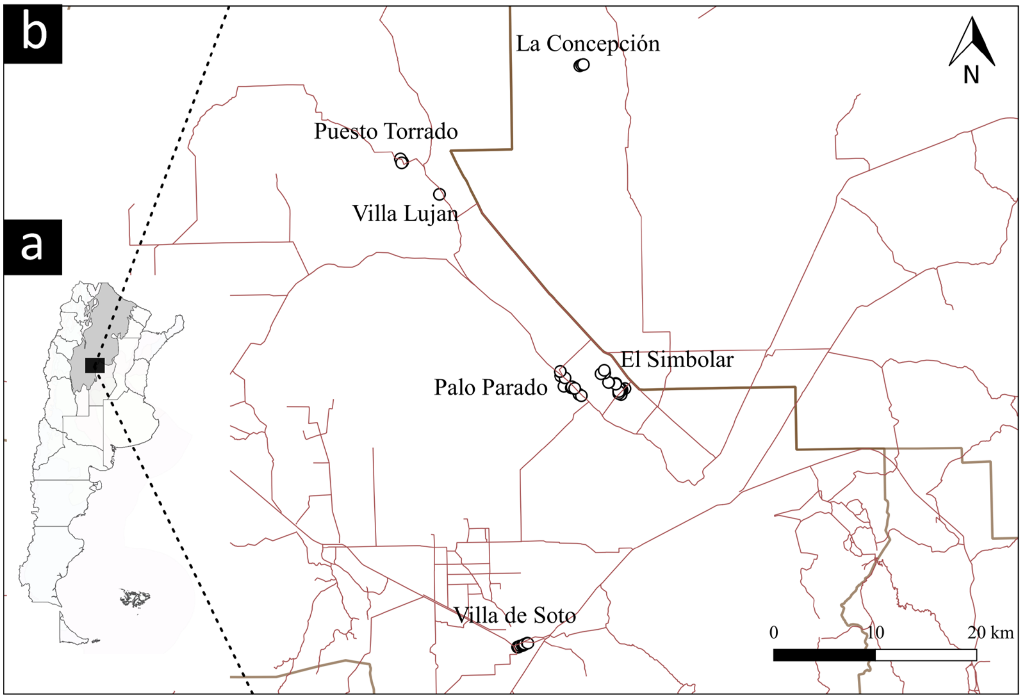

Figure 1. a) Location of the study area in the extreme south of the Gran Chaco region (shaded area). b) Location of rural houses evaluated in the six communities of Cruz del Eje and Ischilín departments, Córdoba province, Argentina.

was characterized by obtaining a thematic map by supervised classification (maximum likelihood method) of the image. Subsequently, five types of coverage were defined: closed forest, open forest, open shrubland, closed shrubland and cultural land (comprising agricultural lands and small towns). Coverage classes were defined based on training sites that were registered in the field and considering the units defined by Cabido & Zak (1999) and Hoyos et al. (2013). To check the accuracy of the classification obtained, the confusion matrix method was used. The ENVI 5.1 software (Environment for Visualizing Images, Research Systems, 2013) was used for the pre-processing and processing of the images.

On the thematic map, a circular area with a radius of 200 meters was generated around each house, from which the class area (Ha.) of each kind of coverage was extracted. The Fragstat 4.2 software (McGarigal et al. 2012) was used for extracting the class metrics.

For each rural house, additional variables were calculated in order to characterize the spatial dependence of infested peridomiciles: *housing density* (HD) in an area of 200 m radius (number of houses / Ha.) and *infested peridomiciles density* (IPD) in an area of 200 m radius (number of infested peridomiciles / Ha.).

Statistical analysis

Spatial heterogeneity of infested peridomiciles between rural communities was measured using SaTScan software v9.6 (Kulldorff 1997). We use spatial analyses with a Poisson model to detect clusters of significant high and low infestation within a maximum circular size equal to 50% of the entire area.

To evaluate the effect of spatial dependence variables (HD and IPD) and vegetation cover variables on the occurrence of infested peridomiciles (binary variable) we used generalized linear models (GLM) with binomial error distribution, and logit link function. In order to avoid collinearity, correlation analyses among explanatory variables were performed to make a selection.

We hypothesized that rural peridomiciles spatially located in environments with high density of housing and higher density of positive peridomiciles around will be more likely to be infested. In addition, since density vegetation cover was mentioned as a possible modulator of dispersion, it would be expected that houses surrounded by less dense vegetation cover (like open shrublands) will have more chances of peridomicile infestation than others surrounded by dense and higher vegetation.

The set of candidate models considered the individual effects of each predictor on the response variable as well as joint models evaluating the additive effects of the possible combinations. The best model was selected following Akaike's information criterion (AICc), using the function *aictab* of the package *AICmodavg* in the R software version 3.4.3. Multicollinearity between the variables included in each developed model were also tested with the variance inflation factor (VIF) (Zuur et al. 2007). The effect-size estimates for each variable was averaged, using the *modavg* function from the package *AICmodavg* in the R software version 3.4.3, for all coefficients included in models that showed a difference in AIC values ≤ 2 with the model that showed the lowest AIC. The odd ratios for the binomial GLM were calculated for each predictor using the exponential transformation of the estimated coefficient (Zuur et al. 2009). Finally, the relative importance of the explanatory variables was determined by summing the weights/probabilities (aiccwt) of the models in which each predictor appears (Calcagno 2013).

RESULTS

Entomological data

From the total of houses visited during the study, 43.9 % (29) were infested only in peridomestic habitats and 1.5 % (1) was infested in both ecotopes (domestic and peridomestic habitats). A total number of 633 triatomines were collected during the active search, including 451 nymphs and 182 adults of *T. infestans* recorded in peridomestic habitat mostly in chicken coops and less frequently in goat pens. Table I report the values obtained.

Estimation of vegetation cover and spatial variables

The thematic map obtained from Landsat 8 image with supervised classification is displayed in Figure 2a-b. The classification of the satellite image to obtain the thematic map had an accuracy of 93 % and a kappa value of 0.92, according to the confusion matrix.

Of the five classes of vegetation cover defined in the study area, four were represented in the closest surroundings of the houses: open forest, closed shrubland, open shrubland and cultural land. The latter shows a strong negative correlation with the area of open shrubland (r = -0.80) and closed shrubland (r = -0.77). So, the cultural land effect on the response variable was evaluated in a single model, but it was not considered in the construction of the joint models, since the analysis focused on the vegetation cover classes as a possible dispersion modulator in order to contrast the hypotheses proposed.

Spatial analysis and multi-model inference

The spatial analysis of infested peridomicile resulted in three non-significative clusters showing that the infestation was homogeneously distributed between rural communities in the study area.

To analyze the predictors of infested peridomicile occurrence, we built fourteen candidate models (Table II) considering the individual effects of each predictor on the response variable as well as joint models evaluating the possible combination between variables in agreement with the alternative hypothesis. From the fourteen candidate models of the multimodel inference approach, four of them described equally well the results (ΔAICc ≤ 2.0). These four-best fitting GLMs included the housing density in combination with infested peridomicile density and open shrubland area as predictors. The most parsimonious model for explaining the occurrence of infested peridomicile was the one that included only the housing density as an explanatory variable (AICc

Table I. Entomological data collected during 2012-2013 on rural communities in Northwest of Córdoba province, Argentina.

Rural community	Evaluated houses	Infested domicile	Infested peridomicile	Triatomines	
				Nymphs	Adults
Puesto Torrado	5	0	2	38	1
Villa Lujan	2	0	0	0	0
Palo Parado	15	1	7	74	24
El Simbolar	26	0	9	71	22
La Concepción	3	0	2	4	44
Villa de Soto	15	0	9	264	91

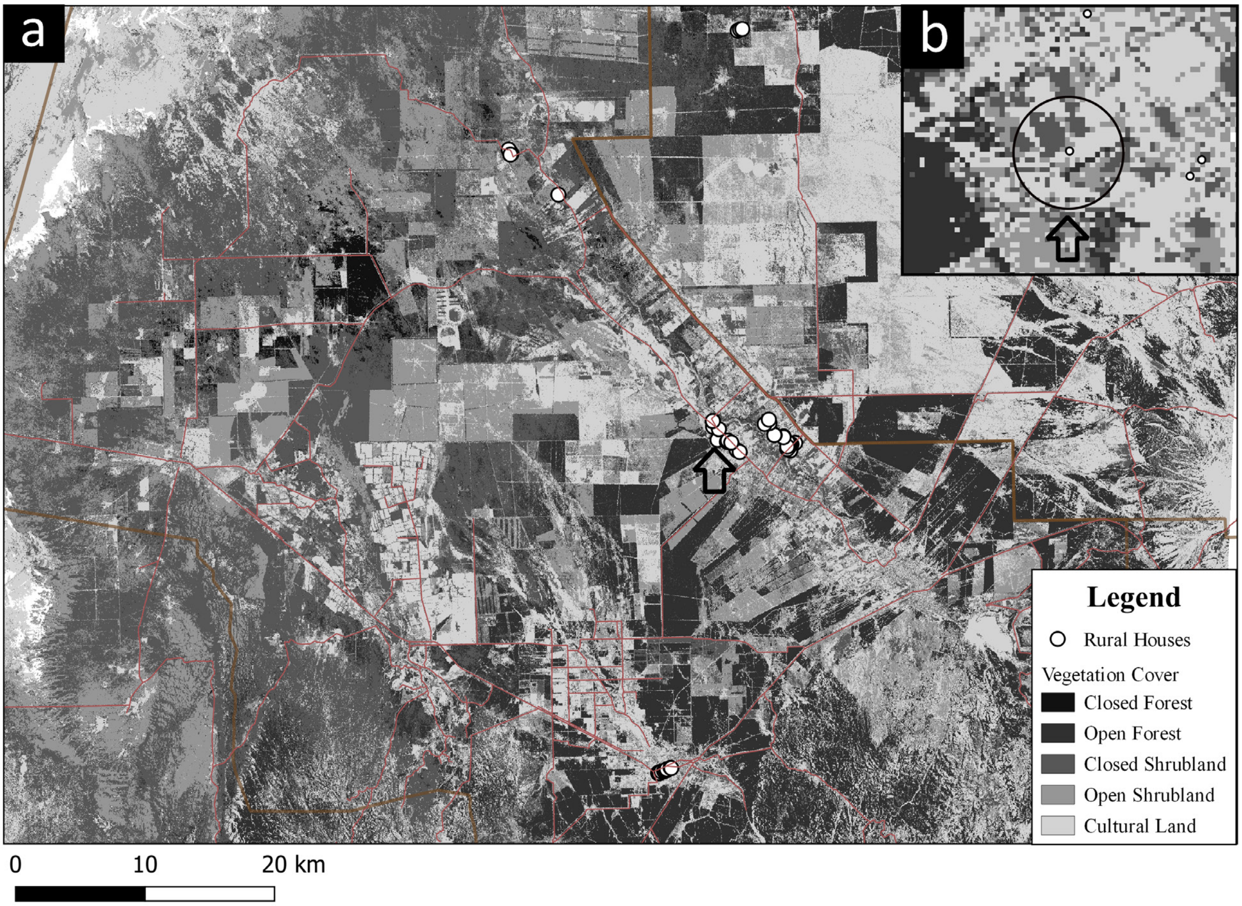

Figure 2. a) Thematic map of estimated vegetation covers in the study area. References on the map. b) Detail of the circular area of influence with a radius of 200 m from which the class area of each kind of coverage and spatial variables were calculated. The detailed area corresponds to the area indicated by the arrow in figure 2.a.

= 91.17). However, the model including housing density and open shrubland area also had good explanatory power with a slightly higher AICc (92.12).

No multicollinearity was found between the explanatory variables in the four-best fitted GLMs (VIF<1.81).

In line with the alternative hypothesis, the model-averaged estimate reveals that housing density and open shrubland have a positive effect on peridomestic infestation with an estimated log-odd value of 0.35 (95%CI [-0.04; 0.75]) and 0.22 (95%CI [-0.17; 0.62]) respectively. Whereas the infested peridomicile density estimated log-odd value shows a negative effect on the response variable (-3.53; 95%CI [-9.99; 2.93]) though with a high unconditional standard error (SE= 3.29) and a wide confidence interval. The estimated odd ratios for housing density were 1.34 (95%CI [0.98; 1.90]) and for open shrubland and infested peridomicile density were 1.25 (95%CI [0.84; 1.88]) and 0.02 (95%CI [0.00; 16.68]) respectively.

Finally, the AIC weights of the models (Table II) revealed that the housing density had the higher relative importance supporting the models followed by the open shrubland area.

Table II. **Model set. Results of the multi-model inference analysis of all GLMs considered in this study to explain the occurrence of peridomestic infestation (Y) in rural houses of the northwest of Córdoba province, Argentina.**

Model	Model structure	AICc	ΔAICc	AICcWt
m 1	Y (HD)	91.17	0.00	0.23
m 12	Y (HD + Open Shrubland)	92.12	0.95	0.14
m 7	Y (HD + IPD)	92.19	1.02	0.14
m 13	Y (IPD + HD + Open Shrubland)	93.20	2.03	0.08
m 4	Y (Open Shrubland)	93.30	2.14	0.08
m 3	Y (Cultural Land)	93.91	2.75	0.06
m 6	Y (Open Forest)	94.30	3.13	0.05
m 14	Y (IPD + HD + Closed Shrubland)	94.45	3.29	0.04
m 2	Y (IPD)	94.57	3.40	0.04
m 5	Y (Closed Shrubland)	94.62	3.45	0.04
m 10	Y Open Shrubland + Open Forest)	94.63	3.47	0.04
m 11	Y (IPD + Open Shrubland)	95.39	4.22	0.03
m 9	Y (Open Shrubland + Closed Shrubland)	95.50	4.33	0.03
m 8	Y (Open Shrubland + Closed Shrubland + Open Forest)	96.66	5.49	0.01
Null Model	Y (1)	99.02	7.85	0.00

Abbreviations: HD housing density, IPD infested peridomicile density. ΔAICc, represents the difference in the value of the Akaike´s information criterion (AIC) with respect to the AICc value of the best candidate model. AICcWt represents the relative likelihood of a model.

DISCUSSION

Entomological data recorded in this study shows high peridomestic infestation (43.9 %) and very low domestic infestation (1.5 %) by *T. infestans* in rural houses of the northwest of Córdoba Province during 2012-2013. Previous reports published within the same area, pointed out that low domestic infestation was related with the improvement of housing construction and that the risk of peridomestic infestation was strongly associated with the presence of chicken coops (Crocco et al. 2019). Since rural houses were visited after a three year-period without chemical control, the levels of peridomestic infestation recorded supports the fact that without a sustainable control campaign the populations of *T. infestans* remain far from the elimination objectives proposed by the Southern Cone Initiative (Segura 2002).

The results obtained in this study show that the probability of a peridomicile to be infested by *T. infestans* in the study area increased by 1.34 times more when peridomicile structures are in environments with higher housing density. The effect of housing density as a predictor of infestation status for peridomestic structures as well as domicile had already been observed by McGwire et al. (2006) in similar rural areas of northwest of Córdoba province. Given that local livestock economy in the area is based on smaller-scale poultry and goat production, a higher density of housing is related to a higher density of chicken coops and goat pens. This means greater chances of triatomine dispersion among ecotopes in search of food, as it was recorded in the same area by Soria et al. (2019).

Although the infested peridomicile density variable has an unexpected negative effect on the probability of a peridomicile to be infested, this may be due to the fact that the number of rural houses visited around each positive house for *T. infestans* was not always constant because some inhabitants were absent or were reluctant to participate, preventing us to do the search of triatomines.

Based on the models carried out in this study, it can be observed that the probability of a peridomicile to be infested also increases by 1.25 more times when houses are surrounded by open shrubland. In general, studies that consider vegetation as a variable related to the presence of *T. infestans*, evaluate its indirect effect on temperature and precipitation using temporal series of NDVI (Gorla 2002) or landscape metrics to reflect the livestock productivity in the area (Porcasi et al. 2011). However, little it has been mentioned of the possible effect of local vegetation around the house as a potential modulator of dispersion of triatomines between neighboring ecotopes. According to Vazquez-Prokopec et al. (2004) the spatial heterogeneity generated by the effects of landscape and vegetation cover may affect the spatial distribution of *T. infestans* infestations and the risk of house invasion. Scarce vegetation cover around houses can facilitate dispersion between nearby peridomicile because physical and chemical signals from the peridomiciliary area can be sensed in a greater range and they can be used as an orienting cue (Guerensten & Lazzari 2009, Catalá 2011).

Multiple factors are determining the chances of peridomestic infestation among which the structural characteristics of the peridomestic structures and its distance to the house, as well as the density of hosts and the history of vector control interventions in the area strongly influence the occurrence of infestation (Gurevitz et al. 2011, Cecere et al. 1997, Lopez et al. 1999). However, we should also consider the effect of landscape surrounding the house and its potential role as a barrier (in the case of dense and high vegetation) or dispersion facilitator (in the case of low and scarce vegetation).

In order to better understand the factors that modulate the dynamics of dispersion and reinfestation of triatomines at local scales, it is relevant to reinforce the study of the ecological determinants that favor the dispersion of triatomines between habitats, since dispersing triatomines can colonize habitats treated with insecticide, initiating new cycles of colonization and disease transmission (Schofield & Matthews 1985).

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