

## Spatial Stratification of House Infestation by *Triatoma infestans* in La Rioja, Argentina

David E. Gorla,\* Ximena Porcasi, Hugo Hrellac, and Silvia S. Catalá

Centro Regional de Investigaciones Científicas y Transferencia Tecnológica, Anillaco, La Rioja, Argentina; Programa Provincial de Chagas, Ministerio de Salud, La Rioja, Argentina

**Abstract.** Vectorial transmission of Chagas disease has been decreasing over the past few decades because of effective vector control programs in the southern cone of South America. However, the disease is still actively transmitted within the Gran Chaco region. In this area, vector populations are abundant and highly prevalent in poor rural houses. This study analyses the spatial pattern of rural house infestation by *Triatoma infestans* in a 56,000 km<sup>2</sup> area in the province of La Rioja, Argentina, before the re-initiation of systematic activity on vector control intervention. Data on 5,045 rural houses show that infestation has high spatial heterogeneity, with highly infested localities concentrated in a few areas. House infestation has a negative significant relationship with locality size. Rural houses in the region are highly dispersed and this feature has been and will remain a challenge for any vigilance system to be installed in the region.

### INTRODUCTION

Control of vectorial transmission of Chagas disease is recognized as a major success in the southern cone countries of South America. Uruguay interrupted vectorial transmission by 1997, Chile in 1999, and Brazil in 2006. In Argentina, five provinces outside the Gran Chaco region (of 19 initially endemic for this disease) certified interruption of vectorial transmission in 2001, but the disease is still actively transmitted in the Gran Chaco region. The epidemiology of Chagas disease in the Gran Chaco is complex, and combines a number of environmental, socioeconomic, and political factors that contribute to the persistence of vectorial transmission of Chagas disease.<sup>1</sup>

The Gran Chaco occupies approximately one million km<sup>2</sup> and is the second largest biome in the Americas after the Amazon region. An east-west rainfall gradient characterizes three subregions, with the humid chaco to the east, a dry chaco in the middle, and an arid chaco to the southwest, with annual rainfalls of 1,000, 600, and 350 mm, respectively (worldclim.org data, annual average for 1950–2000). The Gran Chaco of Argentina is occupied by 9.1 million persons (according to the last national census of 2001), 20% of whom are established in dispersed rural settlements, with an average human population density of less than 0.5 persons/km<sup>2</sup>.<sup>2</sup>

Towards the southern tip of the Gran Chaco, the region of Los Llanos in the province of La Rioja, Argentina, has historically been shown to be a hyper-endemic region for Chagas disease. The area has a subsistence economy based on domestic animals (mainly goats, cows, and chickens) and wild fauna. A few communities in the eastern part of this region occupy an area with sufficient rainfall that enables cattle grazing all year round, but most of the Los Llanos region has rainfall that only allows the raising of goats because the rainy season is from November through February.

Control activities against Chagas disease vectors in La Rioja have a long history, starting with the first evaluation of vector control techniques by insecticide spraying of houses in Villa Mazán (north of La Rioja).<sup>3</sup> Until the beginning of the 1980s, vector control activities were organized as a disciplined vertical program coordinated by the federal government.

In 1983, the national government began decentralization of the national program, a process that progressively reduced the resources and personnel available for Chagas disease control. However, from the beginning of the 1990s, vector control activities were strengthened in disease-endemic provinces through resource allocation for personnel, infrastructure, and supplies. Although this program produced in La Rioja some reactivation of vector control activities, it lasted only a few months. Since 1994, the provincial program progressively stopped systematic vector control activities in the rural areas of the Los Llanos region<sup>4,5</sup> and interviews of technical staff working for the provincial program since 1986). In 1999, a vector control intervention was carried out in the department of Belgrano and part of Chamental, promoted by the national program, as part of a research project that finished by the end of 2000.<sup>6</sup> No epidemiologic surveillance was sustained in the area.

After a long period with no systematic control interventions against *Triatoma infestans* in La Rioja, the provincial government approved in 2005 a five-year program to interrupt vectorial transmission in the region of Los Llanos. Initial activities of the new provincial program on Chagas disease began in 2004, with an insecticide spray program to cover all rural and peri-urban houses of cities in the provincial departments located in the region of Los Llanos. We conducted a study in association with the vector control activities carried out by the Chagas disease control program of La Rioja. The purpose of this study was to analyze the spatial distribution of rural house infestation by *T. infestans* in the region of Los Llanos, and characterize the situation before the large-scale insecticide application that started in 2004.

### METHODS

**Study area.** This study was carried out in the provincial departments of Los Llanos (Belgrano, Chamental, Independencia, Ocampo, Quiroga, AV Peñaloza, San Martín, R Vera) and the departments of Felipe Varela (west) and Capital (north) of La Rioja, Argentina (Figure 1).

The region studied included 7,212 houses in localities with less than 2,000 persons, and 4,662 houses in the rural area. Among these 11,874 houses, 5,456 were built of adobe walls and roofs made with a multi-layer structure of mud and local vegetation.<sup>2</sup> Some houses had walls made of hollow cement blocks. All rural houses had some peridomestic structure to

\* Address correspondence to David E. Gorla, Centro Regional de Investigaciones Científicas y Transferencia Tecnológica, Entre Ríos y Mendoza s/n, 5301 Anillaco, La Rioja, Argentina. E-mail: dgorla@crilar-conicet.com.ar

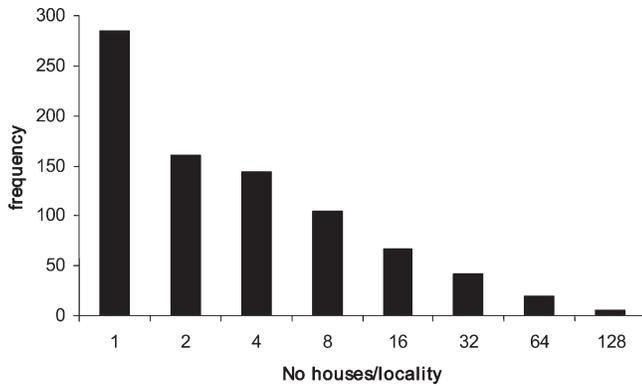


FIGURE 1. Frequency distribution of number of rural houses per locality in Los Llanos, La Rioja, Argentina. There are 5,045 houses in the area.

protect domestic animals. The most frequent of these structures were goat corrals and chicken coops. Houses generally had storage rooms for storing food for the animals and field tools. Storage rooms were places where hens, dogs, and cats usually slept at night. Almost 50% of the houses in the region had dirt floors, without tap water or sanitary infrastructure. On the basis of the national census in 2001, 56,208 persons lived in this region of 56,585 km<sup>2</sup>.

A five-year program of vector control activities by the Programa Chagas La Rioja began in 2004 with evaluation of infestation by *T. infestans* in intradomestic and peridomestic structures of rural houses. Two field teams, each with two persons, searched actively for 15 minutes in the intradomicile (ID) (sleeping rooms) and for an additional 15 minutes in the peridomicile (PD) (corrals of domestic animals, especially goats and chickens, and store rooms), using a dislodging agent (0.2% tetramethrin). One team searched in the ID and the other team searched in the PD. If one live specimen of *T. infestans* was found (any age class, including eggs), the search was stopped and the ecotope ID or PD was recorded as positive. All houses inspected in the first round (infested or not) were sprayed with suspension concentrate formulations of pyrethroid insecticide using manual sprayers at the appropriate concentration of active ingredients (deltamethrin at 25 mg of active ingredient/m<sup>2</sup>) [Bayer, Leverkusen, Germany] or beta-cypermethrin at 50 mg of active ingredient/m<sup>2</sup> [Chemotecnica, Buenos Aires, Argentina].

All rural houses located in settlements with less than 100 units were georeferenced with hand-held Garmin (Olathe, KS) Legend Global Positioning System and identified with an individual code that was marked on a metal plaque attached to an external wall. For operational reasons, a locality was defined as a group of houses separated by more than 2 km from another group. The name of the locality was the one given by the community. This plaque is meant to be used during the surveillance activities as a code that would identify unambiguously any reinfestation or recolonization by *T. infestans*. Entomologic data, evaluation/spraying date, family data, type and number of domestic animals, and construction details of each house were recorded on standard forms and entered into a spatial database that constitutes the geographic information system of the Programa Provincial Chagas of La Rioja. By 2007, all rural houses in the Los Llanos region had been sprayed at least once (according to the best knowledge of

well-trained field personnel). This study reports data collected during 2004–2007 and analyzes the infestation by *T. infestans* before spraying.

Spatial scan statistics were used to measure possible spatial heterogeneity in the house infestation<sup>7</sup> to detect clusters of significant high and low house infestation, compared with the regional average. The unit of analysis was the locality, the circular shape of the spatial scan was used for cluster detection with a maximum circle size equal to 50% of the whole area, and the Poisson model was selected. Although data on house infestation were collected during 2004–2007, the analysis was carried out as an atemporal spatial process.

House infestation was estimated as the proportion of houses infested by *T. infestans* within a locality or groups of localities. The dispersion index of house infestation was estimated as the ber of localities infested by *T. infestans* over the localities of a given area.<sup>8</sup>

## RESULTS

A total of 5,045 houses were identified during this study. These houses were distributed in 827 localities, with a frequency distribution of houses per locality strongly biased to low values (Figure 1). Localities with four or less houses represented 71.1% of all localities and included 22% of all rural houses.

Of these houses, 318 were infested exclusively in the ID, 759 exclusively in the PD, and 806 in both ecotopes, giving a total of 1,883 (37.3%) houses with ID and/or PD infestations. The 1,124 houses infested in the ID (22.3%) were distributed in 464 localities, and the 1,565 houses infested in the PD (31%) were distributed in 552 localities. These figures give dispersion indexes of house infestation of 56.1% for ID and 66.7% for PD infestation (73.9% localities infested in the ID and/or PD). All ID infestation corresponded to *T. infestans*. Other triatomine species were rarely found (< 0.1%) in the PD structures (*T. platensis* and *T. guasayana*).

The proportion of house infestation was inversely correlated with the number of houses in each locality (Figure 2). Among the localities with four or fewer houses, 40% of them had ID infestation and 50% had PD infestation. The fraction

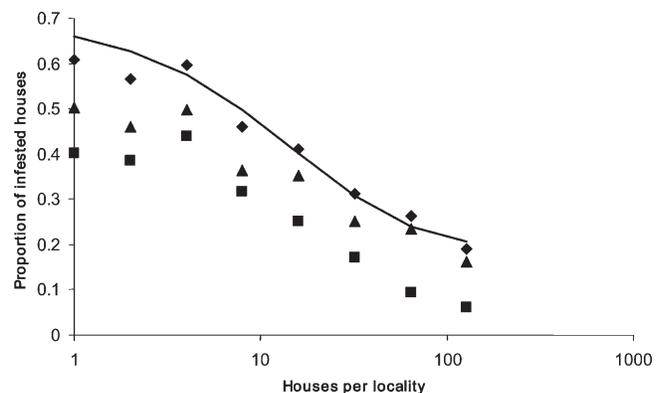


FIGURE 2. Relationship between proportion of infested houses in each locality and number of houses in the locality. Squares = intradomestic infestation; triangles = peridomestic infestation; diamonds = intradomestic and/or peridomestic infestation (IDPD). The line is a logistic regression  $IDPD = 0.1959 / (1 - 0.7179 \times \exp[-0.02115 \times \text{houses per locality}])$ .  $R^2 = 0.97$ .

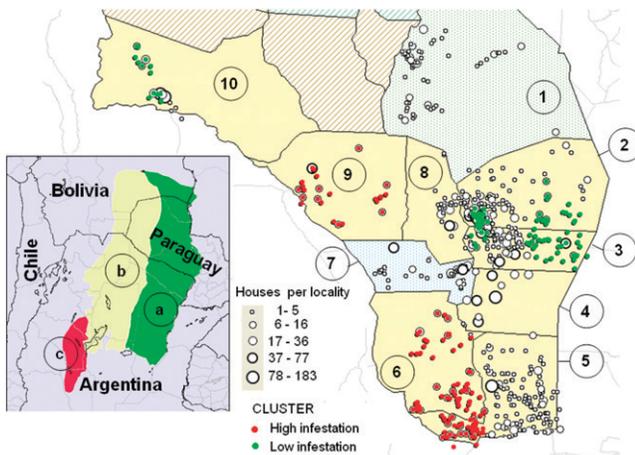


FIGURE 3. Distribution of rural houses in the study areas (white circles) and high and low house infestation aggregations (red and green, respectively). Solid yellow and dotted blue = departments included in the study; solid yellow = departments with georeferenced localities; diagonal = departments not included in the study; 1–10 = provincial departments of Capital, Chamental, Belgrano, Ocampo, San Martín, Rosario Peñaloza, Quiroga, Angel Peñaloza, Independencia, and Varela, respectively; a–c, humid, dry, and arid chaco, respectively.) This figure appears in color at [www.ajtmh.org](http://www.ajtmh.org).

of infested houses in a locality decreases as the size of the locality increases. The fraction of houses with PD infestation remained approximately 10% higher than the fraction of houses infested in the ID. Of the 1,124 houses infested in the ID, 39.8% belonged to localities with four or fewer houses (57.8% to localities with eight or fewer houses). Of the 1,565 houses infested in the PD, 33.7% belonged to localities with four or fewer houses (48.6% in localities with 8 or fewer houses).

Of the 5,045 houses evaluated, the information database of the Programa Chagas La Rioja currently has 4,032 georeferenced houses. Of these houses, 188 were infested only in ID structures, 596 were infested only in PD structures, and 541 were infested in both ecotopes (IDPD), giving a total of 1,325 (32.9%) houses infested in the ID and/or PD in 427 localities. House infestation was not homogeneously or randomly distributed in the study area. The spatial scan statistics showed strong spatial heterogeneity in house infestation. Two geographic clusters showed significantly higher house infestation of ID structures. One cluster had a radius of 33.2 km centered at 66.58°S, 31.81°W, and included 411 houses in 97 localities, where ID infestation was 61.5%. This cluster comprised the localities of the departments of San Martín and Rosario V Peñaloza. The other cluster had a radius of 57.7 km centered at 67.50°S, 30.06°W, and included 171 houses in 25 localities, where ID infestation was 45.0% (all localities within the department of Independencia). Three other clusters showed significantly low house infestation. One had a radius of 20.6 km, centered at 68.72°S, 29.32°W (towards the extreme northwest of the study area, outside the region of Los Llanos, over the pre-Andean mountain system) and included 195 houses in 13 localities, where ID infestation was 2.1%. Two nearby clusters of low infestation included localities in the departments of Belgrano and Chamental, and were centered at 65.78°S, 30.61°W (24.2 km-radius) and 66.34°S, 30.48°W (7.1 km-radius), which together included 604 houses in 87 localities, and showed 2.9% ID infestation (Figure 3).

When PD infestation was considered, the same clusters of high and low infestation were detected, but with higher

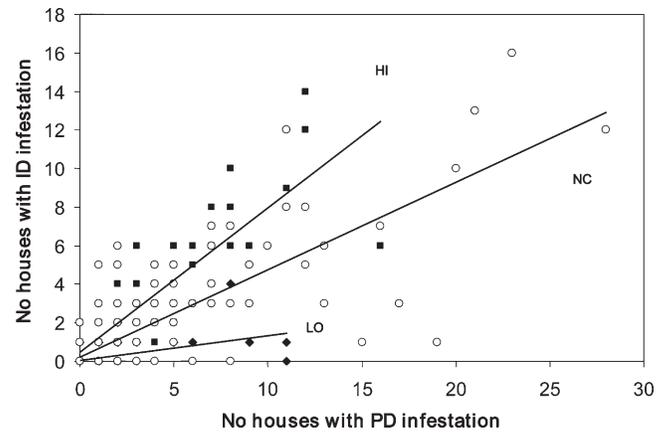


FIGURE 4. Relationship between the number of houses with peridomestic and intradomestic infestation in localities inside and outside clusters of high and low house infestation by *Triatoma infestans*. Diamonds (LO) = houses in localities in low infestation cluster ( $y = 0.049 + 0.13x$ ;  $n = 87$ ); squares (HI) = houses in localities in high infestation cluster ( $y = 0.478 + 0.748x$ ;  $n = 122$ ); white circles (NC) = houses in localities outside high or low clusters ( $y = 0.222 + 0.453x$ ;  $n = 352$ ).

proportion of house infestation. The two clusters of high infestation had 406 and 270 houses, with 66.7% and 57.8% of them infested. The two clusters of lowest infestation had 452 and 318 houses, with 8.4% and 14.8% of them infested in the PD structures. These cold spots are located in the east-central area of Los Llanos (Figure 3).

When we analyzed the 611 infested localities, a positive linear relationship was detected between the number of houses infested in ID and/or PD in a locality (slope = 1.11, adjusted  $R^2 = 0.58$ ), indicating significant association between ID and PD infestation. The slope value did not differ significantly from 1, suggesting that in the absence of vector control intervention during long periods, ID and PD would be occupied by *T. infestans*. The number of houses with ID infestation and the number with PD infestation in a locality also showed strong spatial heterogeneity. When this relationship was measured within the high infestation cluster, the association was much stronger than the association within the low infestation cluster; the association in localities outside high and low infestation clusters showed intermediate association strength (Figure 4).

## DISCUSSION

Transmission of Chagas disease has been strongly reduced in the southern cone countries of South America mainly on the basis of successful vector control programs and screening coverage of blood banks.<sup>9</sup> However, the situation for Chagas disease in the region of the Gran Chaco has shown a markedly different trend compared with the rest of the southern cone region.<sup>14</sup>

This study shows infestation by *T. infestans* in dispersed houses in the rural area of Los Llanos (La Rioja, Argentina) during 2004–2007 after almost a 15 year-period with virtual absence of systematic activities of the provincial vector control program. The high house infestation values (37% of ID and/or PD infestation) and the dispersal of infestation (74% of localities with ID and/or PD infestation) over a large area (56,000 km<sup>2</sup>) demonstrate the risk under which these human

communities lived in the absence of a sustained vector control program.

The only previously well-recorded data within the region of Los Llanos was reported by Gurtler and others<sup>6</sup> for the departments of Belgrano and (partially) Chaco, where a research team with the national program for Chagas disease evaluated the performance of different formulations and spraying techniques on the infestation of PD structures. According to their report, 70.5% of households were infested by *T. infestans* by December 2000 (one year after the insecticide spraying), which was much higher than the 20.6% (of 462) of infested PD structures recorded during September–October 2005 in this study in the department of Belgrano and 25.3% (of 641 houses) recorded during February–May 2007. This three-fold decrease in a 5–7 year period is remarkable because no systematic vector control intervention was carried out during this period. However, the area where the interventions reported by Gurtler and others<sup>6</sup> took place is shown to correspond to where one of the cold spots of infestation is located, suggesting that the 2004 interventions had a prolonged impact. In addition, the higher vegetation cover of the eastern region, and slightly improved socioeconomic status of the rural population of this area during the last years through cattle exploitation may have also contributed to lower infestation rates.<sup>10</sup>

The data recorded during this study show that high infestation of houses by *T. infestans* after a long period without systematic vector control is concentrated in the more isolated rural houses or small settlements with eight or fewer houses. Infestation is on average 10% higher in the PD structures and shows significant linear association between ID and PD structures, particularly in areas of highest infestation levels. Rural houses in the region are highly dispersed, and this feature has been and will remain as a challenge for any epidemiologic surveillance system. Many recommendations for the installation of a sustainable surveillance system depend heavily on community involvement, by providing information on infestation to visiting health agents, or communicating the infestation to a community leader trained to spray the house. However, such ideas are difficult to sustain in regions such as Los Llanos, which has many isolated houses or settlements with fewer than eight houses. In the case of the high infestation cluster to the southwest of Los Llanos (including part of the departments of San Martín and R Vera, the 411 houses are spread over 89 localities, suggesting a need for 89 community representatives (one for every four houses). An alternative approach would involve health agents making regular evaluation rounds, but this would involve travel of 450–500 km to visit the 411 houses located within the cluster of houses with high infestation southwest of Los Llanos. Currently, there is no system in the area with the appropriate mobility to travel these distances to evaluate the houses with a reasonable frequency.

The spatial analysis of house infestation showed highly infested areas southwest (Departments of San Martín and RV Peñaloza) and west (Department of Independencia) of the province. The strength of the PD and ID infestation is higher in localities within the high infestation cluster, suggesting that local causes synergize the infestation and its persistence. These areas represent the extreme situation of house infestation, and unless the quality of the houses and culture of the people change, house infestation by *T. infestans* will remain

high in the absence of perpetual vector control interventions. Clusters of houses with high infestation are associated with low income areas, with rural populations living under a subsistence economy, especially in southwestern Los Llanos. In this area, rainfall is scarce (less than 400 mm/year), pastures (if any) are poor, and goats are the only domestic animals people can raise.<sup>10</sup>

*Triatoma infestans* can be eliminated as an epidemiologically important vector. This status was obtained for 80% of the original geographic distribution of this species.<sup>9</sup> Studies carried out especially during the past decade strongly suggest that the remaining 20% will be more difficult to eliminate. A long-term study carried out in the Argentine Chaco region of Santiago del Estero showed that after 20 years of scientifically supervised community participation in an area including approximately 200 rural houses, interruption of the vectorial transmission of *T. cruzi* by *T. infestans* can be attained.<sup>1</sup> However, other approaches independent of scientifically supervised surveillance have to be considered to interrupt vectorial transmission throughout the Gran Chaco, where approximately 200,000 rural houses are still included in the disease-endemic area. Available evidence suggests that surveillance this will be expensive and heavily dependent on national and/or provincial resources, rather than the local communities themselves. The vector control scheme will need the community to inform about the presence of triatomines in the houses, but vector control activities will have to be carried out by professional staff.

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**Authors' addresses:** David E. Gorla, Ximena Porcasi, and Silvia S. Catalá, Centro Regional de Investigaciones Científicas y Transferencia Tecnológica, Entre Ríos y Mendoza s/n, 5301 Anillaco, La Rioja, Argentina. Hugo Hrellac, Programa Provincial de Chagas, Ministerio de Salud, El Chacho 50. 5300, La Rioja, Argentina.

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