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Community-based entomological surveillance in three Chagas disease-endemic regions in sub-Andean Bolivia

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Background: Chagas disease is endemic throughout most of Bolivia, with prevalence rates of 25% observed in some geographic areas located mainly in the sub-Andean region.

Methods: Community-based entomological surveillance was carried out in the sub-Andean departments of Cochabamba (municipalities of Cochabamba, Punata and Sacaba), Tarija (municipality of Tarija) and Chuquisaca (municipality of Sucre). The surveillance parameters evaluated were: (i) the proportion of cards with the presence of triatomines; (ii) the distribution of positive cards by area; and (iii) the proportion of cards with the presence of infected triatomines.

Results: Of the cards returned, in 852 (3.1%) there was a mention of the presence of triatomines. The species *Triatoma infestans*, *Triatoma sordida* and *Triatoma guasayana* were identified in 812 (95.3%), 39 (4.6%) and 1 (0.1%), respectively. The median monthly positivity rate of the cards during 2011-2018 was higher in Punata (9.1%; IQR=3.2–15.4%). The median monthly rate was highest in 2012 (2.7%; IQR=0–5.6%). Fifty positive cards (5.8%) presented insects that were positive for trypanosomatids, mainly in Cochabamba and Punata.

Conclusions: The report of triatomines foci by inhabitants represents an effective surveillance system coordinated by a network of specialized and multidisciplinary health centers. These strategies, which should be included in the health policies of endemic countries, enable extending and deepening the dialogue among technicians, communities and their local authorities.

Keywords: Bolivia, Chagas disease, Entomological surveillance, Triatoma infestans, Triatoma sordida

Introduction

Chagas disease (CD) is caused by the flagellated protozoan *Trypanosoma cruzi*, which circulates among mammals and blood-sucking insects called triatomines (order Hemiptera, family Reduviidae).[1] Humans can be infected when used as a blood source by triatomines, receiving transfusions with *Try. cruzi*-contaminated blood or solid organ transplantations, congenitally, or when ingesting food contaminated with triatomines excreta.[2] In Bolivia and other Latin American countries, chronic CD is a common cause of heart conduction abnormalities, heart failure and thromboembolic disorders.[3–5] The chronic digestive clinical form is characterized by esophageal or colonic motility dysfunction.[6] Almost 70% of CD cases are benign, without evident impairment of heart function, but requiring periodic cardiac follow-ups through electro- and echocardiography to monitor disease progression. In many populations living in endemic areas, a large number of subjects are unaware that they have CD and therefore do not have access to treatment.[7]

CD occurs in most of the Bolivian territory, in characteristic demographic and socioenvironmental landscapes where close contact between triatomines and humans occurs.[8–10] Therefore, human settlements characterized by inadequate housing have made CD hyperendemic in many regions of the country. Although there are no recent nationally based surveys to estimate the prevalence of CD, 2010 estimates point to the existence of 607 186 people infected, with a positivity rate of 6.1% and an estimated annual incidence of 0.081 cases per 100 inhabitants in Bolivia.[11] Nevertheless, the true burden of CD in Bolivia is unknown, given that the acute phase of CD is rarely reported. A study carried out in Gran Chaco demonstrated seroprevalence rates of 22% in school-aged children in 2017.[9] In 2010, in Punata, Cochabamba, seroprevalence rates of 25.1% were observed in rural areas and 15.3% in urban areas.[8] The disease occurs at an altitude of 300–3000 meters above sea level (masl), which represents approximately 60% of the Bolivian territory—where *Triatoma infestans* is endemic—and involves about 4 million people at risk (approximately 40% of the total Bolivian population).[12]

Triatoma infestans is responsible for most of the transmission in endemic areas such as the mesothermal sub-Andean valleys and the Gran Chaco area.[13,14] This species completes its life cycle in intradomestic and peridomestic habitats and vector control strategies are based on the spraying of residual pyrethroid insecticides both inside and outside of dwellings. In Bolivia, CD prevention, control and vector entomological surveillance actions are carried out by the National Chagas Program (*Programa Nacional de Chagas*; PNCH), and its objectives include both reducing to and maintaining vector infestation rates inside houses at <3% in different regions in the country.[12]

The detection of domestic residual foci of insects and domestic reinfestation is one of the main current challenges of entomological surveillance. This demands an increase in both the effectiveness and sensitivity of surveillance strategies, improving the probability of vector detection and characterization of reinfestation events, mainly when the population density of vector insects is low. The low sensitivity of traditional entomological search methods inside and outside houses seems to be one of the more important technical challenges for vector control, which becomes more difficult (and less cost-effective) as the control progresses, the foci become scarcer and the density of the colonies decreases. Therefore, notification of the presence of vectors by inhabitants (community-based surveillance) can be an alternative.[15–17] This approach can guide insecticide-spraying actions, making them more effective.

According to Pan American Health Organization (PAHO)/WHO technical recommendations, health systems must be prepared to detect changes and respond to them quickly and efficiently. Concerning insect-borne diseases, this response not only requires good management of entomological and epidemiological data at different governmental levels, but also responses with local instruments and interventions of proven efficacy for prevention, control and monitoring with personnel well trained in vector management.[18–20] The objective of the current study is to assess the presence of CD vectors in human dwellings and peridomestic environments through a community-based strategy, in which residents play the main role in the search and capture of triatomines.

Materials and Methods

Description of the study area

Bolivia has 11 428 245 inhabitants spread over 1 098 581 km^2. Bolivian altitude, climate and biogeography vary enormously from one physiographic region to another: (i) the Llanos and Chaco (altitude <400 masl) with a humid tropical climate; (ii) the Altiplano (altitude >3000 masl), with a polar desertic climate; and (iii) the mesothermal valleys (altitude ranging from 400 to 3000 masl), with a temperate climate. The current study was carried out in the sub-Andean mesothermal valleys, including the department of Cochabamba (municipalities of Cochabamba [population=713 108; elevation=2558 masl], Punata [population=32 560; elevation=2552 masl] and Sacaba [population=204 792; elevation=2719 masl]), department of Tarija (municipality of Tarija [population=261 188; elevation=1854 masl]) and the department of Chuquisaca (municipality of Sucre [population=291 819; elevation=2810 masl]; Figure 1). Urban, periurban and rural communities were included in the municipalities of Cochabamba, Tarija and Sucre, while only rural communities were assessed in Punata and Sacaba.

The community-based entomological surveillance

The Platforms for the Comprehensive Care (PCCs) of patients with CD are multidisciplinary specialized health centers that aim to provide the prevention, diagnosis and treatment of CD in urban, periurban and rural areas where the disease is endemic in Bolivia.[21] PCCs work in cooperation with the Bolivian Ministry of Health and, during 2011–2018, implemented an entomological surveillance system with active community participation in Cochabamba, Punata, Sacaba, Tarija and Sucre. During the first clinical visit, admission staff recorded each patient's data, explained to them the central objective of the activity and delivered the material for entomological surveillance (a surveillance card and two duly identified capture vessels: the first destined for triatomines captured in the intradomicile and the second for the peridomicile). Each patient received instructions on the use of the entomological surveillance card for the activity of searching for triatomines in their house[22] (Figures 2 and 3). On their second scheduled visit, patients delivered the entomological surveillance material to the nursing staff for their respective verification of the presence (or not) of triatomines. The triatomines collected by residents were sent to the local entomological reference laboratory for morphological identification according to the taxonomic keys of Lent and Wygodzinsky.[23] If the patient's house was checked and confirmed as positive for triatomines, then the nursing staff assisted the patient in drawing up a basic sketch of the location of the house, referring the information to the CD technicians of the Chagas Departmental Program (PDCh) for the verification and confirmation of the presence of triatomines in the community or neighborhood. The vector control actions in positive houses were carried out by PDCh technicians and consisted of spraying pyrethroid insecticide according to national standards and procedures.[12]

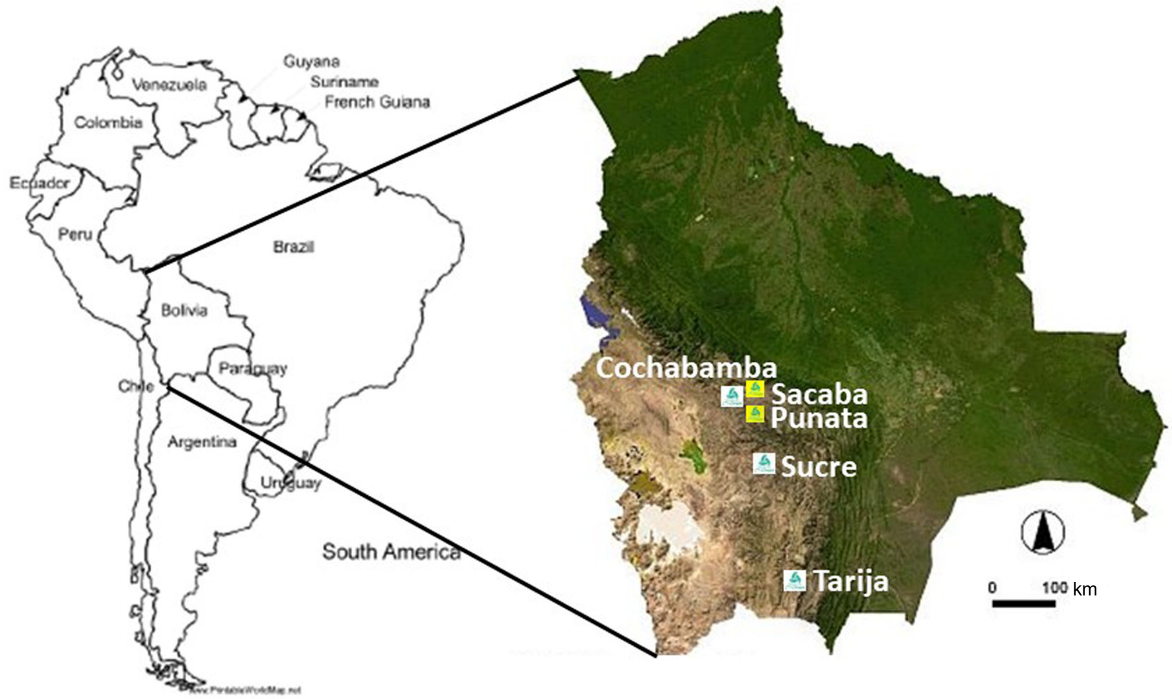

Figure 1. Distribution of Platforms for Patient Care in three departments of the mesothermic valleys of Bolivia, an endemic area for *Triatoma infestans*, the main vector of Chagas disease in the country.

Entomological parameters assessed

Entomological data were grouped by month; surveillance covered 88 mo in Cochabamba, 95 in Punata, 72 in Sacaba, 78 in Sucre and 88 in Tarija. The parameters evaluated were: (i) the proportion of cards with the presence of triatomines, calculated as cards with triatomines/returned cards x 100, assessed separately for intradomiciles and peridomiciles; (ii) distribution of positive cards by area (urban, periurban or rural [only for Cochabamba, Tarija and Sucre]), calculated as the number of positive cards in each specific area/total positive cards x 100; and (iii) the proportion of cards with the presence of infected triatomines, calculated as cards with infected triatomines/returned cards x 100, assessed separately for intradomiciles and peridomiciles. Intestinal contents of collected triatomines were suspended in saline solution, and infection with trypanosomatids was assessed by light microscopy. Monthly medians of the entomological parameters were assessed. These parameters were also compared in distinct categories defined by: (i) municipality (Cochabamba, Punata, Sacaba, Tarija or Sucre); (ii) year (2011 to 2018); and (iii) season (rainy [October to March] or dry [April to September]). Each card was assumed to represent one specific domiciliary unit (house).

Results

Proportion of cards with the presence of triatomines

From 36 221 surveillance cards delivered by PCCs during the study period, 27 643 (76.3%) were returned. The monthly proportion of cards returned by patients during 2011–2018 ranged from 5% to 88% (median=74%) in Cochabamba, 45% to 90% (median=68%) in Punata, 52% to 93% (median=79%) in Sacaba, 58% to 92% (median=75%) in Sucre and 47% to 98% (median=82%) in Tarija (Table 1). Of the 27 643 individual surveillance cards returned, on 852 (3.1%) there was a mention of the presence of triatomines in the domestic (intradomicile or peridomicile) environment; these cards were considered positive. As shown in Table 1, the median monthly positivity rate of the cards during the period was significantly higher in Punata, where it reached 9.1% (IQR=3.2–15.4%). Considering the years, the median monthly rate was higher in 2012 (median=2.7%; IQR=0–5.6%). Regarding the seasons, the positivity rates were higher in the dry compared with the rainy season (median 2.7%; IQR=0–5.3% vs 1.6%; IQR=0–4.4%).

Distribution of positive cards by area, collection site and triatomine species identified

As shown in Figure 4, the number of positive cards returned annually was higher in Cochabamba and Punata. In Cochabamba, the majority of the community collections of triatomines occurred in rural or perirurban areas. Specifically, of the 334 positive cards returned in Cochabamba, 290 (87%) came from rural (n=110) or periurban (n=180) locations. In Cochabamba, the rate of positivity of cards ranged from 5.9% in 2011 to 2% in 2018. This distribution pattern also occurred in Tarija and Sucre but with a proportionally smaller absolute number of cards. In Sacaba and Punata, only rural areas were included in the survey, and in this way all positive cards originated from rural locations.

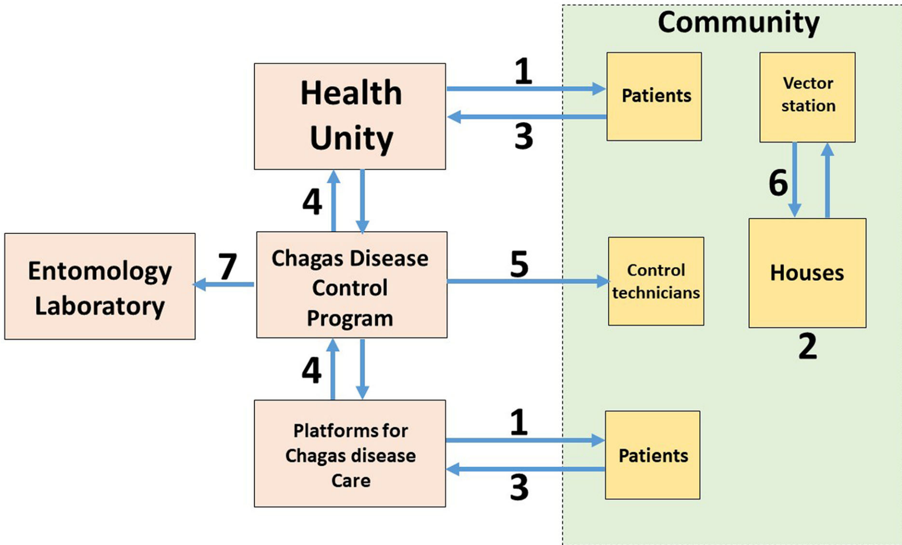

Figure 2. Scheme of the community-based entomological surveillance network coordinated by specialized Platforms for the Comprehensive Care (PCCs) of patients with Chagas disease: (1) patients attend the Platform for Chagas Disease Comprehensive Care or the Health Unity; (2) patients carry out the search for insects in their houses; (3) patients report the presence or absence of triatomines in their homes to the Platform for Chagas Disease Comprehensive Care; (4) the Platform for Chagas Disease Comprehensive Care and Health Unities report the triatomine-positive houses to the Chagas Disease Control Program; (5) field technicians apply insecticides to positive houses; (6) vector stations support the entomological surveillance; and (7) insects are examined at the entomology laboratory for species identification and examination for the presence of trypanosomatids.

Punata, with 323 community reports of the presence of domestic triatomines during 2011–2018, had the highest annual rates of positive cards, which ranged from 15.2% in 2013 to 3.7% in 2017.

In Figure 5, it can be observed that a large part of the community collection of CD vectors occurred inside the house in most years of the study in each of the five study localities. In Cochabamba, 63.7% of the reported insects were caught inside the house. This proportion ranged from 48.1% in 2013 to 73.7% in 2015. In Punata, the proportion of intradomiciliary reports of triatomines was 60%, ranging from 48% in 2012 to 79% in 2017. Similar rates were observed in Tarija, Sucre and Sacaba. Of the 852 positive cards, the species *Tri. infestans*, *Triatoma sordida* and *Triatoma guasayana* were identified in 812 (95.3%), 39 (4.6%) and 1 (0.1%), respectively (not shown). The 39 cards positive for *Tri. sordida* were collected in Cochabamba (n=17) and Punata (n=22). At these two sites, *Tri. sordida* was collected in all study years, from 2011 to 2018. The only *Tri. guasayana* specimen was collected in Punata in 2018.

Infection with trypanosomatids in collected insects

Of the total 852 triatomine-positive cards, 50 presented insects positive for trypanosomatids by light microscopy of the intestinal contents, which suggests a natural infection rate of around 5.8%. As shown in Figure 6, infected triatomines were mainly collected in Cochabamba and Punata. In Cochabamba, 24 positive cards presented infected triatomines (6.5%); trypanosomatids infection rates ranged from 12.2% in 2014 to 4% in 2017. In Punata, the overall rate of infection with trypanosomatids was 15/324 (4.8%), reaching 5/61 (8.2%) in 2014.

Discussion

Despite chemical control having substantially reduced the incidence of CD in Latin America, the presence of residual foci of triatomines and reinfestation events persists in many regions.[7,24,25] Therefore, continuous entomological surveillance plays a crucial role in control strategies over the long term. In this study, we described data generated by a successful community-based entomological surveillance system guided by a specialized healthcare network.

There were high rates of community adherence, reflected by the proportion of surveillance cards returned. One of the relevant factors for adherence to the project was probably the motivation that the health personnel of the PCCs (doctors and nurses) stimulated in the patients, as part of the model of integral healthcare for CD. Similar responses were evidenced by Urquiola when 'motivational training' was implemented in a rural community, prior to an entomological evaluation intervention, with active support from its community leaders. The results showed an adherence rate of 60% compared with 1% in the community that did not receive motivational training.[26] Other experiences of community participation for surveillance of CD vectors have been reported in South America.[27–29] Abad-Franch et al. also demonstrated that healthcare personnel participation at all stages of the process—from planning to final evaluation—improves community-based strategies.[15] Other studies demonstrated that adapting the components of education and communication to the sociocultural environment of the community are necessary to stimulate participation and notification.[30–32]

According to PNCH (unpublished) data from 2018, the triatomine infestation rate reached a regional average of 1.4% in Bolivia. In the present survey, the triatomine-positivity rate

Figure 3. Flyer distributed to residents of the communities included in the study, with guidance on triatomine collection procedures.

Table 1. Median monthly triatomine positivity rates of returned surveillance cards and median monthly card return rates by place, year and season in sub-Andean Bolivia.

	Median monthly positivity rate (%) of returned cards (IQR)	Median monthly card return rate (%) (IQR)
Place		
Cochabamba	4 (1.9–5.1)	74 (68–77)
Punata	9 (3.2–15.3)	68 (63–76)
Sacaba	2 (0–4)	79 (73–84)
Sucre	0 (0–1.8)	75 (67–78)
Tarija	0 (0–1.4)	82 (78–88)
Year		
2011	1.4 (0–7.3)	73 (62–81)
2012	2.6 (0–5.6)	75 (66–82)
2013	2.7 (1.3–7.4)	75 (67–80)
2014	1.6 (0–5)	75 (69–80)
2015	1.9 (0.5–5.2)	77 (72–82)
2016	2.3 (0.8–5.9)	77 (70–81)
2017	1.1 (0–2.6)	78 (75–84)
2018	1.6 (0–3.8)	72 (67–78)
Season		
Dry	2.7 (0.8–5.1)	76 (68–81)
Rainy	1.6 (0–4.7)	76 (69–82)

among returned cards suggests that the vector infestation rate among the studied houses reaches twice this value. This higher positivity rate may be related to selection bias, because patients with CD live in the houses studied, which are possibly more vulnerable. It is also possible that the infestation rates generated by the traditional surveillance system are underestimated, because failures in the detection of vectors are inevitable, especially when the density of the insect population is low.[33]

The detection of triatomines was more frequent during the dry compared with the rainy season. This can be explained by the reduction of natural food sources in the wild environment during the dry season, with an intensification of the search for blood sources in and around the houses, which consequently increases the frequency of reinfestation events. Similar information was also observed at wild-spot capture sites of *Tri. infestans* in the Cotapachi Cochabamba area, where the densities of insects were higher during the dry season.[34]

The monthly proportion of cards recording the presence of triatomines was much higher in Punata, with 26 months in which >15% of patients reported the presence of insect vectors in their home environment. It is important to note that, in Punata, only rural communities were included in this surveillance. This may be related to higher positivity rates because, in this environment, the greater proximity to preserved areas that may represent wild habitats of *Tri. infestans* can lead to more frequent reinfestation events. In Sacaba, where again only rural households were included, the medians of positivity rates were higher than in Tarija and Sucre. In agreement with these findings, in Cochabamba, Tarija and Sucre, houses located in urban areas were those with the lowest proportion of positivity for triatomines. In the rural and periurban belt of the city of Cochabamba, associated with higher triatomine-positivity rates, the ideal environmental conditions for the proliferation of *Tri. infestans* consist of (i) human settlements—established to the east, south and west of the city, partly due to immigration since the 1980s—living in circumstances of poverty; and (ii) the historical presence of wild foci of *Tri. infestans* near rural and periurban areas, where families consistently report the presence of the vector.[35–38]

In the five locations studied, a high proportion of the triatomine specimens collected was inside the houses. This

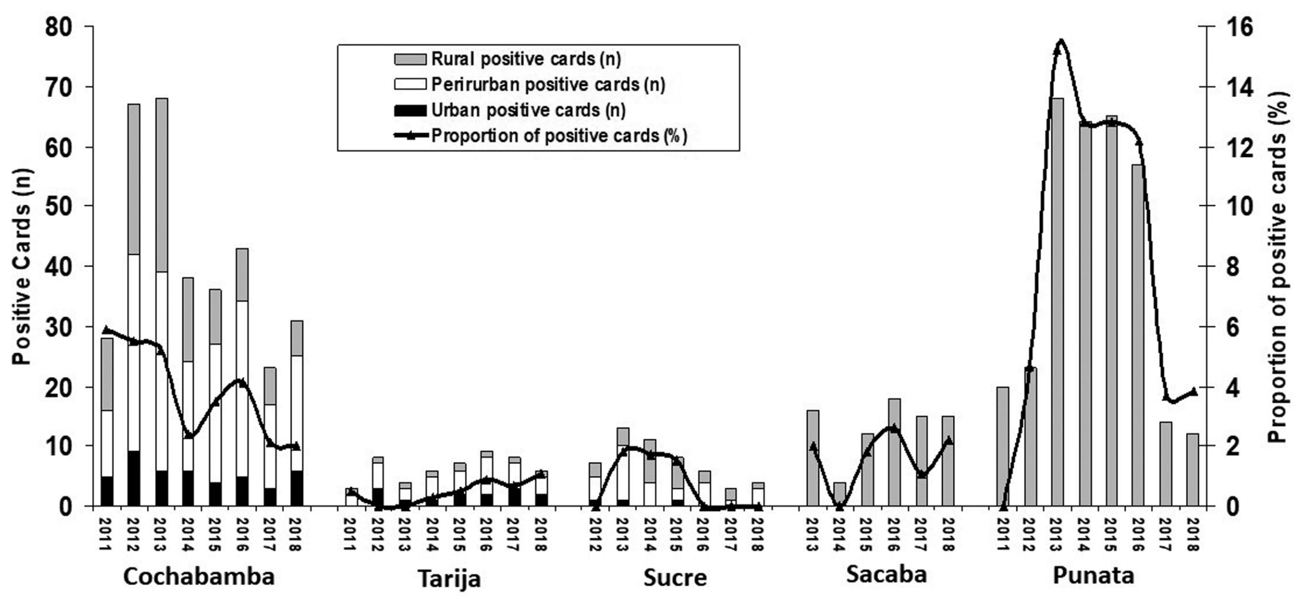

Figure 4. Number of triatomine-positive surveillance cards and cards' positivity rates in different study areas by year. In Sacaba and Punata, only rural communities were studied.

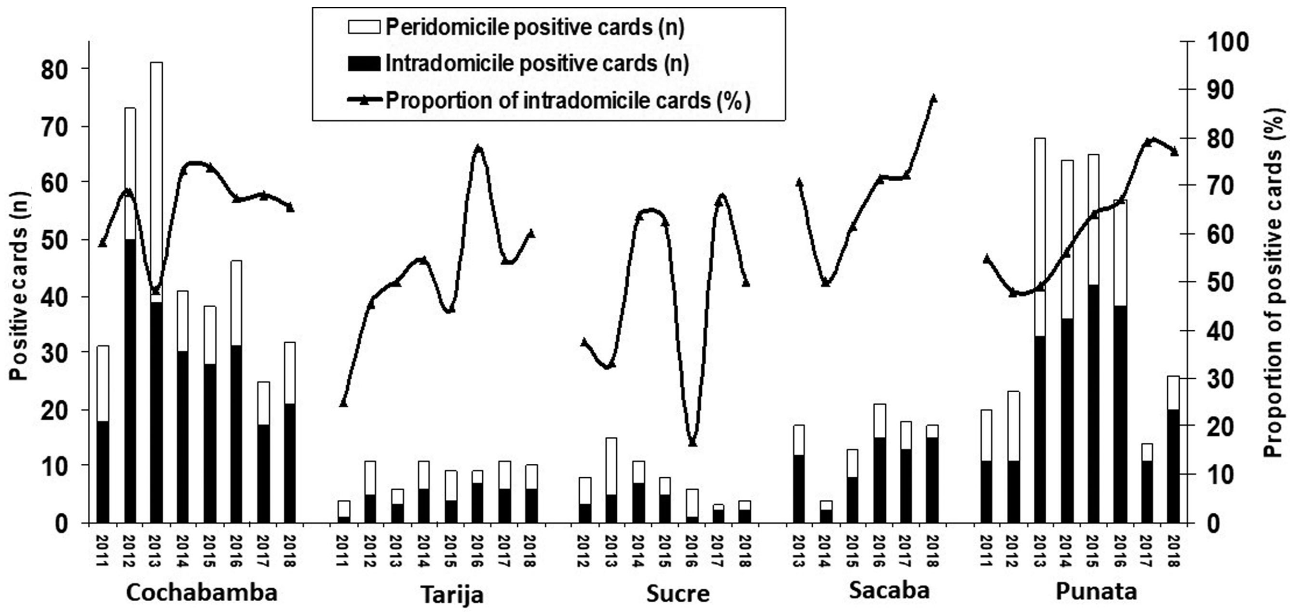

Figure 5. Distribution of positive cards by the place of collection (peridomicile or intradomicile) and the proportion of positive cards at intradomiciles in different study areas by year.

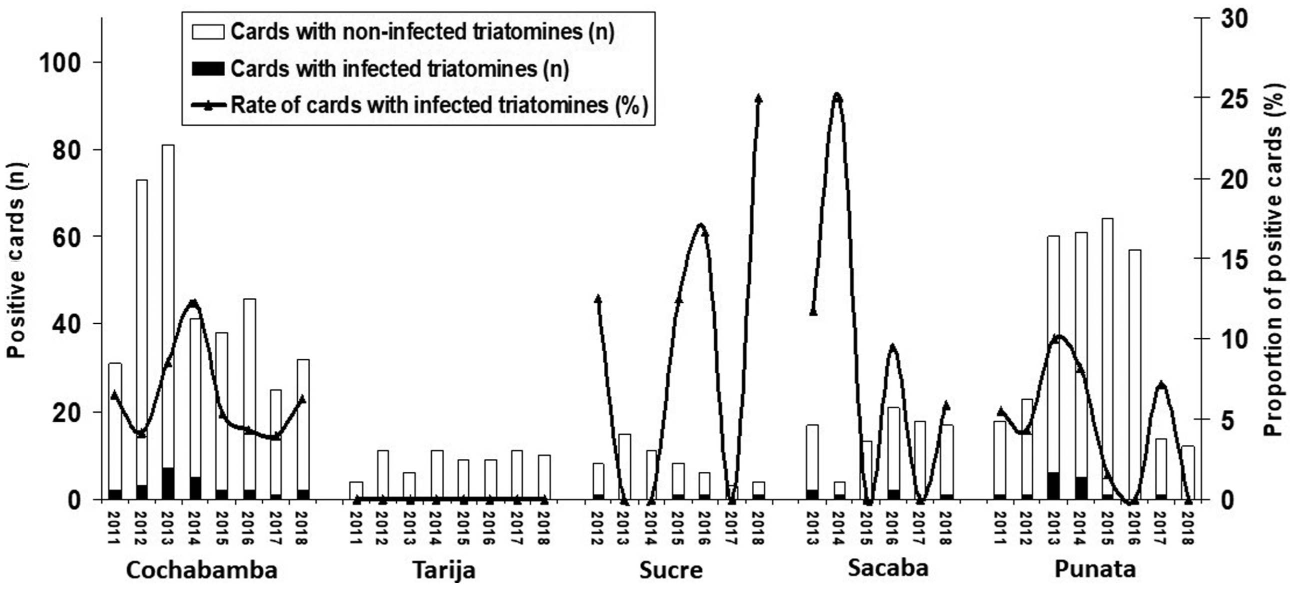

Figure 6. Number of cards containing triatomines infected and not infected by trypanosomatids (light microscopy of insects' gut content) in different study areas by year.

proportion reached values >50% in several years, in all locations, suggesting large extant intradomicile colonization and a high risk of CD transmission. This finding may also be related to a greater concern of residents to search and collect insects inside their houses, due to the perception of a greater risk of transmission. Triatomines have nocturnal habits and can be more noticeable by family members when they leave their hiding places to bloodfeed.

Regarding the infection of collected triatomines by trypanosomatids, we observed infected insects in all study locations, with the exception of Tarija. The proportion of surveillance cards in which there were infected insects ranged from 5 to 25% across the different years of surveillance, suggesting the circulation of the parasite in domestic environments and reinforcing the risk of CD transmission. According to historical information for the rural area of Cotapachi, Quillacollo, in the department of

Cochabamba, the natural infection rate of *Tri. infestans* captured in houses and in wild areas was 67.4% and 60%, respectively.[35]

At the beginning of the twenty-first century, *Tri. infestans* infestation rates in endemic Bolivian areas reached 55%. Given this situation, the PNCH—with a loan from the Inter-American Development Bank and technical support from the PAHO—implemented sustained vector control actions accompanied by entomological evaluations with the hour/man/house methodology. This strategy consisted of a direct search for insects following the method proposed by Schofield.[33] By 2008, at the conclusion of these activities, a significant reduction had been achieved, and *Tri. infestans* infestation rates in houses dropped to <3% in the entire endemic area.[12]

Nevertheless, the relatively low sensitivity of the hour/man/house method in the entomological search in a situation of low infestation and low density of vector colonies became a relevant technical problem. Therefore, the need to detect residual foci or reinfestation events became one challenge, requiring the transition from a vertical monitoring and intervention model to a horizontal and participatory structure.

Among evidence corroborating this, we highlight the work of Garcia-Zapata et al. in Brazil, in which the detection of vectors was 10–16 times more likely using 'participatory' strategies than those when program agents visited houses.[38] Gürtler et al., in Argentina, through a 4-y follow-up survey, showed that *Tri. infestans* detection within the houses was seven times higher with community participation than with an active search.[39] In Venezuela, Feliciangeli et al. also demonstrated that community participation is more effective for the entomological surveillance of CD,[40] a strategy that was also successfully carried out in the Brazilian Amazon.[41]

The report of triatomines infestation foci by inhabitants of CD-endemic localities is a simple and direct method of entomological assessment, representing an effective community-based surveillance system coordinated by a network of specialized and multidisciplinary health centers. These strategies, which should be included in the health policies of endemic regions, enable the advancement and deepening of the dialogue among technicians, communities and their local authorities.

Limitations

The main limitation of the study was the non-determination of insect developmental stages, as the presence of nymphs inside houses gives a more accurate idea of the colonization process. In addition, the positivity of the surveillance cards did not take into account the amount of insects collected inside the houses, which would provide information on the abundance of vectors, an important entomological parameter in assessing the risk of transmission. Potential biases related to differences in the interest of residents of different communities to participate cannot be ruled out either.

Authors' contributions: Study design: MRC. Data analysis: MRC, M-JP, JG, FT, FACC and FAM. Collection and analysis of field data: JP, HMA, YEC, GSU, JS, MC, WG, LOD, IGM, DC and MRC. Manuscript writing: MRC, M-JP, JG, FT, FACC and FAM. All the authors read and approved the final version of the manuscript.

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Competing interests: None declared.

Ethical approval: This study was approved by the CEADES Ethics Committee.

Data availability: Data are available from the Chagas Platform database, under CEADES Ethics Committee, for researchers who meet the criteria for access to confidential data. All manuscripts' data is available by contacting the Corresponding Author.

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