Artículo original

Effect of community education in an integrate control for *Triatoma dimidiata* (Hemiptera: Reduviidae)

Efecto de la educación comunitaria para control integrado del *Triatoma Dimidiata* (Hemiptera: Reduviidae)

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ABSTRACT

Introduction: The Mesoamerican endemic specie *Triatoma dimidiata* is the main vector of Chagas disease in Central America, after the elimination of an introduced vector *Rhodnius prolixus*. The traditional method of vector control using insecticides results in reinfestation. An integrated Ecohealth approach, including education, house improvements and domestic animal management was shown effective for long-term control of *T. dimidiata,* and it was applied in several villages in Guatemala.

Objective: To evaluate the changes in community practices after an Ecohealth intervention in La Prensa, Olopa Chiquimula.

Methods: Through three surveys, we measured risk factors associated with *T. dimidiata* infestation, the infestation index, blood sources of *T. dimidiata*, the presence of *Trypanosoma cruzi* were analyzed using PCR. Statistics analysis included Wilcoxon signed-rank tests, Mc-Nemar test, Chi-square test and Fisher exact test to compare the surveys.

Results: Over the years, risk factors associated with the presence of *T. dimidiata* and population density of the vector were observed. We found a decrease in consumption of human blood and the parasite in the vector population. However, we found the consumption of bird blood meal increased

Conclusions: Our results provide evidence that an ecohealth approach for an endemic Chagas vector has impact on reducing vector-human contact, possibly by influencing people's behavior. Increasing the community knowledge about these risk factors can be an effective strategy to further reduce the risk of house reinfestation and Chagas transmission.

Keywords: community behavior; ecohealth intervention; Chagas; *Triatoma dimidiata*.

RESUMEN

Introducción: La especie endémica mesoamericana *Triatoma dimidiata* es el vector principal de la enfermedad de Chagas en América Central, después de la eliminación de un vector introducido *Rhodnius prolixus*. El método tradicional de control de vectores que utiliza insecticidas resulta en reinfestación. Se demostró que un enfoque integrado de ecosalud, que incluye la educación, mejorías en el hogar y manejo de animales domésticos, es efectivo para el control a largo plazo del *T. dimidiata*, y se aplicó en varias aldeas de Guatemala.

Objetivo: evaluar los cambios en las prácticas comunitarias después de una intervención de ecosalud en La Prensa, Olopa Chiquimula.

Métodos: a través de tres encuestas, se midieron los factores de riesgo asociados con la infestación de *T. dimidiata*, el índice de infestación, las fuentes sanguíneas de *T. dimidiata* y la presencia de *Trypanosoma cruzi*. Estas encuestas se analizaron mediante PCR. El análisis estadístico incluyó pruebas de Wilcoxon de rango con signo, la prueba de Mc-Nemar, la prueba de Chi-cuadrado y la prueba exacta de Fisher para comparar las encuestas.

Resultados: A lo largo de los años, se observaron factores de riesgo asociados con la presencia de *T. dimidiata* y la densidad de población del vector. Encontramos una disminución del parásito en la población de vectores y en el consumo de sangre humana. Sin embargo, encontramos que aumentó el consumo de harina de sangre de aves.

Conclusiones: Nuestros resultados proporcionan evidencia de que un enfoque de ecosalud para un vector de Chagas endémico impacta en la reducción del contacto vector-humano, posiblemente al influir en el comportamiento de las personas. Aumentar el conocimiento de la comunidad sobre estos factores de riesgo puede ser una estrategia efectiva para reducir aun más el riesgo de reinfestación en la casa y la transmisión de Chagas.

Palabras clave: comportamiento de la comunidad; intervención de ecosalud; *Chagas Triatoma dimidiata*.

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Introduction

Chagas disease, or American trypanosomiasis, is caused by *Trypanosoma cruzi*, a parasite most commonly transmitted by insect vectors (80%), and much less commonly by blood transfusion, organ transplantation, congenitally or via contaminated comestibles.[1] Chagas vectors are present from the southern United States to the south of Argentina and Chile. Nearly six million people, mostly in Latin America, are infected with *T. cruzi* and approximately 30% of these are expected to develop life-threatening clinical symptoms making Chagas the economically most devastating parasitic disease in the Americas.[2,3] As treatment may not be effective during the chronic stage[4] and no vaccines are presently available, control of insect vectors is the most efficacious approach to fight Chagas disease. The endemic *Triatoma dimidiata* is now the main Chagas vector in Guatemala following interruption of transmission by the introduced vector, *Rhodnius prolixus*, through the reduction of the population, close to its elimination in 2008.[5]

Controlling *T. dimidiata* vector species is difficult due to its residence inside the houses and high mobility between multiple habitats (domestic, peri-domestic and sylvan), ongoing domestication, diversity of hosts, as well as particular house conditions and common practices found in Central America that favor house infestation.[6,7,8]

Previous data showed communities at high risk of Chagas transmission in Chiquimula.[9] Five villages of Olopa (locality of Chiquimula), were highly infested with *T. dimidiata* [9,10] and of the five villages, La Prensa had the highest infestation. *T. dimidiata* were moderately (12.98%) infected with *T. cruzi*.[9] Interventions to control infestation of the vector in this locality were needed.

Also, previous studies have revealed the most important factors that correlate with house infestation with *T. dimidiata* include house construction materials (walls of natural materials with many hiding places, dirt floors), house integrity (e.g. cracked adobe, poor plastering)[11,12,13] and common practices/customs transmitted between generations[14] e.g. accumulated clutter, keeping animals in the houses, poor house hygiene. And even though there is no evidence of vector resistance to the insecticide used according to the Ministry of Public Health and Social Assistance of Guatemala. Simply spraying insecticide is insufficient for long-term control of *T. dimidiata*, due the reinfestation of houses.[15]

Therefore, we have developed an Ecohealth approach to interrupt transmission by *T. dimidiata* with the goal of decreasing contact of vectors with humans by addressing transmission risk factors revealed by preliminary studies as the basis of the intervention.[11,12,16] The approach was made between September 2011 to 2013, and includes: (1) assessing risk factors for Chagas transmission by previous studies and a semi-structured survey, as first step. The next step (2) Third step, house improvements performed by the community with local materials to make the houses refractory to *T. dimidiata*, and lastly, (3) educating the community about risk factors and what they can do to avoid them, followed by a single insecticide application to knock down the numbers of insect vectors, between July to September 2011 (4) domestic animal management to remove blood sources from the houses, both activities made until 2013.

The evaluation of the impact of the Ecohealth outcomes is made across three moments. First evaluation before the intervention, second and third after the intervention, in one-year intervals. Four activities are done to understand the impact in the community: to stablish a) inhabitants' common practices, we make a semi-structured survey. Every visit to the locality, we search and collect all the treatomines found in the houses, with the objective of measure b) *T. dimidiata* entomological indices of the localities, c) blood sources in *T. dimidiata* and d) *Trypanosoma cruzi* infection prevalence in *T. dimidiate*, measures of human/vector contact (b and c) and transmission risk.[11,16,17] d) In this study, we tested the impact of the Ecohealth intervention three years after the intervention (2015), in La Prensa, Olopa, Chiquimula, on: 1) Changes in practices of the inhabitants, 2) house infestation with T. dimidiata, and 3) blood sources and T. cruzi infection in T. dimidiata.

Methods

Study site

The study was carried out in the village of La Prensa, municipality Olopa in the southeastern region of the department of Chiquimula, Guatemala (N 14°43'20”, W - 89°16'29), which is a modified humid tropical forest with many coffee plantations and subsistence farms. Encompasses considerable altitude ranges from 1050 above mean sea level.[(18)]

In La Prensa we start with a locality characterization, through a basal survey to understand the state of the 224 houses of the community prior to interventions. We include houses characterization, an entomologic interview and a blood sources assessment. After the interview, we perform an Ecohealth Intervention to control chagas disease in this locality. Community members were thaught how to avoid the triatomines. Finally two interviews were made to measure the effect of the intervention.

Population characterization

Chiquimula is largely Maya-Chorti ethnicity. Most people speak spanish and some elders still speak Ch´orti. The Maya-Chorti are present in southwest Honduras to eastern Guatemala and northern El Salvador, related to the Maya of Yucatan, Mexico, Belize and northern Guatemala. The main economic activity is subsistence agriculture of basic grains.[(19)] They cultivate corn, rice, beans, coffee, sugar cane and cassava. They use wicker, tulle and palm to make baskets, which they sell. This poor community lacks basic services and has a high prevalence of many diseases.[(18)]

Characterization of houses

A series of questions related to house structure and condition were completed by direct observation of the 224 structures, by an interviewer from the Laboratory of Applied Parasitology and Entomology (LENAP, University of San Carlos, Guatemala) or the accompanying Ministry of Health technicians.

Following the description of *Monroy et al.*[(6)] and *Bustamante et al.*,[(7)] “bad house hygiene” was characterized by presence of garbage or clutter inside the house, unswept floors, evidence of animals inside the house including animal droppings and lack of running water or a latrine/bathroom. Similarly, “bad bed hygiene” was recorded if the bed was unmade or dirty, there was clutter on top or underneath the bed, and/or there was evidence of animals having slept on or under the bed.

Wall plastering condition was considered “good” if it was smooth and had no cracks or crevices, or if the house was made of block. “Bad” plastering consisted of no plastering in an adobe house, walls made of vegetable material or mud and sticks, or incomplete, cracked, or crumbling plaster. Depending on these conditions houses were classified as slight risk, A (good house and bed hygiene, good plastering), moderate risk, B (not all walls plastered or some deteriorated plaster, some bad house or bed hygiene) or highest risk, C (bad house and bed hygiene, walls unplastered), following the classification of *Monroy et al.*[6]

Entomologic survey

While one person interviewed the resident, a second person searched for triatomines inside the house and in peridomestic structures (e.g. surrounding wood piles, animal pens), using flashlight and forceps, for 35-45 min per house. The samplings were carried out in 224 structures in a period of one week every intervention. All triatomines collected were transported to the laboratory at the University of San Carlos where they were recorded in the electronic database and stored at -20 ° C in vials with a 95% ethanol-5% glycerin mixture until DNA extraction and subsequent analyses. *T. dimidiata* were identified using the key of Lent and Wygodzinsky.[20] We did not found/collect any *R. prolixus*.

Blood sources assessment

Blood sources and *T. cruzi* in *T. dimidiata* were determined by polymerase chain reaction of deoxyribonucleic acid extracted from *T. dimidiata* abdomens using primers designed to specifically amplify bird, dog, human and pig DNA. In addition, we tested the collected *T. dimidiata* for infection with *T. cruzi* by PCR. Both assays were exactly as reported by *Lima-Cordón et al.*[9]

Ecohealth Intervention

A survey, encompassing house condition, common practices and entomology, were conducted by person/hour method: (1) before house improvement (Base line, B, September 2011). For the house and common practices survey, after receiving informed oral consent (oral informed consent was obtained from all adult participants or from parents or legal guardians of minors.) a semi-structured survey (62 questions) was given to an adult resident by a trained interviewer from LENAP or from the Ministry of Health, Vector-borne disease division. This survey covered family and socioeconomic factors, household practices, domestic animals and knowledge of Chagas disease.

The Ministry of Health personnel provided training to all participants and then sprayed all infested houses with Deltrametrin Ultra Low Volume wettable powder (5 mg/L) to initially “knock down” the numbers of triatomines in the houses. Then the inhabitants were offered the opportunity to learn to improve their houses using local materials to make the houses refractory to the triatomines. July through September, 2011. The villagers implemented the house improvements, first plastering the walls following the formulation that has been shown to resist cracking(12) and then "cementing" the floors, again using a low-cost formulation of local materials that has previously been shown to provide a smooth, solid floor for many years.(12,13) We could not favor the implementation of chicken coops.

A community facilitator, paid by the project, visited the village monthly to monitor implementation of house improvements (2012 to 2013) and to provide additional education to teach the villagers how to avoid house infestation by *T. dimidiata*.

All participants were provided information on Chagas disease, the risk factors for transmission, and how they could improve their homes and modify their practices including removing clutter to reduce the risk of contracting Chagas disease. To measure the effect of Ecohealth intervention on these risk factors two surveys more were made (2) following house improvement (post-intervention, F, November 2013) and (3) follow up (Fu, June 2015), as describe in the basal one.

Statistical analysis

To measure if there were differences between the interviews, first step was evaluating what changes did the community in all the years.

We group the variables in dichotomous and and discrete quantitative variables from every intervention. The discrete quantitative variables were: number of dogs, number of birds, accumulation grains number, number of pigs, number of cows, and number of beds and level of risk. The variables barns position, wood position, construction materials position, henhouses position, henhouses material roof, henhouses walls were assigned into non-average numerical values. The dichotomies variables were: animal trail, bird trail, mouse trail, objects accumulator, beds hygiene, beds separated from the wall, house hygiene, grain accumulator, wood accumulator, construction materials accumulator, henhouse presence, henhouse hygiene and *Triatoma dimidiata* presence.

All the next analysis was made in the platform R.(21) We search homogeneity of variance in politomous variables with the function levenTest of the package car.(22) Wilcoxon signed-rank tests (95% of confidence, Effect < 1.6) were used to show the differences in, at least one of all the groups, with the function wilcox_test from the package coin.(23) The p values were correct by Holm´s method using the P.adjust function of the package stats.(24)

To search differences in the tree years with the dichotomous variables were made contingency tables with the package tidyr,[25] and tested with Mc-Nemar test (95% of confidence, Effect < 1.6) using the function mcnemar.test of the package stats. The p values were correct by Holm´s method using the P.adjust function of the package stats.[24]

Not all the variables were associated with the presence of *T. dimidiata.* To found the risk factors in this village we made a Chi-square test and Fisher exact test, between presence of triatomines and all the practices evaluated in the tree measures, with the functions chisq.test and fisher.test from the package stats (95% of confidence).

To found any changes over the three years in the presence of particular blood sources on *T. dimidiata* and to determine a association between triatomines infected with *T. cruzi* and triatomines collected we tested the data in a contingency table using a Chi-square test (95% of confidence), with the chiq.test function in the package stats.

Ethical clearance

This project received ethical clearance from the Ministry of Health in Guatemala (Requisition Number: 14-11, date: 24-05-2011), and the Panamerican Health Organization (PAHO-2011-08-0017.R1).

Results

By 2015, from houses to improve (12% houses type B and 88% houses type C), only 45% made the change of the walls (22% type B, 78% type C), in order to remove the cracks where the vectors are hiding, only a couple made the change in floor.

We found a decrease in the number of triatomines trough the years despite the intervention was made once. Of the 224 houses sampled, 71 were infested in the first measure, were all the risk factors were present. In 2013 it was show a decrease on the presence of *T. dimidiata* ($p < 0.001$) and in 2015 the infestation index stayed slow (table 1). The result show the sustainability of the ecohealth interventions by controlling the infestation of the houses.

We found a decrease in consumption of human blood and dog blood (Fig.) through the second and third survey, despite the proportion in the total of tritomines collected differs (table 1). Nevertheless chi-square detected significant association with the food source "bird" which increases by 2015. By the association found between the number of triatomines and triatomines infected with *T. cruzi* (table 1, $p < 0.001$) we found the parasite remains constant en the vector population across the time.

Table 1 - Infestation index of *T. dimidiata*, blood sources of *T. dimidiata* abdomens by PCR and *T. dimidiata* infected with *T. cruzi*

Intervention	Infestation Index (%)	Blood meal found in *T. dimidiata* and *T. dimidiata* infected with *T. cruzi*				
		Bird*(%)	Pig (%)	Dog (%)	Human (%)	*T. cruzi*** (%)
Base line	31.8	8.3	0.3	9.5	5.5	9.1
Final line	4.9	76.1	0	17	2.4	9.7
Follow up	5.4	39.9	0	6.2	9.6	9.6

*Blood meal associated with the number of *T. dimidiata* ($p < 0.05$).
** Association between number *of T. dimidiata* and infection with *T. cruzi* ($p < 0.001$).

In the first year of the intervention, we analyze the factors and practice in all the houses visited. We found several widespread, associated to the presence of *T. dimidiata* in the houses (table 2). The results from the search of risk factors showed different factors associated with *T. dimidiata* in the three measures. From the Base Line we found factors related order in the house, like objects accumulator, grain accumulator, wood accumulator; and risk factors related to the presence of animals inside the rooms, like presence of birds, mice, dogs and henhouse ($p < 0.001$). Across the years new risk factors were identified related to the hygiene. We found that the hygiene in beds and house became risk factors after the intervention in 2013 ($p < 0.001$). Despite this, in the last interview we found a decrease in the presence of animals inside of the rooms, bad hygiene of the houses, and risk level C of the houses by 2015 ($p < 0.05$).

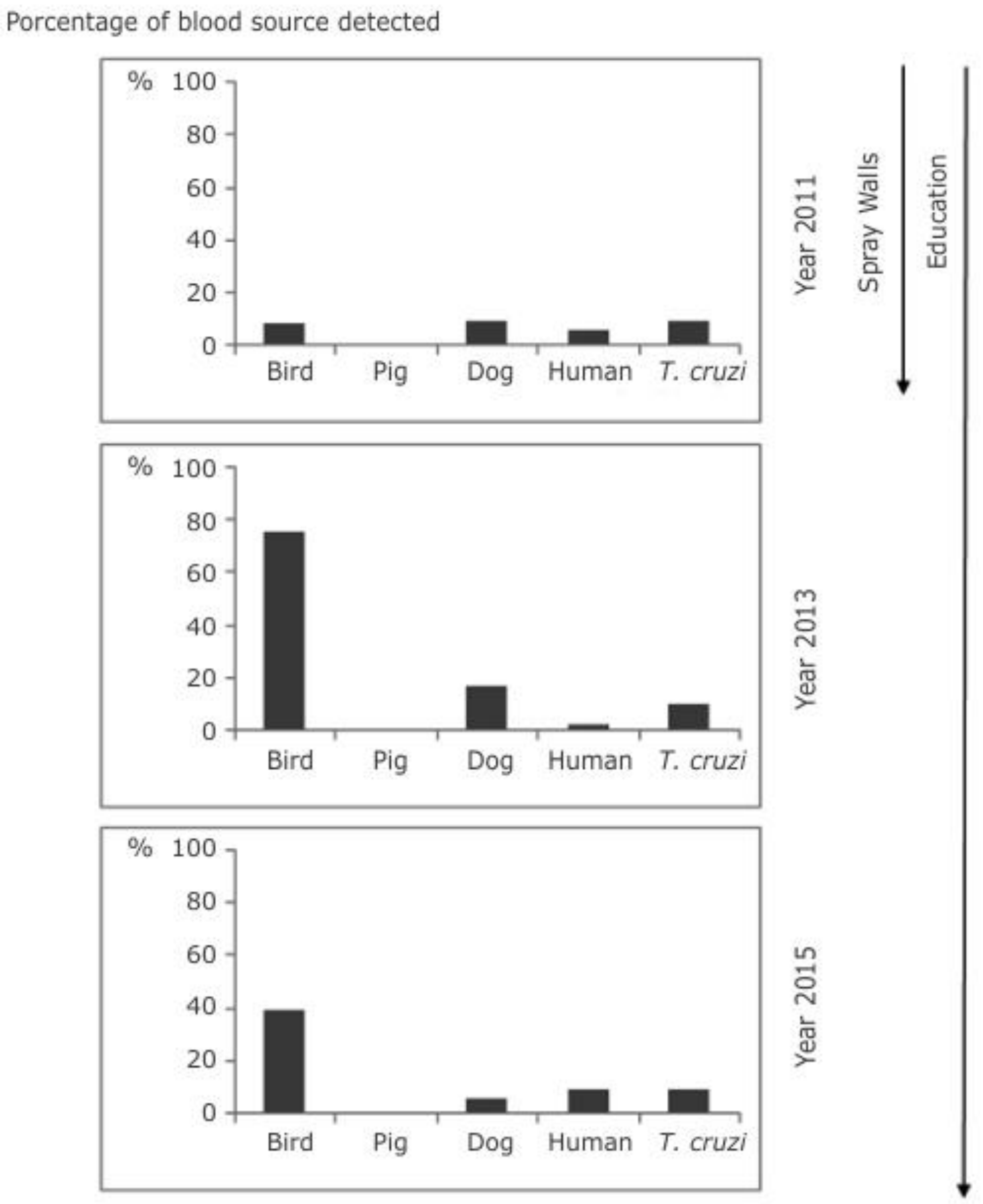

Fig. - Change in the percentage of positive individuals for each of the four food source tests and *T. cruzi* infection during the period 2011-2013-2015. Timeline of the intervention and measurements.

Table 2 - House factors/practices changes in the community between measures, associated with infestation with *Triatoma dimidiata* La Prensa, Olopa, Chiquimula before and after Ecohealth intervention

Factor	Wilcoxon signed-rank test. P value correct by Holm´s method			Mc-Nemar test. P value correct by Holm´s method (effect < 1.6)		
	BF	BFu	FFu	BF	BFu	FFu
Number of dog	> 0.05	*↓	*↓	-	-	-
Number of birds	>0.05	-	-	-	-	-
Accumulations of grains number	>0.05	-	-	-	-	-
Number of pigs	>0.05	-	-	-	-	-
Number of cows	>0.05	-	-	-	-	-
Number of beds	>0.05	-	-	-	-	-
Barns out of the house	*↑	>0.05	>0.05	-	-	-
Wood out of the house	*↑	>0.05	**↑	-	-	-
Construction materials out of the house	>0.05	-	-	-	-	-
Henhouse out of the house	**↑	**↑	**↑	-	-	-
Henhouse rods material wall	**↓	>0.05	**↓	-	-	-
Henhouse rods material roof	**↓	>0.05	**↓	-	-	-
Risk level A of house	**↑	>0.05	**↑	-	-	-
Animal trail	-	-	-	**↓	**↓	**↓
Bird trail	-	-	-	**↓	*↓	**↓
Mouse trail	-	-	-	**↓	**↓	**↓
Objects accumulator	-	-	-	**↓	>0.05	**↓
Bad beds hygiene	-	-	-	*↓	>0.05	*↓
Beds separated from the wall	-	-	-	>0.05	>0.05	>0.05
Bad house hygiene	-	-	-	>0.05	>0.05	**↓
Grain accumulator	-	-	-	>0.05	>0.05	**↓
Wood accumulator	-	-	-	*↓	*↓	>0.05
Construction materials accumulator	-	-	-	*↓	>0.05	>0.05
Henhouse presence	-	-	-	>0.05	>0.05	>0.05
Bad hygiene henhouse	-	-	-	>0.05	>0.05	*↓
T. dimidiata presence	-	-	-	**↓	**↓	**↑

*p<0.05; **p<0.001. ↑ Increase. ↓ Decrease. BF: Base line vs final line, BFu: Base line vs follow up, FFu: Final line vs follow up.

The light gray cells have factors correlated with infestation of *T. dimidiata* in the Base Line. The dark gray cells have factors correlated with infestation of *T. dimidiata* in Final line and Follow up, but not in Base Line.

Discussion

The integrated vector control approach carried on in the village La Prensa resulted in a decrease of the presence of the vector, in the change of some habits and human practices in a Maya /Chorti population that do not allow the reproduction of the vector. Animals inside the house are a risk factor well know in Chagas transmission, as well as firewood piles inside the houses, mouse signs, birds signs and other animal signs,[12] changing human activities related to that risk factor may result in a decrease of the number of bugs inside the houses and also in a change of blood source of the vector.

We can assume chemical applications prior to the intervention without re-spraying, in the next years, do not influence the results presented across the evaluation time because the insecticide used has a short-term effect (90-180 days), allowing reinfestation after this time.(16,26) The educational impact on the population can be separated from the impact of the use of insecticides in this intervention, after the effect of the insecticide, in the dynamics of the vector population, from three to six months of the spraying (after March 2012). The Ecohealth integrated approach show an advantage over the traditional vector control method of insecticide use.(11) The consistency of the results over three years (infestation index, blood sources and human practices) demonstrates the effectiveness of the intervention.

Residue of *Triatoma dimidiata* infestation

In the case of the village La Prensa the number of triatomine bugs found after the intervention of Ecosalud showed that the houses became refractory to the triatomines. The absence of conditions to live inside of the houses for the triatomines decreased the capacity of reinfestation according to the observed by Pellecer Et al. (2013),(14) which implies that people's living habits also plays a role in the control of these individuals. The density of *T. dimidiata* due to reinfestation was expected to be high by 2013, as it has been reported.(11,12) In the case of the community analyzed, the set of interventions were efficient for the decrease the capability of the reinfestation from these organisms.

In previous Ecohealth experiences the reduction of human blood sources was significant, by changing the house risk factors in the walls and floor the residue of insect was not able to consume human blood, the transmission of *T. cruzi* and therefore of Chagas' disease was reduced.(12,27) This implies that the human blood source has not been available for *T. dimidiata* in comparison to the other sources evaluated. According to these results the control of human exposure to the vector can be approached from the control of the number of organisms sharing space with humans such as birds and dogs or the proximity of human dwellings to that of the bird pens.(28)

The number of nymphs found after the intervention was less, the recolonization by triatomines coming from nearby villages or from jungle habitats bordering La Prensa could happened [6]. This way, the effectiveness of the method in the control of Chagas' disease is supported because contiguous villages were also sprayed and improved at the same time as La Prensa, which prevented possible unfavorable events. In this way, it can be inferred that the intervention for the reduction of triatomines must be carried out in broad regions at the same time, where all the affected communities are covered, one of the priorities of the Ecosalud intervention. The number of nymphs collected after the intervention indicates that the insects are keep reproducing inside the houses but in a less extend than before the improvement.

Triatoma dimidiata change of food sources

The bird and dog consuming in different years were affected by the Ecohealth intervention. *T. dimidiata* consume organisms available, birds, and decrease consume human´s blood as the results found in El Tule Jutiapa by *Pellecer et al.* [14] The refractory effect of the houses forces the insects to consume what they found out of the houses and provide information of the movement of the population of *T. dimidiata*. The increase in the consumption of birds is advantageous, because birds are totally free of *T. cruzi* susceptibility and are unable to transmit Chagas' disease.[29]

Permanence of the animals inside the houses after the intervention in 2013 (Fig. 1), means a constant availability of chickens and dog´s blood, despite the variation in availability of human blood as food source.[28,29] These could be due to the habit of keeping pets inside the rooms, since the majority of people do not have a specific place to keep out the chicken and dogs. Dogs for communities are appreciated for security reasons.

Due to relevance plays by these animals as food resources of the insects; been part of dynamics of the disease; the fact of being the first contact with the triatomine and in the case of dogs, being reservoirs of *T. cruzi* the interventions in this communities have to take care of keep pets away from homes. The consent to keep dogs and birds away from human dwellings must be understood by the residents, so communities themselves generate the ideas to make on their own way to keep domestic animals outside the house,[30] in the case of dogs don´t allow to sleep inside the houses.

Human blood is a very important food source for triatomines.[27,31] The change in the human as a resource was not significant in contrast to the change observed in Jutiapa where a significant drastic change in the availability and feeding by insects of human blood.[12] The poor house improvements results in La Prensa may be related.

Human practices

Decrease in the community practices that favor the presence of *T. dimidiata* like the house hygiene, bed hygiene and keep animals inside the houses, were based on the ecosystem intervention by the educational approach. It's shown that the communication with people involved in the Ecohealth intervention plays an important role in the disease control.[32] Empowering the community about their health is one of the main aspects that allow the disease control,[12] because it allows them to not only use physical tools but the knowledge of how to prevent and reduce the transmission of Chagas' disease which favors the common welfare. Human activities, as a risk factor, where altered by the holistic intervention, by constant visits and exchange of ideas about health with the field technicians.

Keeping the hygiene in the beds or in the bedroom requires that the inhabitants keep constant vigilance over their belongings, thus it prevents triatomines from staying between them or laying their eggs in these places. The inhabitants' ability to reduce the transmission of Chagas' disease is favored in this way since they detect how to avoid contact with triatomines that otherwise are obscured by the limited knowledge of the disease.[29,30] Knowledge transfer must be carried out in a personalized way so that the credibility and effectiveness of the knowledge presents positive results.[32] Education helped diminish the possibility of the triatomines to remain inside the houses as in the case of La Prensa.

House improvement

Only 45% of the house owners did the house improvements, these could be due to several reasons: first, the source of incomes of the village is based in subsistence farming, meaning, all the family efforts is a secondary priority. Second, harvesting or seeding season, correspond with the time of the Ecohealth intervention, highlighting the incorrect time to ask house improvement rebounding in the low participation of the people. Third, house is not a priority for the families, food is the main priority for the families, and is reflect in the house improves. The leader organization in each village is very important to accept the house improvement, some other villages in the area have reached 80% of house improvement, but in the case of La Prensa the leader- ship was very poor. Despite the low participation in the housing improvement, and that the houses weren't sprayed again after 2012, the number of triatomines remained low. In the case of the village El Guayabo were the house improvement were very high, the decrease of the number of bugs after the intervention was outstanding.

The housing improvement eliminates the possibility that triatomines survived in cracks in the walls and in the ground because they covered the cracks that allowed favorable conditions of concealment and reproduction of insects.[17] Improvement of housing reduces the permanence of the triatomines within the houses,[13] but it isn't limited to this. Also includes the construction of chicken coops with material that is provided to the inhabitants of the communities, this set of interventions leads to the consequent change in the availability of food sources by triatomines, [15,30] who feed on birds, dogs, pigs, and others instead of humans.

In La Prensa it was not possible to give the community wire mesh to build places for chicken coops explains the fact that again animals remain could be found inside the house again. When the house improvement was made the triatomines moved outside but since them didn´t have where to go, stood close to the houses. This can explain the difference of what happens in *Jutiapa*.[12] Actions still need to be taken so that the bird pens and the places where the dogs sleep became refractory environments of the triatomines as part of the future objectives of the control of the vectors since although it is favorable that they consume these organisms and not human, all possible future contact with the triatomines must be eliminated.[29,30]

In conclusion, our analysis shows that the Holistic Ecohealth intervention carried out in *La Aldea* La Prensa was effective in controlling *T. dimidiata* densities, reducing the number of triatomines in the houses and the human feeding by the vector. The approach seems to be sustainable at least three years after the intervention the insects have been kept out of the houses. The future strategies should include: a) control of domestic animals that live with the inhabitants of the affected sectors like construction of chicken coops, and b) aware people about the risk involved of have domestic animals near of houses.

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Bibliographic references

1. World Health Organization, WHO. Control of Chagas wished. An etiological treatment. Tech Rep Ser. 2002;905:1-109.

2. Pan American Health Organization, PAHO. Quantitative estimate of Chagas disease in the Americas. Montevideo: PAHO / WHO; 2006.

3. World Health Organization, WHO. Chagas disease in Latin America: an epidemiological update based on 2010 estimates. Wkly Epidemiol Rec. 2015;90:33-43.

4. Morillo CA, Marin-Neto JA, Avezum A, Sosa-Estani S, Rassi A, Jr., Rosas F, et al. Randomized Trial of Benznidazole for Chronic Chagas' Cardiomyopathy. The New England Journal of Medicine. 2015;373(14):1295-306.

5. Hashimoto K, Schofield CJ. Elimination of *Rhodnius prolixus* in Central America. Parasit Vectors. 2012;5:1-10.

6. Monroy C, Bustamante DM, Pineda S, Rodas A, Castro X, Ayala V, et al. House improvements and community participation in the control of *Triatoma dimidiata* reinfestation in Jutiapa, Guatemala. Cad Saude Publica. 2009;25(Suppl. 1):S168-78.

7. Bustamante D, Hernández M, Torres N, Zúniga C, Sosa W, Abrego V, et al. Information to act: household characteristics are predictors of domestic infestation with the Chagas vector *Triatoma dimidiata* in Central America. Am J Trop Med Hyg. 2015;93:97-107.

8. Weiss RJ, McMichael AJ. Social and environmental risk factors in the emergence of infectious diseases. Nature Medicine. 2004 [cited 2018 Apr 11];10:S70. Available from: http://dx.doi.org/10.1038/nm1150

9. Lima-Cordón R, Stevens L, Solorzano-Ortíz E, Anaité Rodas G, Castellanos S, Rodas A, et al. Implementation Science: Epidemiology and feeding profiles of the Chagas vector *Triatoma dimidiata* prior to Ecohealth intervention for three locations in Central America. PloS Negl. Trop Dis. 2018;12(11):e0006952.

10. Tabaru Y, Monroy C, Rodas A, Mejia M, & Rosales R. The geographical distribution of vectors of Chagas disease and populations at risk of infection in Guatemala. Medical Entomology and Zoology. 1999;50:9-17.

11. Hashimoto K, Cordon-Rosales C, Trampe R, Kawabata M. Impact of single and multiple residual sprayings of pyrethroid insecticides against *Triatoma dimidiata* (Reduviidae; Triatominae), the principal vector of Chagas disease in Jutiapa, Guatemala. Am J Trop Med Hyg. 2006;75:226-30.

12. Bustamante D, Monroy C, Pineda S, Rodas A, Castro X, Ayala V. et al. Risk factors for intradomiciliary infestation by the Chagas disease vector *Triatoma dimidiatain* Jutiapa, Guatemala. Public Health. 2009;25(Suppl. 1):S83-92.

13. Monroy C, Castro X, Bustamante D, Pineda S, Moguel AR, Ayala V, et al. An ecosystem approach for the prevention of Chagas disease in rural Guatemala: Ecohealth Research in Practice: Innovative Applications of an Ecosystem Approach to Health. New York: Springer; 2012. p. 153-62.

14. Pellecer MJ, Dorn PL, Bustamante DM, Rodas A, Monroy MC. Vector Blood Meals Are an Early Indicator of the Effectiveness of the Ecohealth Approach in Halting Chagas Transmission in Guatemala. Am J Trop Med Hyg. 2013;88:638-44.

15. Weeks EN, Cordón-Rosales C, Davies C, Gezan S, Yeo M, Cameron M. Risk factors for domestic infestation by the Chagas disease vector, *Triatoma dimidiata* in Chiquimula, Guatemala. Bulletin of Entomological Research. 2013;103:634-43.

16. Sosa-Estani S, Segura EL. Integrated control of Chagas disease for its elimination as public health problem - A Review. Mem Inst Oswaldo Cruz. 2015;110:289-198.

17. Dorn P, Melgar S, Rouzier V, Combe A G, Rosales R, Rodas A, et al. Monroy C. The Chagas vector, *Triatoma dimidiata* (Hemiptera: Reduviidae), is panmictic within and among adjacent villages in Guatemala. J Med Entomol. 2003;3:436-40.

18. Municipal Development Council of the Municipality of Olopa Chiquimula. Secretary of Planning and Programming of the Presidency. Development Plan Olopa, Chiquimula. Guatemala. Secretaría de Planificación y Programación de la Presidencia, SEGEPLAN. 2010.

19. Hernández JF. Vegetation dynamics in three forests of the Chortí region in Chiquimula and community participation in the sustainable use of natural resources. Guatemala: National Council of Science and Technology, National Secretariat of Science and Technology, National Fund for Science and Technology, Faculty of Chemical Sciences and Pharmacy; 2007.

20. Lent H, Wygodzinsky P. Revision of the Triatominae (Hemiptera, Reduviidae) and their significance as vectors of Chagas disease. Bull Am Mus Nat Hist. 1979;163:123-520.

21. Core Team R. A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna: Austria; 2017 [cited 2018 Apr 11]. Available from: https://www.R-project.org/

22. Fox J, Weisberg S. An [R] Companion to Applied Regression, Second Edition. Thousand Oaks CA: Sage. 2011 [cited 2018 Apr 11]. Available from: http://socserv.socsci.mcmaster.ca/jfox/Books/Companion

23. Hothorn T, Hornik K, van de Wiel MA, Zeileis A. Implementing a Class of Permutation Tests: The coin Package. Journal of Statistical Software. 2008 [cited 2018 Apr 11];28:1-23. Available from: http://www.jstatsoft.org/v28/i08/

24. Zeileis A, Meyer D, Hornik K. Residual- Based Shadings for Visualizing (Conditional) Idependence. Journal of Computational and Graphical Statistics. 2007;16:507-25.

25. Wikham H, Henry L. Tidyr: Easily Tidy Data with ´spread()´ and ´gather()´ Functions. R package version 0.8.1. 2018 [cited 2018 Apr 11]. Available from: https://CRAN.R-project.org/package=tidyr

26. Yashioka K, Nakamura J, Pérez B, Tercero D, Pérez L, Tabaru Y. Effectiveness of Large-Scale Chagas Disease Vector Control Program in Nicaragua by Residual Insecticide Spraying against *Triatoma dimidiata*. Am J Trop Med Hyg. 2015;93:1231-9.

27. Sasaki H, Rosales R, Tabaru Y. Host feeding profiles of *Rhodnius prolixus* and *Triatoma dimidiata* in Guatemala (Hemiptera: Reduviidae: Triatominae). Med Entomol Zoo. 2013;54:283-9.

28. Gürtler RE, Cecere MC, Lauricella MA, Cardinal M, Kitron U, Cohen JE. Domestic dogs and cats of *Trypanosoma cruzi* infection in rural northwestern Argentina. Parasitology. 2007;134:69-82.

29. Minter DM. Effects of the presence of domestic animals in houses infested on the transmission of Chagas disease to man. Bol Of Sanit Panam. 1978;84:332-43.

30. Urioste-Stone S, Pennington P, Pellecer E, Aguilar T, Samayoa G, Perdomo H, et al. Development of a community-based intervention for the control of Chagas disease based on peridomestic animal management: an eco-bio-social perspective. Trans R Soc Trop Med Hyg. 2015;109:159-67.

31. Zeledón R, Solano G, Zúñiga A, Swartzwelder JC. Biology and ethology of *Triatoma dimidiata* (Latreille, 1811) 3 Habitat and blood sources. J Med Entomol. 1973;7:363-70.

32. Salazar J, Olguín F, Olivera E, Apt W, Gil L, Lillo R, et al. Zulantay I. Enfermedad de Chagas crónica en Chile. Experiencia de intervención educativa. Parasitol Latinoam. 2006;61:94-7.

Conflict of interests

The authors do not declare a conflict of interests.