Ten years (2004–2014) of Chagas disease surveillance and vector control in Ecuador: successes and challenges

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Abstract

OBJECTIVE   To describe the current situation of Chagas disease in Ecuador and to evaluate the impact of vector control for the period 2004–2014.

METHODS   Since 2004, the Ministry of Public Health has formalized activities for the surveillance and control of Chagas disease and we analyzed here available records.

RESULTS   More than 200 000 houses were surveyed, and 2.6% were found to be infested (95% CI: 2.6–2.7), and more than 51 000 houses were sprayed with residual insecticide, with important yearly variations. A total of 915 cases of *T. cruzi* infection were registered. The Amazon region is emerging as a high priority area, where nearly half of *T. cruzi* infection cases originate. The costal region and the southern highland valleys remain important high-risk area. Vector control efforts over the past 10 years have been effective in the coastal region, where *T. dimidiata* predominates, and resulted in important reductions in house infestation indices in many areas, even reaching negligible levels in some parishes.

CONCLUSION   Vector efforts need to be sustained and expanded for the elimination of *T. dimidiata* to be feasible. Novel vector control interventions need to be designed to reduce intrusion by several triatomine species present in the Amazon region and southern Ecuador. Strong political commitment is needed to sustain current achievements and improve the national coverage of these programmes.

keywords *Trypanosoma cruzi*, American Trypanosomiasis, insecticide

Introduction

Chagas disease, or American tripanosomiasis, is caused by the protozoan parasite *Trypanosoma cruzi*, which is transmitted through the faeces of hematophagous insects of the triatomine family. Following a short acute phase, infected patients enter an initially asymptomatic chronic phase. 30–40% then evolve into a symptomatic chronic phase, characterised by a Chagasic cardiomyopathy and/or digestive megasyndromes [1].

Chagas disease in a major public health in Latin America, where current estimates suggest a total of nearly 6 million cases [2]. It causes healthcare costs of $24 billion and a burden of 29 385 250 Disease Adjusted Life Years (DALYs) [3]. Despite this, it is a neglected disease, disproportionately affecting poor populations [4, 5]. In Ecuador, there are an estimated 100–200 000 cases and both the cardiac and the digestive forms of the chronic phase have been observed [6]. The seroprevalence of *T. cruzi* infection is highly variable among the provinces, ranging from <1 to 5–6%, with a national average of 0.7% [6–8]. In 1978, Chagas disease notification became mandatory in Ecuador, which also joined the intergovernmental Initiative of Andean Countries for Chagas Disease Control in 1997.

The main vector species in Ecuador are *Triatoma dimidiata* and *Rhodnius ecuadoriensis*, and several additional species are considered secondary vectors, particularly in the Amazon region [9, 10]. *T. dimidiata* is present in most of the coastal region, but unconnected to populations from Colombia and hence considered an introduced species [9, 10]. Preliminary molecular analysis supports the possible introduction of *T. dimidiata* from Central America (Nicaragua, Honduras) in colonial times [11–13]. The elimination of *T. dimidiata* from Ecuador by residual insecticide spraying is thus an important goal of

vector control activities [10]. *R. ecuadoriensis* has been found in diverse habitats, with different levels of domiciliation according to the region [14–18]. It is believed to be controllable by insecticide spraying as well.

Since 2004, the Ministry of Public Health of Ecuador has formalised activities for the epidemiologic and entomologic surveillance of Chagas disease, as well as vector control activities, through the *Instituto Nacional de Investigación en Salud Pública* (INSPI, National Institute for Research in Public Health) and the *Servicio Nacional de Control y Vigilancia de enfermedades transmitidas por vectores artrópodos* (SNEM, National Service for the Control and Surveillance of Diseases Transmitted by Arthropods) [19]. These programmes are intended to follow recommendations from a technical consultation through PAHO/WHO [20]. The objective of this work was to analyse the records of Chagas disease entomological and epidemiological surveillance activities from the Ministry of Public Health, to obtain a description of the current situation in Ecuador and to evaluate the impact of vector control activities over the past 10 years (2004–2014). Such analyses of national programmes are valuable in assessing the efficacy of established policies and programmes and making adjustments when needed [21–27].

Materials and methods

Ethical considerations

All data were anonymous and used with the permission of the Ministry of Public Health of Ecuador.

Entomological data

Entomological records span the years 2004–2014 and are based on entomological collections by timed manual searches of domiciles and peridomiciles by trained vector control teams from the Ministry of Health, according to standard procedures [28]. Entomological surveillance started in 2004, and insecticide spraying was initiated in 2006. Both surveillance and insecticide spraying were conducted concurrently, although a response time of 1–12 months occured, due to logistical and financial constraints of the programme. Intradomiciliary insecticide spraying was performed with 5% deltamethrin wp, as well as in selected peridomestic sites, according to established guidelines [28]. All data were available at the province level for 2004–2006 and at the parish level since 2007. However, both surveillance and vector control activities were restricted to selected parishes within selected provinces that varied from year to year, based on

the resources available to the surveillance and control programme (Table 1).

Data from human cases

Human case records span the years 1990–2014 and are based on both passive and active surveillance of cases. Only confirmed cases were included, based on the definitions of the Ministry of Public Health [28], that is cases with a positive direct parasitological test or at least two positive serological tests of different principles (ELISA, indirect hemagglutination assay and/or indirect immunofluorescence) [8]. Data were available at the parish level for all years.

Statistical analysis

Data were summarised by year, at the parish or province level, depending on data availability, and for the entire study period. We focused on the infestation index (proportion of houses infested by triatomines), and on the intensity of vector control interventions, which was considered as the number of houses sprayed each year. Maps of triatomine infestation and human cases distribution were elaborated in QGIS 1.7 [29]. Geographic and environmental data were obtained from the *Instituto Nacional de Estadisticas y Censos* (INEC, National Institute of Statistics and Census, http://www.ecuadorencifras.-gob.ec/).

Linear mixed models were used to evaluate the associations between vector control activities and changes in triatomine infestation levels. Only parishes and provinces for which data were available for at least 3 years were included in the analysis. Because data were grouped by year, a lag time of 1–12 months between spraying and follow-up surveillance was included into our analysis. A lag time of 13–24 months was also tested by shifting infestation data accordingly, in comparison with insecticide spraying data. The models were adjusted using restricted maximum likelihood (REML). The infestation index was log-transformed, to better satisfy a normal distribution and other model assumptions [23]. As in previous studies, we accounted in some models for the potential non-independence of repeated surveys in the same parishes and provinces by considering them as a random factor, and temporal autocorrelation (year) was specified as a fixed effect [23]. The fit of the models was assessed by comparing predicted and observed house infestation, and model comparisons were based on Akaike information criteria (AIC) and Bayesian information criteria (BIC). All analyses were performed in JMP 9.0 (SAS Institute Inc., Carry, NC, USA).

Results

Entomological surveillance and vector control efforts

Active entomological surveillance for triatomine infestation partially covered 11 provinces; 12 have never been investigated. However, not all 11 provinces were surveyed every year, nor were all parishes of these provinces covered. Some parishes were studied repeatedly, others less frequently (Table 1). Overall, more than 200 000 houses were surveyed between 2004 and 2014, and more than 5000 were found to be infested, giving an overall infestation index of 2.6% (95% CI: 2.6–2.7) (Table 1). In response to this infestation, more than 51 000 houses were sprayed with residual insecticide, with large variations from year to year depending on the resources available for the vector control programme (Table 1).

House infestation was reported in 8 of 11 provinces: El Oro, Guayas, Loja, Manabí, Orellana, Pichincha, Santo Domingo de los Tsáchilas and Sucumbios, with infestation levels ranging from 0.2% up to 29%, and no infestation was found in the provinces of Los Ríos, Santa Elena, and Zamora Chinchipe (Figure 1). A total of nearly 60 000 triatomines were collected, of which 36 035 had taxonomic information. The most frequently reported species was *T. dimidiata* (86%) followed by *R. ecuadoriensis* (12%), which were observed in the western and southern provinces, and they represent the main vector species. Secondary species detected included *Panstrongylus rufotuberculatus* (1%), *Triatoma carrioni* (0.3%), *P. howardi* (0.1%), *P. geniculatus* (<0.1%), *P. chinai* (<0.1%), *R. pictipes* (<0.1%) and *R. robustus* (<0.1%), mostly in the Amazon and southern region of the country.
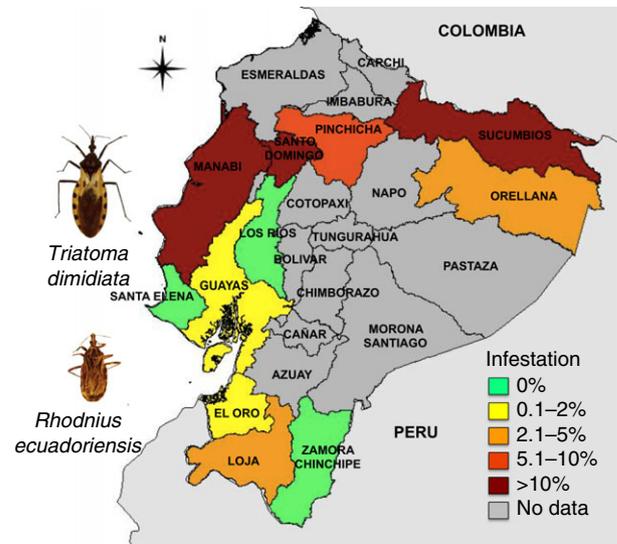

Figure 1 Map of house infestation for years 2004–2014. House infestation was calculated at the province level over the years 2004–2014, based on active entomological surveillance as explained in the Materials and Methods section. The colour codes represent the indicated infestation levels. There is no data reported for 12 provinces. The main vectors species in the western and southern regions are *T. dimidiata* (86% of collected bugs) and *R. ecuadoriensis* (12%).

Epidemiologic surveillance

A total of 915 cases of *T. cruzi* infection have been registered by the Ministry of Public Health over the years 1990–2014, with a gradual increase over the years, which likely represented improvements in case

Table 1 Infestation by triatomines and vector control efforts in Ecuador

Year	Number of provinces studied	Number of parishes studied	Number of houses studied	Number of infested houses	Infestation index [95% CI]	Number of houses sprayed
2004	6	NR	7639	205	2.7 [2.3–3.1]	0
2005	8	NR	22 511	746	3.3 [3.1–3.6]	0
2006	8	NR	30 994	1700	5.5 [5.2–5.7]	7320
2007	1	12	10 567	156	1.5 [1.3–1.7]	326
2008	2	8	11 831	162	1.4 [1.2–1.6]	917
2009	6	57	45 240	714	1.6 [1.5–1.7]	3605
2010	4	23	15 539	445	2.9 [2.6–3.1]	2641
2011	3	26	19 117	421	2.2 [2.0–2.4]	1982
2012	4	22	23 366	571	2.4 [2.2–2.6]	22 630
2013	3	13	10 677	152	1.4 [1.2–1.7]	9577
2014	1	7	3499	20	0.6 [0.4–0.9]	2367
Total	–	–	200 980	5292	2.6 [2.6–2.7]	51 365

NR, data not reported at the parish level but only at the province level.
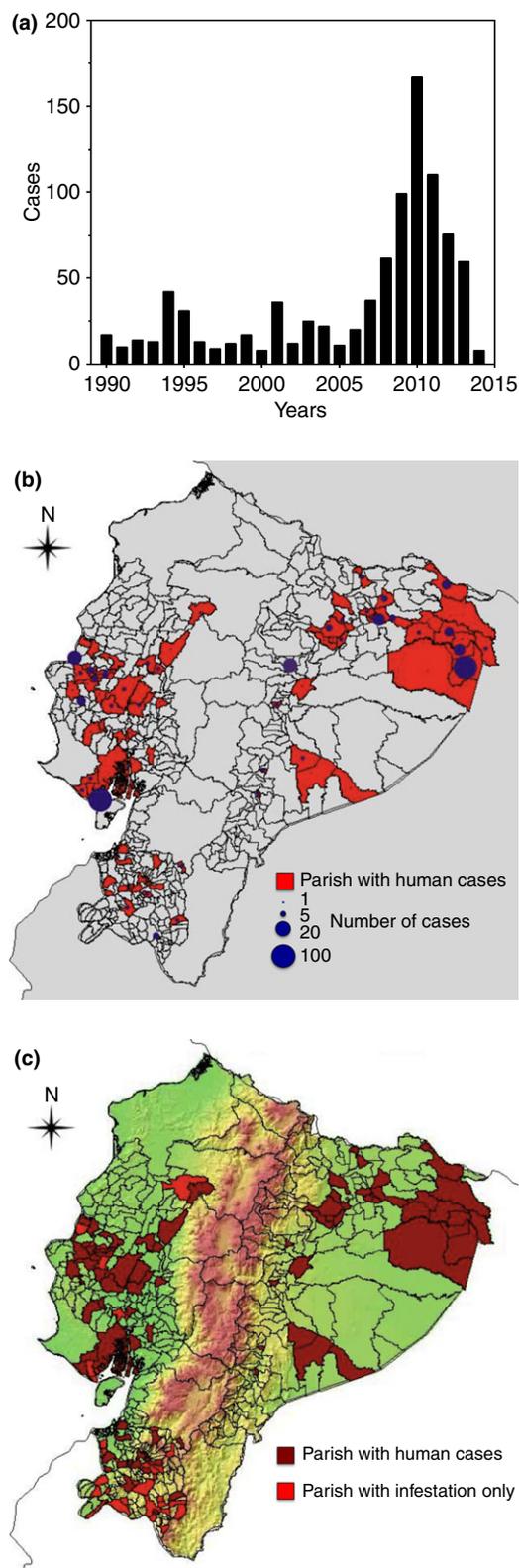
Figure 2 Human cases distribution and cumulative risk areas. (a) Number of human cases in Ecuador from 1990 to 2014. (b) Geographic distribution of cases at the parish level. Parishes with human cases are indicated in red. The size of the blue circles is proportional to the number of cases as indicated. (c) Combined distribution of human cases and house infestation by triatomines at the parish level.

reporting (Figure 2a). Cases originated from 11 provinces (El Oro, Guayas, Loja, Los Ríos, Manabí, Morona Santiago, Napo, Orellana, Pastaza, Santo Domingo de los Tsáchilas and Sucumbios). About half of the cases (415 cases, 45%) were from the Ecuadorian Amazon region; the other half were distributed in the western coastal area (334 cases, 36%) and the southern highland valleys of the western Andes (166 cases, 18%) (Figure 2b). Importantly, in several instances, human cases were registered from parishes where no house infestation had been detected/reported through the vector surveillance programme. Conversely, in a few instances, particularly in the southern region, house infestation had been detected in many parishes but few human cases were recorded. Thus, combining human cases distribution with house infestation distribution allowed to identify a greater area in which *T. cruzi* transmission to humans may be occurring (Figure 2c). This map indicated three ecological regions with potential/demonstrated *T. cruzi* transmission to humans: (i) the western coastal region, where *T. dimidiata* predominates followed by *R. ecuadoriensis*; (ii) the southern highland valleys of the western Andes, where *R. ecuadoriensis* is the principal vector; and (iii) the Ecuadorian Amazon, where several vector species can invade houses. Importantly, neither human cases nor house infestation were recorded for most of the higher elevation Andean region.

Impact of the vector control programme

Vector control activities were initiated in 2006, covering over 51 000 houses with indoor residual deltamethrin spraying during the period 2006–2014 (Table 1). Nonetheless, as with entomological surveillance, the coverage of vector control was irregular and varied from year to year based on available resources, although the number of houses sprayed tended to rise over time in most regions (Figure 3). The data suggest that the sporadic insecticide spraying in a small number of houses performed in the initial years had limited effect on house infestation, as seen in Manabí or Loja. However, more sustained spraying of a larger numbers of houses in later years did lead to significant reduc-
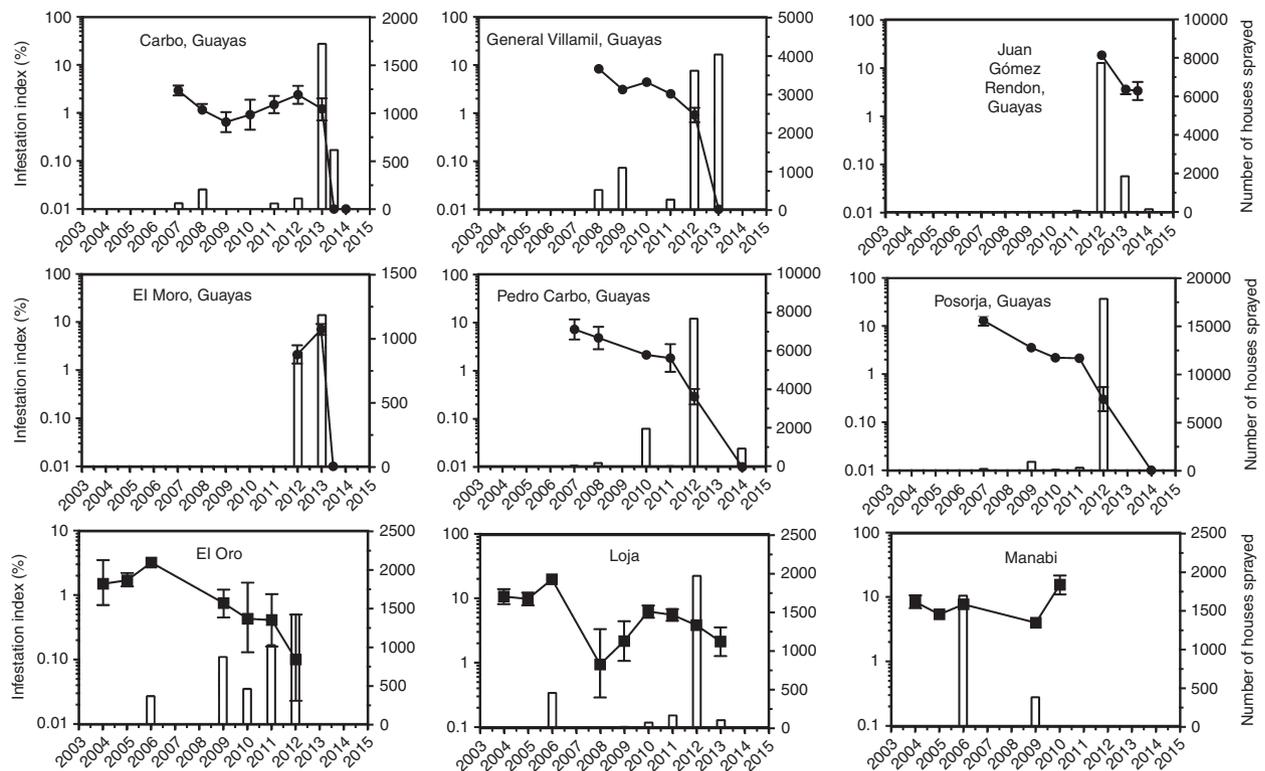
Figure 3 Impact of vector control efforts on house infestation. Changes in house infestation index (black circles, with 95% CI, left axis) over the years are shown, as well as the number of houses sprayed (white bars, right axis), for six parishes of the Guayas province (Carbo, General Villamil, Juan Gómez Rendon, El Moro, Pedro Carbo and Posorja) and for the provinces of El Oro, Loja and Manabí.

tions in house infestation in most parishes of the province of Guayas, in the provinces of El Oro and to a lesser extent in Loja (Figure 3). Modelling confirmed the strong association between the increased intensity of the vector control intervention, expressed as the number of houses sprayed each year, and a decrease in house infestation with an included lag time of up to 1 year (whole model: $P < 0.001$, AIC = 133.3; BIC = 148.1; Table 2). The model also included the years as a fixed effect covariate, as well as the parish/province as a random effect (Table 2). The fit of the model was very good, with a R^2 between observed and predicted infestation of 0.78 (Figure 4), and the decrease in house infestation was the strongest in recent years, when insecticide spraying intensified. No trends were observed in the residuals. Assuming a longer lag time of up to 2 years did not result in a better model (whole model: $P < 0.001$, AIC = 132.0; BIC = 145.8), but the significant effect of insecticide spraying was lost ($P = 0.82$), suggesting that its effectiveness is not sustained beyond 1 year.

Discussion

We analysed the records of entomologic and epidemiologic surveillance of triatomines and Chagas disease cases from the Ministry of Public Health of Ecuador, to evaluate the current situation of Chagas disease in the country and the impact of vector control efforts over the past 10 years. (2004–2014). This type of analysis has been found to be highly valuable to assess programme effectiveness, as well as to provide cues to improvements in their implementation in several other countries [22]. For example, community participation proved very helpful in strengthening Chagas disease surveillance and control in Honduras [26]; while in Argentina [27]; in Guatemala [25] and in Cochabamba, Bolivia [23], among others, the efficacy of vector control activities has been confirmed.

Chagas disease surveillance and control programmes were implemented in Ecuador largely upon recommendation of an extensive consultation by PAHO/WHO, which summarised the situation in the early 2000, and made

Table 2 Modelling of the association between house infestation and insecticide spraying intensity

	Coefficient estimate	SE	[95% CI]	*P* value
Fixed effects				
Intercept	−1.155137	0.3105	[−1.7848; −0.5254]	0.0007*
Year [2005–2004]	−0.0585	0.3614	[−0.7983; 0.6812]	0.8724
Year [2006–2005]	0.2987	0.3622	[−0.4428; 1.0402]	0.4165
Year [2007–2006]	−0.1601	0.4088	[−0.9923; 0.6721]	0.6979
Year [2008–2007]	−0.3941	0.3532	[−1.1156; 0.3273]	0.2733
Year [2009–2008]	−0.0800	0.2972	[−0.6874; 0.5272]	0.7895
Year [2010–2009]	0.1169	0.2483	[−0.3911; 0.6251]	0.6411
Year [2011–2010]	−0.1229	0.2485	[−0.6315; 0.3854]	0.6244
Year [2012–2011]	−0.1029	0.2762	[−0.6657; 0.4598]	0.7118
Year [2013–2012]	−0.2991	0.2598	[−0.8301; 0.2319]	0.2589
Year [2014–2013]	−1.9932	0.4426	[−2.8923; −1.0941]	<0.0001*
Spraying intensity	−0.000064	2.912e-5	[−0.000123; −4.73e-6]	0.035*
Random effects: REML variance components	**Variance**	**SE**	**[95% CI]**	**% of total variance**
Parish/province	0.1650	0.1209	[−0.0719; 0.4020]	45.7
Residual	0.1959	0.0519	[0.1238; 0.3564]	54.3

The model takes into account a lag time of 1–12 months between insecticide spraying and house infestation. SE, standard error. *indicates significant *P* values.
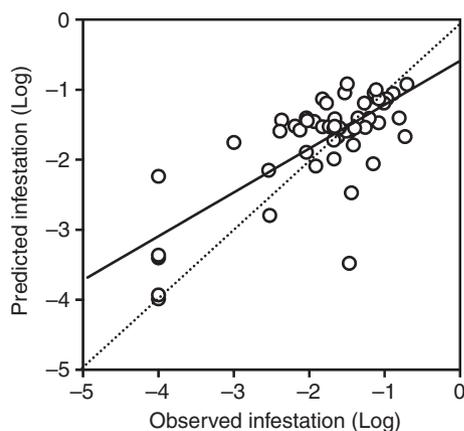

Figure 4 Comparison of observed and predicted infestation in response to vector control. The model provided a very good fit of observed and predicted infestation (R^2 = 0.78), based on the intensity of insecticide spraying expressed as the number of houses sprayed each year, with the year as a fixed covariate and the geographic location (parish/province) as a random factor.

clear recommendations on the public health benefit of such programmes due to the high estimated burden of Chagas disease in the country [20]. This report identified the coastal region as well as the southern Andean valleys as high-risk regions that needed to be prioritised for Chagas disease surveillance and vector control, while the Amazon region was considered as intermediate risk and

priority [20]. In response, the high-risk areas were the initial focus of surveillance activities, particularly for vector surveillance, although some limited work was done in provinces of the Amazon region. In fact, due to limited resources, both human and financial, there have been important variations in the geographic coverage of the surveillance activities, which focused on a variable number of provinces and parishes from year to year. Thus, a major limitation of the data analysed is that they do not correspond to a homogenous and systematic national coverage and may thus still present an incomplete picture of the distribution of Chagas disease in Ecuador. Also, because of limited follow-up after insecticide spraying (in most cases a single visit 1–12 months postintervention), so that vector surveillance and control could focus on new infested parishes, the data are somewhat biased towards a high infestation and tend to minimise the effect of insecticide spraying. Nonetheless, they provide highly valuable information on the current situation in at least parts of the country, some of which confirm previous estimates, while others are being challenged.

First, these data confirm the role of *T. dimidiata* and *R. ecuadoriensis* as primary vectors in the country, representing 98% of the vectors collected over the past 10 years. Infestation levels also remain significant in many parts of the country, strengthening the need for continued vector control activities. Second, there has been a marked increase in the number of registered cases, which likely reflect improvements in the epidemiologic

surveillance system. However, the number of registered cases is still well below the estimated 100–200 000 cases [6, 20], and the difficulties in identifying more cases in recent years highlight the need for reinforced epidemiologic surveillance. In fact, previous studies have identified cases from almost all the provinces, with the notable exception of Chimborazo, Tungurahua, Cotopaxi and Carchi from the Andean region [20]. Thus, improvements in epidemiologic surveillance are still needed, and recent efforts at decentralising Chagas disease surveillance should help making diagnosis more readily available throughout the country.

Combining entomologic and epidemiologic data confirms the major Chagas disease risk areas, but still provides an incomplete picture of the distribution of the disease in Ecuador. Indeed, transmission is also very likely in most of parishes (and provinces) adjacent to those where it was reported, even though neither cases nor infestation have been reported to date. *T. cruzi* transmission was recently described in the province of Esmeralda in north-eastern Ecuador [30] and in Pastaza, in the Amazon region [31, 32]. Nonetheless, current data clearly indicate the existence of three major epidemiologic scenario for Chagas disease transmission in Ecuador [6, 20]. The western coastal region is a confirmed high-risk region [33], where *T. dimidiata* predominates, although *R. ecuadoriensis* is also present. About 36% of all cases originate from this region. The Amazon region, which was initially classified as of medium risk [20], appears as the main source of cases in the country (45% of cases) and should thus be considered a very high priority for surveillance and control [8]. Conversely, the southern highland valleys west of the Andes, previously classified as a high-risk area [20], only account for 18% of the cases, in spite of reports of frequent house infestation [17, 18] and a seroprevalence of 3.6% [7]. Further studies should confirm the possible epidemiological changes in the Amazon region, which may be associated with increasing deforestation [8].

Based on initial assessments [6, 20], vector control has been exclusively focused on the western coastal region and to a lesser extent, in the southern highland valleys. Importantly, to date, no vector control activities have taken place in the Amazon region, even though about half of the reported cases originate from this region. Our analysis confirms the significant efficacy of vector control activities over the past 10 years, in spite of their limitation and constraints, but highlights the need for sustained high coverage activities to ensure continued success. Indeed, the effect of insecticide spraying was significant only when infestation was monitored within a year postspraying, and it was lost when a longer time lag was considered. In fact,

it seems clear that the proposed elimination of *T. dimidiata* from the coastal region will require a strong and concerted effort to replicate the results obtained in a few parishes to the entire region. Vector control in other regions also needs to be strengthened, not only in the southern highland valleys, but critically in the Amazon region as well. Control of *R. ecuadoriensis* with insecticide spraying in southern Ecuador has been met with mixed success [17, 34], possibly due to a rather intrusive behaviour. Similarly, limited house infestation has been observed in the Amazon region, but several opportunistic sylvatic vector species can invade houses to feed on humans, and will require alternative strategies to be implemented for their control [34, 35]. Combining information from entomological and epidemiological surveillance is also key to better identify risk areas. Finally, achieving sustainability over time and a wide geographic coverage of surveillance and control activities has been a challenge for many national programmes for Chagas disease control throughout Latin America, as it requires a strong political will and commitment [23, 27, 36].

In conclusion, the analysis of national epidemiologic and entomologic surveillance data confirmed the presence of at least three distinct Chagas disease transmission scenarios in Ecuador. Importantly, the Amazon region is emerging as a high priority area, where nearly half of *T. cruzi* infection cases originate. The coastal region and the southern highland valleys remain two of the historically important high-risk area, even though risk seems to have decreased in the later region. Vector control efforts over the past 10 years have been effective in the coastal region, where *T. dimidiata* predominates, but need to be sustained and expanded for the elimination of this vector to be feasible. Also, novel vector control interventions need to be designed to reduce intrusion by several triatomine species present in the Amazon region as well as in southern Ecuador. The successful control of Chagas disease in Ecuador will thus require strong political commitment to sustain current achievements and increase the national coverage of these programmes.

Acknowledgements

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