

Exploring the association between *Trypanosoma cruzi* infection in rural communities and environmental changes in the southern Gran Chaco

Mariana Laura Moreno^{1/+}, Laura Hoyos², Marcelo Cabido², Silvia Susana Catalá¹, David Eladio Gorla¹

¹Centro Regional de Investigaciones Científicas y Transferencia Tecnológica, 5301 Anillaco, La Rioja, Argentina ²Instituto Multidisciplinario de Biología Vegetal, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Córdoba, Argentina

The association between land use and land cover changes between 1979-2004 in a 2.26-million-hectare area south of the Gran Chaco region and Trypanosoma cruzi infection in rural communities was analysed. The extent of cultural land, open and closed forests and shrubland up to 3,000 m around rural communities in the north, northwest and west of the province of Córdoba was estimated using Landsat satellite imagery. The T. cruzi prevalence was estimated with a cross-sectional serological survey conducted in the rural communities. The land cover showed the same patterns in the 1979, 1999 and 2004 satellite imagery in both the northwest and west regions, with shrinking regions of cultured land and expanding closed forests away from the community. The closed forests and agricultural land coverage in the north region showed the same trend as in the northwest and west regions in 1979 but not in 1999 or 2004. In the latter two years, the coverage remote from the communities was either constant or changed in opposite ways from that of the northwest and west regions. The changes in closed forests and cultured vegetation alone did not have a significant, direct relationship with the occurrence of rural communities with at least one person infected by T. cruzi. This study suggests that the overall decrease in the prevalence of T. cruzi is a consequence of a combined effect of vector control activities and changes in land use and land cover.

Key words: Chagas disease - land cover changes - Gran Chaco

Chagas disease is one of the most important endemic diseases in Latin America and it is caused by *Trypanosoma cruzi* and transmitted by haematophagous insects of the subfamily Triatominae (Hemiptera: Reduviidae). Vector control programmes in the Southern Cone countries of South America were highly successful in reducing the impact in about 80% of the original distribution area of *Triatoma infestans* (Gorla 2002, Schofield et al. 2006), which is the main vector species in the area. The infestation of rural homes was eliminated by systematically spraying the houses with residual insecticides, which interrupted the vectorial transmission of the parasite and decreased the disease incidence. Such programmes were successful in the Southern Cone countries of South America, except in the Gran Chaco region.

The Gran Chaco is the second largest ecosystem in Latin America after the Amazon Basin. It covers about one million square kilometres (Pennington et al. 2000) and occupies most of northern Argentina, eastern Bolivia, western Paraguay and a small area of south-western Brazil. The region underwent profound socio-environmental changes starting at the end of the 19th century (Bucher & Schofield 1981), primarily as the result of deforestation for charcoal and fuel wood production and

more recently because of the expansion of soybean cultivation (Grau et al. 2005, Zak et al. 2008).

The rural communities of the Gran Chaco region are the last places where *T. infestans* resists the vector control efforts that started in the Chaco region of Argentina in the 1960s. The political and economic instabilities in the region have had a negative effect on effective vector control measures during the last 50 years and the *T. infestans* populations in the Gran Chaco appear to be the most genetically variable (Panzeria et al. 2004, Bargues et al. 2006, Pérez de Rosas et al. 2007, Piccinali et al. 2009) and the best adapted to domestic and peridomestic environments because of their phenotypic plasticity (Catalá et al. 2007, Hernández et al. 2008, Dujardin et al. 2009). Because of their biological characteristics, these populations are the most resilient to vector control interventions (Cécere et al. 2002, Gürtler et al. 2004). The high genetic variability, including a resistance to pyrethroid insecticides (Picollo et al. 2005), seems to be associated with the proximity to the centre of origin of the species, which includes two allopatric genotypes (Panzeria et al. 2004, Bargues et al. 2006): the Andean genotype, which probably originated in the Andean valleys of Bolivia, and the non-Andean genotype, whose origin is in the ecotone between the Andean valleys and the Chaco region of Tarija (Bolivia) near the border with Argentina.

Historically, Chagas disease has been highly endemic in the Chaco region, most notably in the province of Santiago del Estero in Argentina. During the 1970s and 1980s, around 200 acute cases were reported each year. The vector control interventions in the area decreased the reports of acute cases to about 20 per year after the mid 1990s and to fewer than 10 during the last few years. Northern province of Córdoba, the region south of Santi-

Financial support: FONCYT PICTR275, CONICET

+Corresponding author: marimore2002@yahoo.com.ar

MLM current address: INBIAL, Universidad Nacional de Jujuy, Jujuy, Argentina

Received 4 July 2011

Accepted 1 December 2011

ago del Estero and the southern extreme of the Gran Chaco were highly endemic for Chagas disease and showed a pattern similar to that of Santiago del Estero (Chüit 1989), although a greater reduction occurred in the prevalence of *T. cruzi* in the rural communities of the Chaco region in Córdoba. Moreno et al. (2010) recently showed that the *T. cruzi* prevalence in young children (under 10 years of age) was zero or very low, which suggests that the vector-borne transmission of *T. cruzi* has been reduced in most of the area. The spraying of houses with residual insecticides in the north and west of Córdoba was systematic during the 1980s. At the beginning of the 1990s, vector control activities were decentralised and performed by local field teams who responded to communities that reported houses infested with *T. infestans*. Pyrethroids were the active ingredient used in house spraying throughout this period (Sosa Estani et al. 2006).

During the last three decades of the 20th century, changes in the land cover of northern Córdoba, which comprises the southern extreme of the Gran Chaco, have been characterised by deforestation to create agricultural land and cattle pasture land. Approximately 80% of the area that was originally undisturbed, seasonally dry Chaco forests is now occupied by annual crops and improved pastures. Since 1969, the forests have shrunk at a rate of 2.75% per year (Zak et al. 2008). The working hypothesis of this study is that the reduction in prevalence of *T. cruzi* was caused not only by the use of residual insecticides, but also by the changes in land cover and land use around rural communities, which promoted the elimination of infestations by *T. infestans*.

The specific objective of this study was to evaluate the changes in land cover and land use around rural communities in the southern region of the Gran Chaco between 1979-2004 and to analyse the association of these changes with infection by *T. cruzi*.

SUBJECTS, MATERIALS AND METHODS

Study area - This study was conducted in the province of Córdoba (central Argentina), which is a region where Chagas disease is endemic. The study area covered 2.26 million hectares, which was divided into three regions: the north (0.99 million hectares), the northwest (0.76 million hectares) and the west (0.50 million hectares) (Fig. 1). The changes in land use and land coverage were analysed using Landsat satellite imagery and the prevalence of *T. cruzi* infection was determined with a serological study of the human populations of rural communities.

Estimation of land coverage - A land cover map of the study area provided by L Hoyos et al. (unpublished observations) indicated nine types of land cover: closed forests (14% of the studied area), open forests (14%), closed shrublands (22%), open shrublands (3%), cultured vegetation (comprising agricultural lands, implanted pastures and small towns) (41%) and other land-cover types (halophytic vegetation, grasslands with scattered shrubs, water and salt) (6%). For the purpose of this study, we only considered four cover types: closed forests, open forests (or secondary forests), shrublands (both types of shrubland and the grasslands with scattered shrubs were merged into a unique class) and cultured vegetation.

Analyses of changes in land coverage at the regional scale are usually performed to measure the impact of humans on the environment. Although small populations of wild *T. infestans* have been reported to live in rockeries and birds' nests in southern Bolivia and in parrots' nests located inside hollow trees in northern Argentina (Noireau et al. 2005, Ceballos et al. 2009), the *T. infestans* populations in the study area are exclusively found in domestic and peridomestic habitats (e.g., houses, goat corrals, chicken pens, grain deposits). Because the vector species occupies exclusively domestic habitats, changes at the regional scale would not necessarily affect its populations. For the purpose of this study, the quantitative assessment of changes in land use and land coverage between 1979-2004 focused on the land immediately around rural communities located within the area endemic for Chagas disease in the north, northwest and west of the province of Córdoba. The estimates of land coverage by supervised classification of satellite imagery (Zak & Cabido 2002, L Hoyos et al., unpublished observations) were compared for 1979, 1999 and 2004; beginning with a town, the analysis proceeded from the centre outward in 500-m concentric rings (up to 3,000 m). After the three shrubland/grassland classes were merged and water was discarded, the 2004 image classification showed an accuracy of 80% (Kappa = 0.72) and 115 of the 145 validation sites were confirmed as correctly classified (L Hoyos et al., unpublished observations).

The prevalence of *T. cruzi* infection - We performed a cross-sectional analysis to estimate the prevalence of *T. cruzi* in the human population (defined as those up to 40 years of age living in the rural communities of the

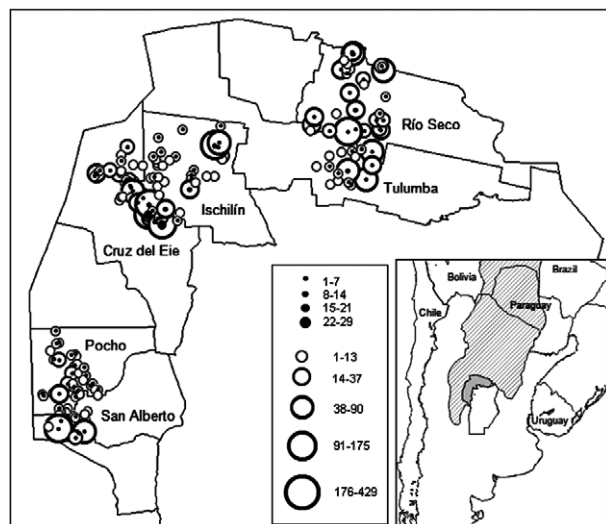


Fig. 1: location within province of Córdoba of the three regions where the serological and land cover studies were carried out. Circles show the location of each rural community. Circle size represent the number of people studied for *Trypanosoma cruzi* infection (white) and number of people seropositive for *T. cruzi* (black). The inset shows the location of the study area, north and west of Córdoba to the south of the Gran Chaco (diagonal pattern).

3 selected areas). Blood samples taken from 5,240 persons were analysed using two serological tests to detect *T. cruzi* infection. All infected children younger than 15 years of age received parasitological treatment (benznidazol) from the Health Ministry of the province of Córdoba and all infected subjects older than 15 years of age were offered clinical counselling. The *T. cruzi* infection in the north was evaluated in 1,827 persons in 48 rural communities. The serological study was performed on 2,501 persons in 76 rural communities in the northwest and on 912 persons in 61 rural communities in the west. Additional methodological details and data analyses of the prevalence of *T. cruzi* in these regions are described by Moreno et al. (2010).

Data analysis - The types of land coverage within each circle centred over each rural community were analysed for all three regions in each year. A univariate linear regression was used to study the shape and significance of the relationship between the land coverage and the distance from the rural communities.

A spatial analysis of seropositive cases (spatial scan statistics, purely spatial) was performed using a Poisson model to detect significantly high rate clusters (Kulldorff 1997).

The rural localities of all regions were classified as infected (coded 1) or not infected (coded 0), according to the presence or absence of persons with *T. cruzi* infections. A simple logistic regression analysis (with the corresponding 95% confidence interval) was used to investigate the association between changes in land coverage and the occurrence of at least one person infected with *T. cruzi* in each rural community of each region. For this analysis, we only considered the vegetation that demonstrated major changes on the local scale (closed forests and cultured vegetation). Changes in the land coverage were estimated as the relative change of a particular type of vegetation (closed forest or cultured vegetation) between 1979-2004 using the equation $[(a_2 - a_1) \times 100] / a_1$, where a_2 and a_1 are the surface areas (in hectares) of a particular coverage in 2004 and 1979, respectively.

RESULTS

Although all of the vegetation units identified in the 1979 map are still present in the 2004 map, their spatial arrangements have changed markedly. In 1979, closed forests occupied a considerable proportion of the study area and had a distribution that was nearly contiguous with a few deforested areas. Cultured vegetation was less extensively distributed at that time, especially in the northwest and west. Two classes of land coverage, closed forests and shrublands, shrank; the former was the most adversely affected, occupying half of the area in 2004 that it covered in 1979. Meanwhile, cultured vegetation and open forests have expanded.

The land coverage around the rural communities in the north, northwest and west in Córdoba showed significant heterogeneity in time and space. The area dedicated to agricultural land around the rural communities decreased at increasing distances from the rural communities in the northwest and west between 1979-2004, which suggests that agricultural activity developed only

near the communities and was not an extensive activity. The cultured land coverage in the north showed agricultural activities concentrated around the rural communities in 1979, with about 44% and 32% of the land within a 500 m and 3,000 m radius, respectively, covered by agricultural land. In 1999, the trend changed, as the agricultural land expanded significantly and covered a higher surface area away from the communities (46% within 3,000 m). This trend continued in 2004, with 53% and up to 63% of the land coverage being agricultural near the communities and within a 3,000 m radius, respectively (similar linear slope but significantly higher offset) (Table I), which suggests the strong development of agriculture as an extensive activity. The agricultural land in the northwest was highly concentrated around rural communities (on average, 55% of the land coverage within a 500 m radius) and there were no significant changes between 1979-2004 (the regression lines for the cultured coverage vs. the distance from the rural community show no differences between 1979-2004) (Table I). The west showed the lowest proportion of coverage devoted to agriculture and the environment experienced few changes during the studied period (Fig. 2A).

The closed forests around the rural communities of the northwest were more abundant farther away from the communities; in 1979 and 1999, closed forests comprised 36% of the land coverage within the 3,000 m radius, but that coverage decreased to 15% in 2004. A similar trend was observed in the west, although the coverage within the 3,000 m radius was lower in 1979 and 1999 than that of the northwest (maximum of 23%) and similar to that of the northwest in 2004 (15%). The closed forest coverage in the north exhibited a different pattern, with increasing coverage away from the communities in 1979 (up to a maximum of 22%) followed by a progressive decrease in 1999 and 2004 (Fig. 2B).

The proportion of coverage that consisted of open forests in the west was low in 1979, increased in 1999 (peaking in the 2,000 m radius at 39%) and decreased to an intermediate level in 2004. In the northwest, the proportion of open forest was very low in 1979 and 1999, but increased in 2004, especially farther away from the rural communities. In the north, open forests comprised about 10% of the coverage in both 1979 and 1999 and that coverage increased in 2004, especially near the communities.

Shrubland was the main type of coverage in the west (50-60%) in both 1979 and 2004, but it decreased with the distance from the rural communities in 1999. The northwest and north had lower proportions of shrub coverage, with an increasing trend in the northwest and a decreasing trend in the north over time.

The cultured land and closed forests around the rural communities displayed a significantly negative relationship in the west during all three studied years. A similar pattern was observed in the north in 1979, but not in 1999 or 2004 (Table II).

The serological study showed that 5.4%, 7.9% and 7.5% of 1,827, 2,501 and 912 studied persons, respectively, in the studied rural communities were infected by *T. cruzi* in the north, northwest and west, respectively. In the north and west, 0.59% of children younger than 15 years of age

were infected, whereas in the northwest, 2.94% were infected, reflecting an increase of almost five fold.

Using the satscan statistics (Kulldorff 1997), an analysis of the spatial distribution showed that 61 of the 99 (61.6%) *T. cruzi* seropositive cases in the north were concentrated in an area centred at 30°16'13"S 63°25'37"W with a radius of 19.5 km. A similar analysis of the west revealed that 59 of the 68 (86.8%) seropositive cases were concentrated in an area centred at 31°31'7"S 65°30'19"W with a radius of 16.9 km. A spatial analysis of the seropositive cases in the northwest showed two small but significant aggregations of cases (centred at 30°16'54"S 64°46'4"W and 30°37'14"S 64°57'18"W) that included 23 of the 197 seropositive cases (11.7%).

The rest of the seropositive cases in the northwest were dispersed throughout the region (Fig. 1).

Changes in closed forests and cultured vegetation between 1979-2004 did not show a significant relationship ($p > 0.05$) with the presence of *T. cruzi* infection in the human population under 40 years of age in the rural communities of the north, northwest and west in Córdoba.

DISCUSSION

As a consequence of the long-lasting vector control programmes for Chagas disease that were initiated in the 1960s, as well as the concerted, multi-country programmes coordinated by the Southern Cone Initiative since 1991, the incidence of new *T. cruzi* infections across

TABLE I
Linear regressions between land cover category and distance (500-3,000 m) from the rural communities

Land cover	Region	Year	Offset	Slope (95% CI) ($\times 10^{-5}$)	R ²
Cultural	North	1979	0.4441	-4.14** ^a (-5.64, -2.63)	0.92
		1999	0.3679	3.71** ^b (1.32, 6.10)	0.78
		2004	0.5226	4.19** ^b (2.04, 6.34)	0.85
	Northwest	1979	0.5193	-1.05** ^c (-12.67, -8.27)	0.97
		1999	0.6737	-1.34** ^c (-17.22, -9.54)	0.95
		2004	0.5526	-1.01** ^c (-13.32, -6.90)	0.94
	West	1979	0.1780	-3.89** ^a (-6.87, -0.91)	0.71
		1999	0.1170	-2.69** ^a (-4.23, -1.15)	0.82
		2004	0.1792	-3.21** ^a (-6.10, -0.33)	0.63
Open forests	North	1979	0.1155	3.54** ^a (2.50, 4.58)	0.95
		1999	0.1216	0.49 NS (-0.65, 1.63)	0.08
		2004	0.0812	0.53 NS (-0.53, 1.58)	0.16
	Northwest	1979	0.2133	5.03** ^a (4.55, 5.51)	0.99
		1999	0.1718	7.17** ^a (3.53, 10.8)	0.85
		2004	0.0551	3.73** ^a (1.61, 5.85)	0.82
	West	1979	0.1473	3.06** ^a (1.46, 4.65)	0.84
		1999	0.1020	5.07** ^a (2.97, 7.16)	0.90
		2004	0.0547	3.74** ^a (0.38, 7.10)	0.63
Closed forests	North	1979	0.1213	-0.81 NS (-4.02, 2.40)	0.11
		1999	0.1135	-0.02 NS (-0.08, 0.08)	0.01
		2004	0.2009	-2.73** ^a (-4.48, -0.98)	0.78
	Northwest	1979	0.0478	-0.45** ^a (-0.79, -0.11)	0.72
		1999	0.0356	0.32 NS (-1.12, 1.75)	0.08
		2004	0.0710	1.76** ^b (0.87, 2.65)	0.85
	West	1979	0.1022	1.26** ^b (0.08, 2.44)	0.61
		1999	0.3089	1.72 NS (-5.43, 8.86)	0.10
		2004	0.2108	1.71 NS (3.09, 6.51)	0.19
Shrubland	North	1979	0.3365	0.77** ^a (0.09, 1.44)	0.65
		1999	0.4011	-4.53** ^b (-6.49, -2.56)	0.89
		2004	0.1953	-1.99** ^b (-3.09, -0.88)	0.83
	Northwest	1979	0.0919	5.03** ^c (2.04, 8.01)	0.81
		1999	0.1016	3.79** ^c (3.55, 4.03)	1.00
		2004	0.2847	2.22** ^{ac} (0.67, 3.76)	0.75
	West	1979	0.5559	-1.68 NS (-3.76, 0.39)	0.45
		1999	0.4828	-6.73** ^b (-11.6, -1.85)	0.73
		2004	0.5498	-2.26 NS (-7.49, 2.96)	0.08

same letters in the slope column indicates non significant differences within land cover category. CI: confidence interval; NS: non significant; R²: correlation coefficient; *: $p < 0.05$; **: $p < 0.01$.

the Southern Cone countries of South America has decreased by 70% (Moncayo & Silveira 2009). Although the transmission of *T. cruzi* has declined in the region, including areas where the vector-borne transmission of *T. cruzi* by *T. infestans* was interrupted (i.e., Chile, Uruguay, Brazil, eastern Paraguay and 5 provinces of Argentina), other areas exhibit a mosaic of active, vector-borne transmission (Diosque et al. 2004), interrupted transmission and reactivated transmission. Within the Southern Cone countries, the Gran Chaco region is the place where *T. infestans* populations are most resistant to vector control efforts (Gorla et al. 2009).

The results of a concomitant study performed in the same area (Moreno et al. 2010) and those of the present study show the complexity of the interactions between vector control activities, the expansion of the agricultural land driven by a secular rainfall pattern, migrations from rural to urban environments and local improvements in quality-of-life in rural communities.

In general, the migration from rural to urban areas is driven by the expectations of rural inhabitants that they will have better opportunities in the urban environment than in the rural environment (urban pull migration). In much of the study area and probably in other areas with-

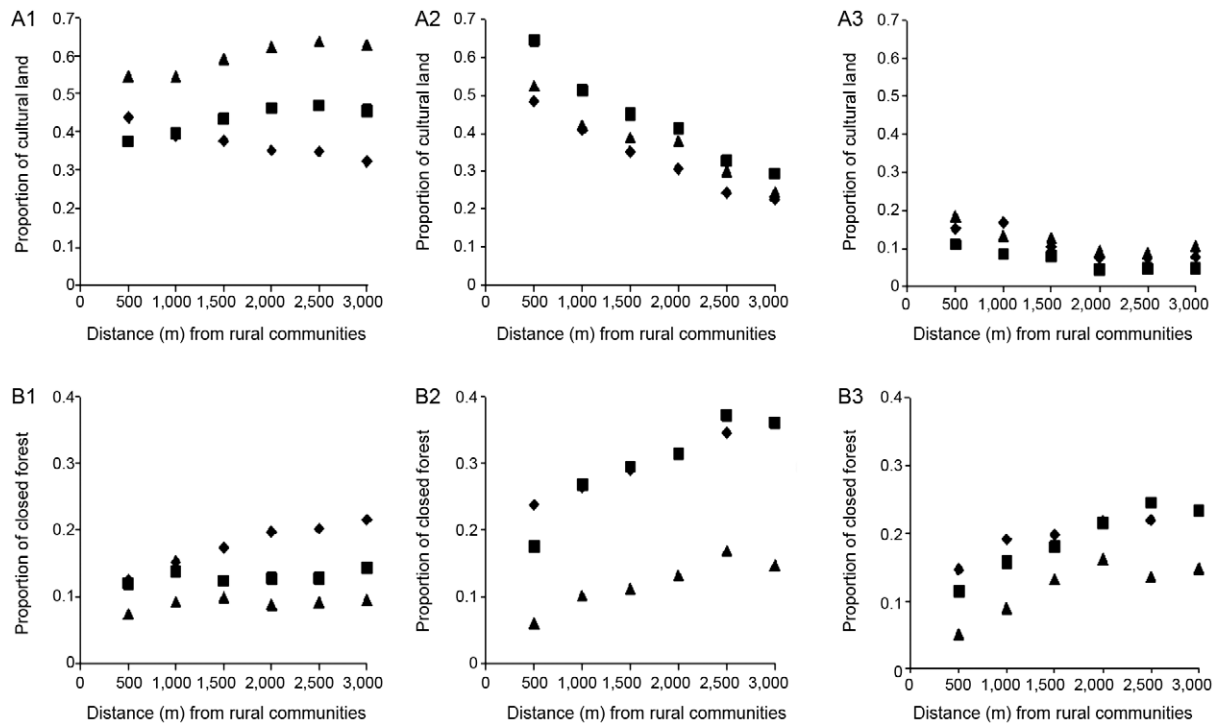


Fig. 2: coverage (as proportion) of cultural land (A) and closed forest (B) at increasing distance from rural communities (from 500-3,000 m). A1-A3: cultural cover in the north, northwest and west regions; B1-B3: primary forest cover in the north, northwest and west regions. Coverages estimated for 1979 (diamonds), 1999 (squares) and 2004 (triangles).

Table II
Linear regression between cultural vs. closed forest covers

Region	Year	Offset (95% CI)	Slope (95% CI)	R ²
North	1979	0.488 (0.420, -0.550)	-0.877 ^a (-1.009, -0.664)	0.97
	1999	0.106 (-0.031, 0.244)	0.0544 NS (-0.260, 0.371)	0.05
	2004	0.0332 (-0.119, 0.185)	0.0960 NS (-0.158, 0.350)	0.02
Northwest	1979	0.460 (0.435, 0.485)	-0.473 ^a (-0.545, -0.402)	0.98
	1999	0.539 (0.483, 0.596)	-0.551 ^a (-0.676, -0.427)	0.97
	2004	0.255 (0.176, 0.335)	-0.359 ^a (-0.566, -0.153)	0.82

^a: p < 0.05 or < 0.01 CI: confidence interval; NS: non significant; R²: correlation coefficient.

in the Gran Chaco, rural-to-urban migration is driven not only by urban pull but also by rural push, i.e., the expulsion of people from rural communities as the result of the agricultural land expansion (especially the expansion arising from soybean cultivation). In the context of Chagas disease epidemiology, the final result is the migration of infected people into urban settlements where they do not always receive proper medical care.

Understanding the successes and failures of the vector-borne transmission of *T. cruzi* is critical for designing interventions aiming at eliminating Chagas disease as a public health problem. In the north, northwest and west of the province of Córdoba, the reduction of the incidence of *T. cruzi* infection in the rural communities where Chagas disease is endemic is a complex process. Sustained vector control interventions (high frequency and geographic coverage) have played a major role in the significant reduction of the vector-borne transmission in some areas, although they are not the only cause. In some cases, vector control is insufficient. This is the case in the northwest, where land use around the rural communities showed few changes between 1979-2004 and vector control interventions were relatively frequent, but with low coverage (Moreno et al. 2010). In the north, even with the relatively low impact of vector control interventions, the improvement of lifestyle and/or quality of life in rural communities, driven by the expansion of agricultural land, has reduced *T. cruzi* transmission (although in some cases, the Chagas problem has simply been transferred to urban settlements because of the migration from poor rural communities to cities). The vector-borne transmission of *T. cruzi* seems to be less prevalent in the north and west, with very low infection rates in younger children and infected people older than 15 years of age largely aggregated in a few small areas. In contrast, the *T. cruzi* infection in the northwest was widely spread throughout the region and in all age classes, even in younger individuals, which suggests that vector-borne transmission is more common there.

REFERENCES

- Bargues MD, Klisiowicz DR, Panzera F, Noireau F, Marcilla A, Pérez R, Rojas MG, O'Connor JE, Gonzalez-Candelas F, Galvão C, Jurberg J, Carcavallo RU, Dujardin JP, Mas-Coma S 2006. Origin and phylogeography of the Chagas disease main vector *Triatoma infestans* based on nuclear rDNA sequences and genome size. *Inf Gen Evol* 6: 46-62.
- Bucher EH, Schofield CJ 1981. Economic assault on Chagas disease. *New Sci* 92: 321-324.
- Catalá SS, Gorla D, Juárez P, Picollo MI, Panzera F, Noireau F, Rojas Cortes M, Dujardin JP, Zerba E, Vassena CI, Pérez R, Calderón G, Abraham L, Hernández ML, Lopes E, Porcasi X, Moreno M, Schater Broide J, Gürtler R, Lucero CI, Ferrandis I, Calleros L, Ferreira MJ, Cardozo L, Girotti J, Mijailovski S, Richer W, Kengne P, Perrineau MM, Cohuet A, Fontenille D, Herrera BI, Gentile A, Gemio A, Alderete P, Diosque P, Recalde P, Zelaya C, Llanos A, Uncos A, Bogado V 2007. Causas biológicas y ambientales de la estructuración espacial en *Triatoma infestans* y sus implicancias en el control vectorial. Proceedings SSA/EC American Trypanosomiasis Update Workshop, Asunción, Paraguay, 25-27 April, p. 1-7.
- Ceballos LA, Piccinali RV, Berkunsky I, Kitron U, Gürtler RE 2009. First finding of melanic sylvatic *Triatoma infestans* (Hemiptera: Reduviidae) colonies in the Argentine Chaco. *J Med Entomol* 46: 1195-1202.
- Cécere MC, Gürtler RE, Canale DM, Chüit R, Cohen JE 2002. Effects of partial housing improvement and insecticide spraying on the reinfestation dynamics of *Triatoma infestans* in rural northwestern Argentina. *Acta Trop* 84: 101-116.
- Chüit R 1989. *Epidemiología de la enfermedad de Chagas en áreas rurales de Argentina*, Thesis, Facultad de Ciencias Médicas, Universidad Nacional de Córdoba, Argentina, 126 pp.
- Diosque P, Padilla AM, Cimino RO, Cardozo RM, Sanchez Negrete O, Marco JD, Zacca R, Meza C, Juárez A, Rojo H, Rey R, Corrales RM, Nasser JR, Basombrío MA 2004. Chagas disease in rural areas of Chaco province, Argentina: epidemiologic survey in humans, reservoirs and vectors. *Am J Trop Med Hyg* 71: 590-593.
- Dujardin JP, Costa J, Bustamante D, Jaramillo N, Catalá S 2009. Deciphering morphology in Triatominae: the evolutionary signals. *Acta Trop* 110: 101-111.
- Gorla DE 2002. Variables ambientales registradas por sensores remotos como indicadores de la distribución geográfica de *Triatoma infestans*. *Ecol Aust* 12: 117-127.
- Gorla D, Porcasi X, Hrellac H, Catalá S 2009. Spatial stratification of house infestation by *Triatoma infestans* in La Rioja, Argentina. *Am J Trop Med Hyg* 80: 405-409.
- Grau HR, Gasparri NI, Aide TM 2005. Agriculture expansion and deforestation in seasonally dry forest of north-west Argentina. *Env Conser* 32: 140-148.
- Gürtler RE, Canale DM, Spillmann C, Stariolo R, Salomón OD, Blanco S, Segura EL 2004. Effectiveness of residual spraying of peridomestic ecotopes with deltamethrin and permethrin on *Triatoma infestans* in rural western Argentina: a district wide randomized trial. *Bull WHO* 82: 196-205.
- Hernández ML, Abraham L, Moreno M, Gorla D, Catalá S 2008. Phenotypic variability associated to genomic changes in the main vector of Chagas disease in South America. *Acta Trop* 106: 60-67.
- Kulldorff MA 1997. A spatial scan statistic. *Theory Meth* 26: 1481-1496.
- Moncayo A, Silveira AC 2009. Current epidemiological trends for Chagas disease in Latin America and future challenges in epidemiology, surveillance and health policy. *Mem Inst Oswaldo Cruz* 104 (Suppl. 1): 17-30.
- Moreno M, Moretti E, Basso B, Frias M, Catalá S, Gorla D 2010. Seroprevalence of *Trypanosoma cruzi* infection and vector control activities in rural communities of the southern Gran Chaco (Argentina). *Acta Trop* 113: 257-262.
- Noireau F, Rojas Cortez MG, Monteiro FA, Jansen AM, Torrico F 2005. Can wild *Triatoma infestans* foci in Bolivia jeopardize Chagas disease control efforts? *Trends Parasitol* 21: 7-10.
- Panzera F, Dujardin JP, Nicolini P, Caraccio MN, Rose V, Tellez T, Bermudez H, Bargues MD, Mas-Coma S, O'Connor JE, Perez R 2004. Genomic changes of Chagas disease vector. *S Am Emerg Infect Dis* 10: 438-446.
- Pennington RT, Prado DE, Pendry CA 2000. Neotropical seasonally dry forests and quaternary vegetation changes. *J Biogeography* 27: 261-273.
- Pérez de Rosas A, Segura E, García B 2007. Microsatellite analysis of genetic structure in natural *Triatoma infestans* (Hemiptera: Reduviidae) populations from Argentina: its implications in assessing the effectiveness of Chagas' disease vector control programmes. *Mol Ecol* 16: 1401-1412.
- Piccinali R, Marcet P, Noireau F, Kitron U, Gürtler R, Dotson M 2009. Molecular population genetics and phylogeography of the

- Chagas disease vector *Triatoma infestans* in South America. *J Med Entomol* 46: 796-809.
- Piccollo MI, Vassena C, Santo Orihuela P, Barrios S, Zaidemberg M, Zerba E 2005. High resistance to pyrethroid insecticides associated with ineffective field treatments in *Triatoma infestans* (Hemiptera: Reduviidae) from northern Argentina. *J Med Entomol* 42: 637-642.
- Schofield CJ, Jannin J, Salvatella R 2006. The future of Chagas disease control. *Trends Parasitol* 22: 583-588.
- Sosa Estani S, Zaidemberg M, Segura E 2006. Descentralización del programa de control de la transmisión de *Trypanosoma cruzi* (Chagas) en Argentina. In Z Yadón, R Gurtler, F Tobar, *Descentralización y gestión del control de las enfermedades transmisibles en América Latina*, A Medici, Buenos Aires, p. 189-202.
- Zak MR, Cabido MR 2002. Spatial patterns of the Chaco vegetation of central Argentina: integration of remote sensing and phytosociology. *App Veg Sci* 5: 213-226.
- Zak MR, Cabido MR, Cáceres D, Diaz S 2008. What drives accelerated land cover change in central Argentina? Synergistic consequences of climatic, socioeconomic and technological factors. *Env Manag* 42: 181-189.