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Research

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Spatial-Temporal Analysis of *Lutzomyia trapidoi* and *Lutzomyia reburra* (Diptera: Phlebotominae), in Rural Tourist Locations, Biosphere Reserve and Leishmaniasis Endemic Area, Ecuador

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Abstract

This research represents the first attempt to assess the spatial and temporal distribution based on micro-meso scales on two species with different host preference habits (anthropophilic vs zoophilic), in the major Leishmaniasis endemic area in Ecuador, tourist locations, and Biosphere reserve. Phlebotomine species, *Lutzomyia trapidoi* (Fairchild) and *Lutzomyia reburra* (Fairchild and Hertig), were analyzed by trap/habitat/month/locality/altitude, through the Poisson generalized regression model. Our data reveal a bimodal pattern for both species related with low precipitations and preference for forest habitat. Altitude, proximity to the forest, and the river were the variables that determine the hypervolume of the spatial distribution of relative abundance, where the overlap of these two species increases the risk of translocation and circulation of the etiological agent of leishmaniasis in sylvatic environments to rural–tourist–biosphere reserve areas and vice versa. The ecological characteristics of these two phlebotomines could explain the permanence of the major active and endemic focus of cutaneous leishmaniasis in the North-Western Ecuador a key aspect in tourism health-security in alternative tourism.

Key words: phlebotomine distribution, ecology, landscape variables, leishmaniasis disease, tourism

Leishmaniasis is a vector-borne disease; its dynamics are dependent on its main vector (sand flies). In an eco-epidemiological context, this transmissible disease is not spatially distributed homogeneously in the foci-territories, but instead in terms of the presence, abundance, and distribution of potential vectors, vertebrate hosts, and potential reservoirs, as well as the species of parasite-*Leishmania*. Additionally, macroclimatic, geographical, and landscape factors are determining factors in the establishment of species, their density, permanence, and spatio-temporal distribution (Turner 1989).

In this sense, the eco-epidemiology addresses the relationship of vectors, ecological factors, and human behavior, and allows to recognize patterns in the risk of infection in geographical areas, where the vector is present at micro-, meso-, and macro-spatial scales (Susser and Susser 1996).

From an ecological approach, the research allows the better understanding of the disease dynamics, by relating the action of human populations in the modification of ecosystems and explaining their influence on the biological and population cycles of the vector species (Turner 1989, Rotureau et al. 2006, Azevedo et al. 2011). Some studies show landscape modifications that have influenced the dynamics, interactions, and exchanges of the elements that make up the ecosystem (Turner 1989), with an impact on the population and physiological attributes of the vector species (reproduction rate, maturation, and feeding) whose response derive in new life strategies product of ecological changes (Rotureau et al. 2006, Azevedo et al. 2011).

The overlap of spatio-temporal variables has raised the need to integrate various factors in multiscale type studies, such as historical data, fragmentation, and/or forest coverage in the local landscape, which represent elements of the surrounding matrix of the landscape, and that in itself the relationship between them becomes a fundamental aspect to establish the space-time dynamics of the species (Turner 1989, Rotureau et al. 2006, Azevedo et al. 2011, Valderrama et al. 2011).

In Ecuador, cutaneous leishmaniasis (CL) is mainly epidemiologically associated with the Sierra region and the subtropical zones of the Pacific coast, the Amazon, and the Andean mountains (Gomez et al. 2014). In the Andean region, the northwest of the Pichincha province is immersed in one of the geographical regions of greatest richness in flora and fauna, the Chocó region (MAE 2013), with increasing urban development and alternative natural and rural tourism (Instituto Nacional de Estadísticas y Censos 2010, Ministerio de Turismo 2018) with the Counties (Canton) Pedro Vicente Maldonado, San Miguel de los Bancos, and Puerto Quito as areas of high endemicity and active foci of the disease (Calvopina et al. 2004, Gomez et al. 2014) due to the presence of anthropophilic and zoophilic phlebotomines (the latter being responsible for enzootic transmission of *Leishmania*) (Calvopina et al. 2004, Arrivillaga-Henríquez et al. 2017).

The present study evaluates the spatial distribution of two sand flies species with contrasting host preferences of anthropophilic versus zoophilia based on micro- and meso-spatial variables within this area of greatest endemicity in Ecuador. The *Lutzomyia* (*Nyssomyia*) *trapidoi* (Fairchild) (Diptera: Psychodidae) species was selected as the dominant and common species within the Northwest zone of Pichincha, and it is the main anthropophilic vector of CL in subtropical and foothill zones in Ecuador (Calvopina et al. 2004, Arrivillaga-Henríquez et al. 2017), indicated in other Neotropical localities as a species associated with fragmented forests and anthropic intervention (Valderrama et al. 2011). Otherwise, species *Lu.* (*Trichophoromyia*) *reburra* (Fairchild and Hertig) (Diptera: Psychodidae) has been associated with caves of armadillos (Vergara et al. 2008), which have been recently reported natural infected by *Leishmania*, and with eco-epidemiological space-temporary importance in the Pichincha province in spite of being conventionally cataloged with zoophilic preferences (Arrivillaga-Henríquez et al. 2017).

An important number of tourist destinations of the Ecuadorian highlands are located in the northwest of the Pichincha province, with a high tourist influx during holidays and holiday periods for national and international tourism, mainly within the trend of rural, natural, agroecological, ecological, and sustainable tourism (Ministerio de Turismo 2018).

Concerning Ecuadorian public policies about sustainable development, public health and tourism, public and tourist safety are key not only for local public health, but for sustainable tourism, and its necessary to know the spatial distribution patterns and temporary phlebotomies in areas with local, national, and international tourist value, since recently the study area has been considered a biosphere reserve by UNESCO (UNESCO 2018).

Materials and Methods

Study Area

The study focuses on the ecoregion of the Ecuadorian western humid forests, located in the Neotropical Region (Morrone 1999), northwest of the political province of Pichincha, in a Chocó biosphere reserve declared by UNESCO (Fig. 1). Four endemic and active localities of cutaneous leishmaniasis were studied: Mashpi (00.10.29.4N, 78.54.28W, 568 m) and Milpe (00.02.19.N, 78.52.37W, 1,120 m) with greater forest cover in the landscape composition, in contrast to Puerto Rico (00.05.33N, 79.14.33W, 316 m) and Via al Progreso (00.04.26N, 79.02.57W, 550 m) which present the greatest landscape fragmentation (Fig. 2). In general, the macro-climatic conditions are similar among the localities within an altitudinal gradient, with maximums of precipitations between January to June and minimums between July to December and an average annual temperature between 17 and 25°C (MAE 2013).

Sampling, Spatio-Temporal, Landscape, and Entomological Analysis

The analyzed data came from a systematic sampling carried out within each locality using CDC light traps with 6 V batteries in three habitats (forest, peridomicile, and housing) during three consecutive nights (27 traps in total, 3 traps/night/habitat/locality). This design was applied in the four locations for three months (324 traps/night). The specimens collected were individualized, counted, and georeferenced by trap/sex/species/locality/altitude/habitat/month. The collection data were entered into a database under the Excel format (Microsoft Office) and through a dynamic table, the data corresponding to *Lu. trapidoi* (1,393 individuals) and *Lu. reburra* (157 individuals) were analyzed. In addition, an in situ characterization of the spatial heterogeneity of each locality was carried out, consisting of tours and subsequent satellite georeferencing of the local landscape, represented graphically (Fig. 2).

The analyzes of relative abundance (number of individuals/trap) and spatial distribution were made at two levels. First, the data were analyzed at a micro-spatial level for intra-local comparisons. The habitat variable was chosen according to three types of habitats, forest, peridomicile (3–60 m around the house) and housing (intra-domicile). Second, it was carried out at the meso-spatial scale, where the same habitat variables were evaluated for the four endemic localities of CL, but through inter-locality level comparisons. Meanwhile, on a temporary scale, data from three samplings were chosen: July 2013, August 2013, and May 2014. Relative abundance was related to spatial-temporal scales, through the Poisson generalized regression model.

The data of the landscape variables were as follows: a) proximity to the forest, obtained through the projection of the records of both species and measurement of the linear distance to each habitat in meters (forest, peridomicile, and housing), b) proximity to the river, obtained through the projection of the species and measurement of the linear distance expressed in meters to the nearest river of the 'RÍOS' vector layer—scale 1: 250,000 (SENAGUA 2013) and c) altitude by locality, obtained from the georeferenced data and categorized into altitudinal intervals, high intervals (1,120 m), intermediate intervals (500–568 m), and low intervals (316 m). The variables of the landscape were related to the apparent abundance using the generalized Poisson regression model through the ArcGis Geographic Information System version 10.1 for the projections and distance measurement (ESRI 2013).

Additionally, for the analysis of landscape variables, the incidence rate ratio (IRR) was calculated in order to establish the relative abundance significance as the species from the nearest forest and river moved away, as well as its increase or decrease in relation to the altitudinal intervals. The Poisson regression showed the probability of registering the species (count data represented by the different traps per night) according to the variables as an explanatory statistical model in response to the variables worked. Statistical analyzes and graphs were made with the statistical package R (Venables and Riplay 2002).

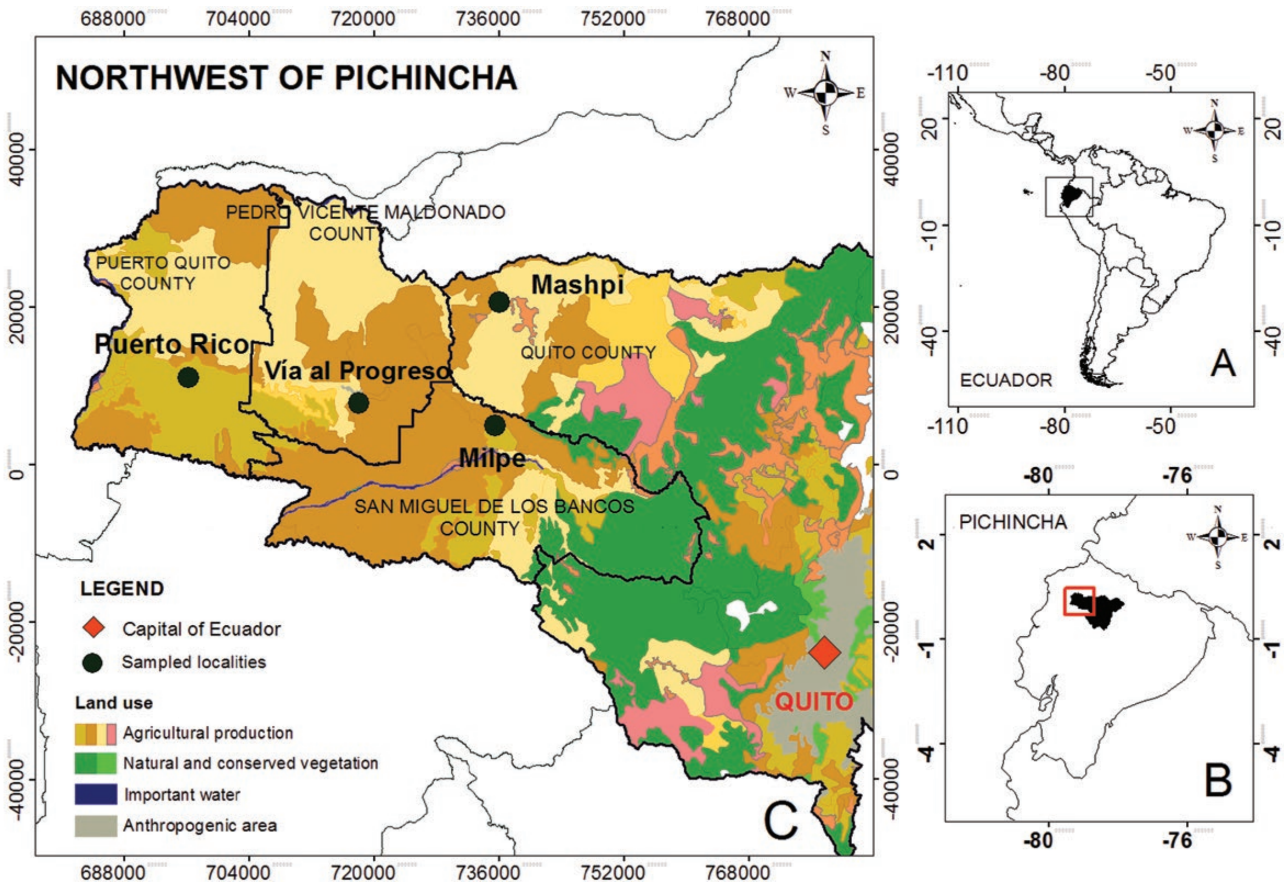

Fig. 1. Study areas. The boxes show (A) location of Ecuador in South America, (B) location of the Pichincha province in Ecuador, and (C) location of the four Counties (Canton) and four study locations in the northwest of the Pichincha province.

Results

Intralocal Spatial-Temporal Distribution of *Lu. trapidoi* Versus *Lu. reburra*

The distribution at spatial scale in the two species was very similar. It showed an overlap and significant differences in Forest habitats in relation to Peridomicile and Housing habitats in the Mashpi, Milpe, and Puerto Rico (Pto. Quito) localities (*Lu. trapidoi*, $P < 0.01$ and *Lu. reburra*, $P < 0.05$). Meanwhile, in the Via al Progreso locality, the greatest abundance was recorded in the Peridomicile habitat, in contrast to the Forest and Housing habitats (*Lu. trapidoi* and *Lu. reburra*, $P < 0.01$; Table 1).

Temporally, the highest abundance of the two species was registered in July 2013 and August 2013 ($P < 0.05$) in contrast to May 2014 for the four locations. With the exception of *Lu. reburra* in the locality of Puerto Rico, a single individual was collected in May 2014 (Table 1).

Spatial-Temporal interlocal Distribution of *Lu. trapidoi* Versus *Lu. reburra*

Significant differences were determined in spatial abundance interlocality by forest habitat, peridomicile, and housing for the two species ($P < 0.01$). On a temporal scale, differences in abundance were significant in July 2013, August 2014, and May 2014 in relation to *Lu. trapidoi* and *Lu. reburra* ($P < 0.05$; Table 1).

Intralocal Distribution of *Lu. trapidoi* Versus *Lu. reburra* and Landscape Variables

The relative abundance of *Lu. trapidoi* was significantly higher ($P < 0.01$) compared with the proximity to the forest proximity in the localities with the highest forest coverage (Mashpi, Milpe, and Via al Progreso). Likewise, significant differences in relative abundance were shown in relation to the proximity to the river ($P < 0.01$) in localities with greater fragmentation in its landscape (Milpe, Puerto Rico, and Via al Progreso). The landscape variables of *Lu. reburra* were not concordant as the abundance with respect to the forest was higher ($P < 0.01$) in two locations (Milpe and Via al Progreso), while the proximity to the river was significant ($P < 0.01$) only in Via al Progreso (Table 2).

Regarding the proximity to the forest variable, the two species decreased their rate of abundance for each meter that moved away from this variable in the towns with the highest forest cover, Mashpi and Milpe (IRR value, Table 2). Meanwhile, the proximity to the river showed that both species decreased their rate of abundance for each meter that moved away from the river in Milpe and Via al Progreso (IRR value, Table 2).

Distribution Based on Interlocal Landcape Variables of *Lu. trapidoi* Versus *Lu. reburra*

The interlocality analysis showed that the proximity to the forest, proximity to the river, and altitude were significant ($P < 0.01$) for the relative abundance of the two species. Meanwhile, the rate of abundance (IRR) in *Lu. trapidoi* was significant as it moved away from the forest, decreasing 0.95 individuals per meter. Otherwise, *Lu. reburra* showed statistical significance with a decrease of 0.60 individuals in the forest and 0.23 individuals in the river for each meter of spatial distance with respect to the two variables (Table 2).

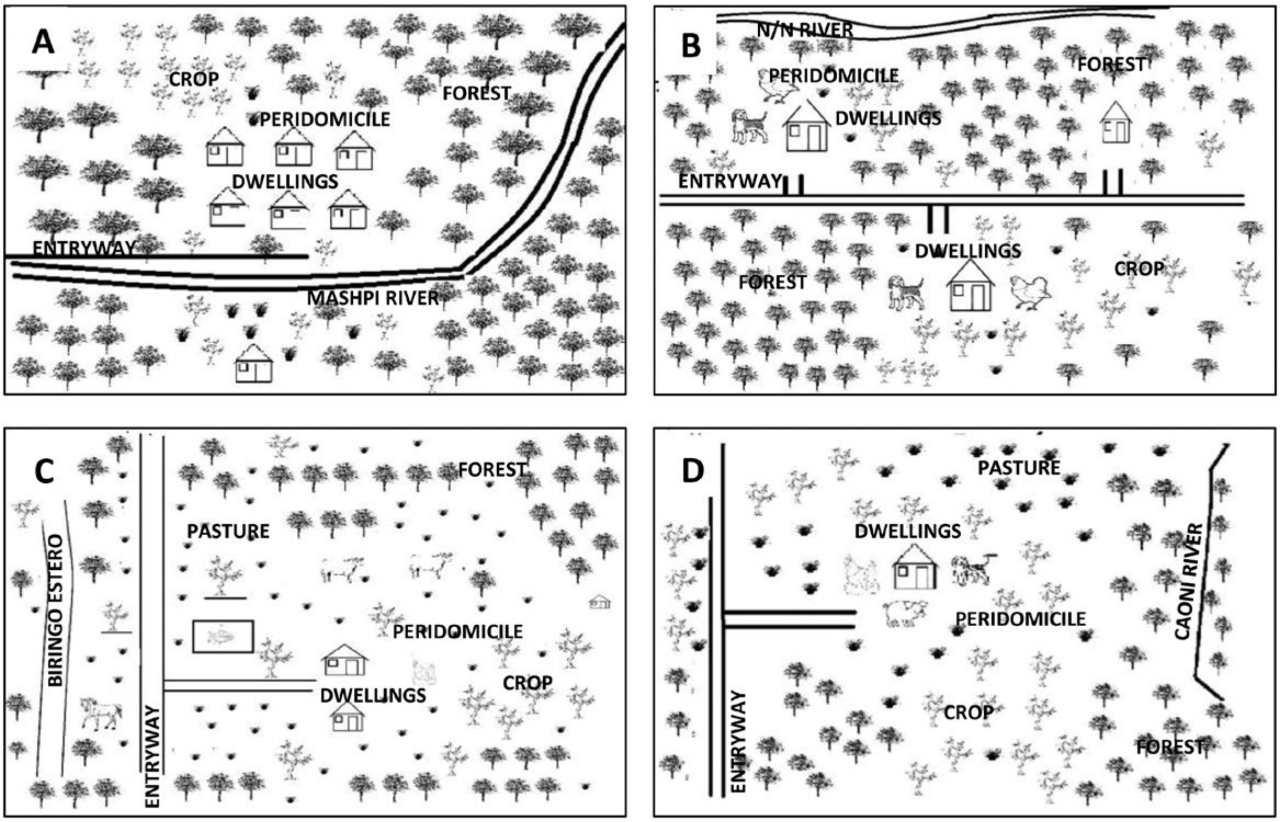

Fig. 2. Diagram of the spatial heterogeneity of local landscapes: (A) Mashpi, (B) Milpe, (C) Puerto Rico, and (D) Via al Progreso.

Within the different altitude ranges, the abundance of *Lu. trapidoi* was associated with low altitudinal intervals ($P < 0.01$), whereas the abundance of *Lu. reburra* was associated with medium- and high-altitudinal intervals ($P < 0.01$).

Discussion

Results suggest that the ecological variables associated with local landscape are key variables and modulators of the relative abundance of the two phlebotomine species. Additionally, the heterogeneity or landscape mosaic affect the ecology of sand flies populations (Andrade-Barata et al. 2005, Azevedo et al. 2011, Valderrama et al. 2011, Gómez-Bravo et al. 2017)

Spatial Distribution of *Lu. trapidoi* and *Lu. reburra*

Although the localities have different landscape structures, the phlebotomine species were closely related to the forest, where they showed greater ecological overlap, as argued by research for other phlebotomine species (Rotureau et al. 2006, Vergara et al. 2008, Azevedo et al. 2011, Brandao-Filho et al. 2011, Santini et al. 2012).

Lutzomyia trapidoi has been associated to intervened landscapes (Azevedo et al. 2008, Valderrama et al. 2008, 2011, Zapata et al. 2012) and our results corroborate the relationship of *Lu. trapidoi* with the modification of the landscape. Localities with the highest disturbance in its surrounding matrix, Via al Progreso and Puerto Rico (Table 1), registered the highest abundance and number of individuals in the forest habitat. *Lu. reburra*, has recently been registered with natural infection in the current study area (Arrivillaga-Henríquez et al. 2017). However, there are no previous ecological investigations about this species in Ecuador at the landscape level. In the present investigation, *Lu. reburra* and its abundance peaks are associated for the first time with localities with greater forest cover (Mashpi and Milpe), whereas the minimums of relative abundance for this species are associated with the localities of lower forest cover (Via al Progreso and Puerto Rico). These minimum values of abundance could be explained based on the occurrence of the lowest number of available host resources for this zoophilic species, derived from the lower occurrence of mainly small mammals, which is the main food source of sand flies, since this species is associated with armadillo caves (Vergara et al. 2008, Reyes and Arrivillaga 2009, Arrivillaga-Henríquez et al. 2017).

In Via al Progreso locality, the spatial heterogeneity between the habitats of housing and peridomicile do not show a clear differentiation as in the rest of the localities. In addition, there were domestic breeding animals in both the surroundings and under construction sites. Therefore, this composition meant greater relative abundance in this peridomicile interface, which has also been evidenced in other phlebotomines studies (Quintana et al. 2012, Fernández et al. 2013). Meanwhile, in the housing and peridomicile habitats of Mashpi, Milpe, and Puerto Rico, the configuration and composition of the landscape showed low values of abundance due to being environments with little vegetal cover (Feliciangeli et al. 2006, Santini et al. 2012).

Temporal Distribution of *Lu. trapidoi* and *Lu. reburra*

The temporal trend of the species was very similar (Table 1), explained by the annual bimodal precipitation pattern in this geographic region. The highest population density peak of phlebotomines was related to the months of lower precipitation. Similar results are reported by other authors (Rebollar-Tellez et al. 1996, Feliciangeli et al. 2006,

Table 1. Poisson *Lutzomyia*showing the relationship of *Lutzomyia trapidoi* and *Lutzomyia reburra* based on spatio-temporal intra and interlocality scales

Habitat	A.T.N.	*P*-value	Month	A.T.N.	*P* > (*z*)
Lutzomyia trapidoi					
Intralocality, Mashpi (1)					
F1/P1	5.89/1.25	1.63e-06*	J1/A1	4.56/3.63	0.09
F1/H1	5.89/0.07	2e-16*	J1/M1	4.56/0.77	4.15e-16*
F1/H1	1.25/0.07	1.15	A1/M1	3.63/0.77	3.91e-09*
Intralocality, Milpe (2)					
F2/P2	5.89/2.74	4.46e-08*	J2/A2	1.70/6.89	2e-16*
F2/H2	5.89/0.30	2e-16*	J2/M2	1.70/0.89	0.8
P2/H2	2.74/0.30	0.001*	A2/M2	6.89/0.89	2e-16*
Intralocality, Puerto Rico (3)					
F3/P3	8.71/0.45	5.13e-11*	J3/A3	7.81/7.70	0.88
F3/H3	8.71/0.03	2e-16*	J3/M3	7.81/1.78	2e-16*
P3/H3	0.45/0.03	0.2	A3/M3	7.70/1.78	2e-16*
Intralocality, Via al Progreso (4)					
F4/P4	1.07/7.89	2e-16*	J4/A4	3.63/5.04	0.01*
F4/H4	1.07/0.78	0.26	J4/M4	3.63/1.07	2.18e-16*
P4/H4	7.89/0.78	2e-16*	A4/M4	5.04/1.07	4.18e-14*
Interlocality					
F (1–4)	2e-16*	J (1–4)		0.001*	
P (1–4)	2e-16*	A (1–4)		2e-16*	
H (1–4)	2e-16*	M (1–4)		2e-16*	
Lutzomyia reburra					
Intralocality, Mashpi (1)					
F1/P1	0.62/0.25	0.23	J1/A1	0.11/0.96	0.001*
F1/H1	0.62/0.16	0.01*	J1/M1	0.11/0.05	0.1
P1/H1	0.25/0.16	0.1	A1/M1	0.96/0.05	0.002*
Intralocality, Milpe (2)					
F2/P2	1/0.44	0.02*	J2/A2	0.48/0.93	0.06
F2/H2	1/0.23	0.001*	J2/M2	0.48/0.30	0.1
P2/H2	0.44/0.23	0.1	A2/M2	0.93/ 0.30	0.001*
Intralocality, Puerto Rico (3)					
F3/P3	0.02	0.99	J3/A3	-	-
F3/H3	0.02	0.99	J3/M3	0/ 0.04	1
P3/H3	-	-	A3/M3	0/ 0.04	0.99
Intralocality, Via al Progreso (4)					
F4/P4	0.67/ 1.78	0.01*	J4/A4	1.81/ 0.74	0.001*
F4/H4	0.67/ 0.52	0.48	J4/M4	1.81/ 0.41	0.001*
P4/H4	1.78/ 0.52	0.01*	A4/M4	0.74/ 0.41	0.11
Interlocality					
F (1–4)	2e-16*	J (1–4)		0.04*	
P (1–4)	2e-16*	A (1–4)		0.002*	
H (1–4)	2e-16*	M (1–4)		2e-16*	

*Significant differences (*P*-value), A.T.N.: Average of specimens/Trap/night, F: Forest, P: Peridomicile, H: Housing, J: July, A: Aug., M: May.

Arrivillaga-Henríquez et al. 2017), in contrast to other Neotropical regions where there are positive correlations between abundance and precipitation (Gerais et al. 2005, Brandao-Filho et al. 2011, Cruz et al. 2012, Quintana et al. 2012, Falcao de Oliveira et al. 2013). However, since the northwest of Pichincha does not have a marked seasonality, the spatio-temporal persistence of the phlebotomine populations would be favored throughout the year, due to the greater number of months with low rainfall in this region that includes the Chocó and the foothills of the Andes (Calvopina et al. 2004).

Altitudinal Distribution, Proximity to the Forest and the River

Results suggest the importance of the proximity to the forest with the abundance of the species studied (Table 2), which has been previously indicated for other phlebotomine species (Rotureau et al. 2006, Azevedo et al. 2011) where maximum values of abundance and diversity are indicated, in contrast to intervened areas with less coverage of surrounding forest. In this intervened forest-zone interface, the edge effect would favor new ecological adjustment events in the phlebotomine populations, due to the concentration of several food resources and richness of niches, representing an interface for climate damping in the face of local landscape changes.

The proximity to the river variable has not been thoroughly studied in phlebotomines (Santini et al. 2012). However, there is an association between *Lu. trapidoi* and the proximity to the river, and it is necessary to consider that in several sectors of the studied localities, the river was landscape-associated with forest zones (Arrivillaga et al. 2013).

Other investigations show greater richness of associated plants and greater humidity at the edges of the river in fragmented

Table 2. Poisson generalized regression model showing the IRR with respect to the proximity to the forest and river, intra- and interlocal altitude of *Lutzomyia trapidoi* and *Lutzomyia reburra*

Locality	Distance	IRR	Coeff. Est.	Error Est.	*P*-value	95% CI
			Lutzomyia trapidoi			
Intralocality						
Mashpi	Forest	–2.10*	–0.021256	0.0028	7.9e-14*	–2.64 to –1.56
	River	0.54	0.005346	0.003214	0.0963	0.095 to 1.17
Milpe	Forest	–0.98*	–0.009848	0.001032	2e-16*	–1.18 to –0.78
	River	–6.96*	–0.072148	0.013476	8.61e-08*	–9.39 to –4.47
Puerto Rico	Forest	0.15	0.001524	0.001834	0.406	–0.21 to 0.51
	River	1.27	0.012663	0.002119	2.29e-09*	0.85 to 1.70
Via al Progreso	Forest	7.48	0.072129	0.005361	2e-16*	6.36 to 8.61
	River	–7.35*	–0.076380	0.009402	4.53e-16*	–9.05 to –5.63
Interlocality						
	Forest	-0.95*	-9.504e-03	6.170e-04	2e-16*	-1.07 to –0.83
	River	0.05	4.618e-04	4.796e-05	2e-16*	0.037 to 0.06
	Altitude	0.06	5.563e-04	1.299e-04	1.85e-05*	0.03 to 0.08
			Lutzomyia reburra			
Intralocality						
Mashpi	Forest	–1.14*	–0.011427	0.0063545	0.0721	–2.36 to 0.10
	River	0.09	0.0009409	0.0063542	0.8823	–1.14 to 1.35
Milpe	Forest	–0.75*	–0.007566	0.002082	0.00028*	–1.16 to –0.35
	River	–3.26*	–0.033149	0.025028	0.18535	–7.89 to 1.60
Puerto Rico	Forest	1.11	1.101e–02	3.238e+01	1.000	–100 to 3.69
	River	8.09	7.776e–02	3.803e+01	0.998	–100 to 2.54
Via al Progreso	Forest	3.8	0.037164	0.007694	1.37e-06*	2.23 to 5.36
	River	–4.05*	–0.041378	0.012114	0.000636*	–6.30 to –1.75
Interlocality						
	Forest	–0.6*	–0.006035	0.0015949	0.000154*	–0.91 to –0.29
	River	–0. 2*	–0.002344	0.0004377	8.5e-08*	0.32 to –0.15
	Altitude	0.08	0.000812	0.0003466	0.019103*	0.01 to 0.15

*Significant IRR/*significant difference (*P*-value)

landscapes (Luoto et al. 2002, Santini et al. 2012). These factors could lead to the appearance of several ecological niches that would favor the phases of immature and adults for their stay in this type of locality-landscape.

Both species were recorded throughout the altitudinal range studied in the northwest of Pichincha (316–1120 m). *Lu. trapidoi* has been mostly associated with lowland areas (Valderrama et al. 2008, 2011, Warner et al. 2010, Gomez et al. 2014), cataloged as a vector primary in the enzootic and domestic transmission cycles due to its high dominance, wide spatio-temporal distribution (Arrivillaga-Henríquez et al. 2017), whereas *Lu. reburra* is mainly associated with localities located at intermediate altitudes (Vergara et al. 2008, Warner et al. 2010). However, in the northwestern Pichincha, this species was found along the gradient in low abundance compared with *Lu. trapidoi*, suggesting *Lu. reburra* as a potential secondary vector in wild and/or domestic transmission cycles (Arrivillaga-Henríquez et al. 2017).

In general, the research showed how the three ecological variables studied in the landscape of the northwest region of Pichincha are ecological variables that modulate the relative abundance of both sand flies species, showing that the concentration of ecological hyper volume is close to the forest and the river, and at intermediate altitudinal intervals (Fig. 3).

Finally, the characteristics of the landscape and the ecological variables allowed to identify the overlap of the space-time ecological niche between species with contrasting food preference, anthropophilic versus zoophilic, and identified with natural infection by *Leishmania* spp in the region (Arrivillaga-Henríquez et al. 2017). The latter would favor the circulation of the etiological agent from rural–urban environments to jungle and vice versa, due to the great diversity of wild hosts present in the remaining forests of the Choco biosphere reserve.

The northwest of Pichincha is one of the regions of the Ecuadorian highlands with high demand for domestic, national and international tourism due to its proximity to the city of Quito (capital of Ecuador and UNESCO world heritage), where tourist activities associated with ecological tourism, nature tourism, adventure tourism, community tourism, and rural tourism are practiced. Some of these activities take place in the forest and intervened areas (hiking, camping) during hours of daily activity of the phlebotomine species studied. This leads to the recommendation of an active information campaign and permanent monitoring for a timely detection and typing of the parasite in humans and domestic animals, including tourists, visitor, and their pets (mainly dogs and cats).

Implications for Tourism and the Agricultural Sector

In northwestern Pichincha, the tourist activity is of great importance due to its natural heritage and landscape value (Medina 2015, Zalles 2016, Maldonado and Palacios 2017, Ministerio de Turismo 2018), which is why national and international tourists are received in the area. Studies related to sandflies have been carried out in the area that focus on the detection and identification of parasites in vector species (Arrivillaga-Henríquez et al. 2017), and also in the epidemiology of LC with human and canine cases (Calvopina et al. 2004, Gomez et al. 2014). However, the focus of present research provides new factors that should be considered for the management of Leishmaniasis locally.

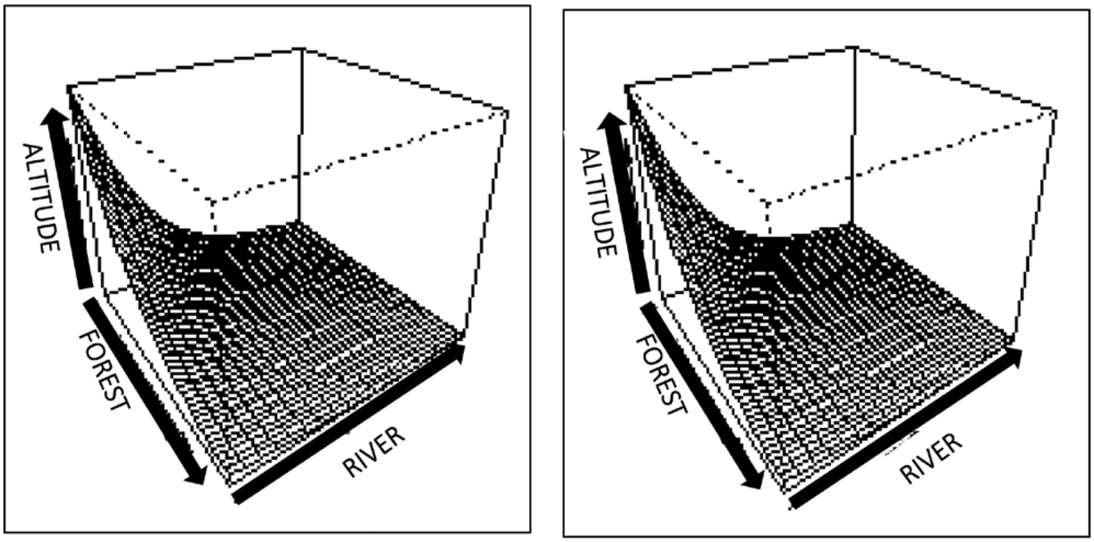

Fig. 3. Concentration of the hyper volume of *Lutzomyia trapidoi* (left) and *Lutzomyia reburra* (right), based on interlocal landscape variables.

First, the territorial space under the decree of the Biosphere Reserve, according to this category of UNESCO, protects under a legal framework all the localities evaluated and located in the northwest of Pichincha (UNESCO 2018, Karmaoui et al. 2019). This implies the protection and maintenance of the relict and secondary forests (Ministerio de Turismo 2018), where *Lu. trapidoi* and *Lu. reburra* species due its proximity to the forest will be persistent as vectors of *Leishmania* in their enzootic cycle, through sustainability and conservation of flora and fauna. Likewise, small mammals are protected, some of them hosts and reservoirs of *Leishmania* (Reyes and Arrivillaga 2009), whereas in the edge of this protected area, the productive activities of the locals (agricultural and livestock) predominate which per se they are risk factors and vulnerability to leishmaniasis (Desjeux 2001, Melchior et al. 2017, Karmaoui 2018, Artun 2019, Rodrigues et al. 2019, Gutiérrez-Torres 2020, Valero and Uriarte 2020).

Finally, these localities are destinations for nature tourism, adventure, fishing, recreation and leisure, ecotourism, and rural or community tourism where the activities associated with the landscape features, have as attractive the forest and the river which represent cultural and ecosystem services supply (Karmaoui et al. 2019). These factors are of high risk for the tourist and local population (Brilhante et al. 2015, Arrivillaga-Henríquez 2018), due to the twilight and night activity (17:00–07:00 h.), and their relative abundance increases at a short distance from these landscape elements.

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