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RESEARCH ARTICLE - TERMITES

Termite (Isoptera) Diversity in a Gallery Forest Relict in the Colombian Eastern Plains

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Abstract

Termites are known to influence soil nutrient cycle and decomposition processes, but its diversity and ecology in Colombian gallery forests have been little studied. Richness and relative abundance of termites found in gallery forest fragments protected within commercial forest plantations were quantified. Sampling was conducted at three sites surrounding the creeks Huerta La Grande, Claro and Los Micos, along 50 m long linear transects divided into five plots (10 × 2 m); in total, there were nine transects and 45 plots. Termite sampling involved the examination of fallen branches, pieces of wood in contact with the soil, arboreal termitaria, epigeal nests and soil samples of 20 cm deep (four per plot). Thirty-eight species, from the families Termitidae (Apicotermitinae, Termitinae, Nasutitermitinae, Syntermitinae) and Rhinotermitidae (Heterotermitinae), were found. No differences regarding termite species, abundance or feeding guilds were detected among sampling sites; neither, association between richness or termite abundance, and tree size, or accumulation depth of leaf litter on the soil or canopy light. The termite diversity found in fragments of gallery forest highlights the importance of maintaining this type of vegetation to preserve biodiversity and the ecosystem services derived from the biological activity of termites.

Introduction

Gallery forests along streams and rivers are important elements of the complex natural savanna ecosystems found in the Colombian Orinoco region. The region is currently experiencing accelerated changes in land use, mainly in the Eastern Plains (Romero-Ruiz et al., 2012), that will have unpredictable consequences for its ecological integrity (Lavelle et al., 2014).

Termites are a key group for the dynamics of tropical forests where they are primary decomposers and drivers of nutrient cycling (Ackerman et al., 2009; Bandeira & Vasconcelos, 2003) but research on termites in general in Colombia is scarce and particularly in forest of the Orinoco region (Jiménez & Decaëns, 2006); few records exist for this group in the region (Lasso et al., 2010; Pinzon et al., 2012). The available studies comprise a comparison of the density of soil macrofauna, including termites, in landscapes with different degrees of intensification (Decaëns et al., 1994), and an analysis of the spatial distribution of nutrients in epigeal termite mounds of *Nasutitermes* in a gallery forest (Jiménez & Decaëns, 2006).

Termites are sensitive to habitat fragmentation and changes in soil use (Bandeira & Vasconcellos, 2003; Constantino & Schlemmermeyer, 2000; Ackerman et al., 2009; Moura et al., 2009). Therefore, their diversity may serve as an indicator of conservation status, for example in forest fragments (Alves et al., 2011, Oliveira et al., 2013, Almeida et al., 2016). Termites are the most abundant organisms in the soil macrofauna of natural ecosystems and semi-cultivated and cultivated areas in the Eastern Plains of Colombia, where they can form more than 50% of the total abundance (Decaëns et al., 1994; Lavelle et al., 2014). Termite activity influences the physical, chemical and biological activity of soils in this region (Galvis et al., 1978; Decaëns et al., 1994; Jiménez & Decaëns, 2006).

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The aim of this study was to characterize termite diversity in fragments of gallery forests conserved within a landscape matrix of pastures and commercial forest plantations in the Eastern Plains of Colombia, in the Orinoco region. We hypothesized that characteristics of the forest (e.g. tree size, canopy light and organic matter accumulation) may explain termite species composition found in the areas.

Materials and methods

Sampling was carried out in gallery forests surrounding the creeks known as Huerta La Grande, Claro and Los Micos, in the basin of the Upia River in the municipality of Villanueva, department of Casanare, Colombia, within the geological formation known as Mesa de San Pedro 4°39.386´ N 72°55.185´ W. The three sites are 2 – 5 km apart and differ in their accessibility for humans, vegetation structure and development. The gallery forest sites have been protected since 1980, and are within commercial pine and eucalyptus plantations.

The area is located at approx. 360 m elevation, has an annual average rainfall of approx. 2900 mm and distinct wet and dry seasons. Rain occurs mostly from April to November; the dry season is from December to March. The annual average temperature in the area is 25.8 °C. The area is within the tropical rainforest life zone, and the vegetation diversity and structure of the sampling sites were characterized by Fernandez et al. (2012).

At each site, termite samples were obtained using the sampling protocol described by Jones and Eggleton (2000) with some modifications: along three linear transects, each 50m long and divided into five plots (10 × 2 m), resulting in 15 plots per site and 45 plots in total. There were at least 50 m from the edge of the forest to each transect and 50m of distance between them, following the linear shape of the forest that surround the creeks. Sampling took 60 minutes per plot; the total sampling effort was 45 hours. Sampling involved examination of and direct manual capture of termites from epigeal nests, fallen branches, pieces of wood in contact with the soil, superficial organic soil layer (four samples per plot: 20 x 20 cm [length x width] and 20 cm deep), and arboreal termitaria up to 3 m high.

Sampling took place at the beginning of the wet season (April 2013) in the Huerta La Grande site, and at the end of the wet season (November 2013) in the remaining two sites.

To describe the structural and environmental characteristics of each sampling site, the height and trunk diameter of trees located on the main line of each transect were measured using an ultrasound measurement instrument (Haglof Vertex IV) and diametric tape, respectively. Also, the percentage of canopy cover was estimated from photographs taken using a fisheye lens adapted to a camera compatible with Winscanopy software. In addition, leaf litter accumulation depth was measured at three points per plot, and the average used for statistical purposes. Also, one soil sample was taken per site to determine soil moisture content, pH and organic C.

Identification at the genus and species levels was conducted using appropriate keys (Bourguignon et al., 2010, 2013, 2016; Carrijo et al., 2011; Constantino, 2002; Cuezzo & Cancello, 2009; Rocha et al., 2012), and by comparison with some specimens kept at the collection (CEFUD) that had been identified by Dr. Reginaldo Constantino. *Nasutitermes* and *Heterotermes* samples were reviewed by Dr. Tiago Fernandes Carrijo. In addition, specimens for which it was not possible to confirm the species were named and numbered as morphospecies.

Samples of Apicotermitinae containing at least ten individuals were separated at the species and morphospecies levels by dissecting the enteric valve and comparing its morphology with that described in the literature (Bourguignon et al., 2010, 2013, 2016). Termite samples are kept in 2 ml vials containing 85% ethanol, in the Colección Entomològica Forestal (CEFUD) at Universidad Distrital Francisco Jose de Caldas in Bogota D.C.

Termites were assigned to the feeding guilds described in the literature (Donovan et al., 2001) using available information for the genus/species (De Souza & Brown, 1994, Constantino, 1999, Bourguignon et al., 2016). Feeding guilds included xylophages (feed on wood), humivores (feed on humus and soil organic matter), intermediate feeders (feed at the soil/wood interface and do not fit into the categories mentioned above; collected under decomposed fallen logs) and litter feeders (feed on plant material deposited on the surface of the forest floor, including grasses, leaf material, litter).

The relative abundance of each termite species (expressed as the number of encounters) was determined by recording the presence of each species only once in each plot up to a maximum of five per transect (15 per site). Richness was calculated as the number of species and morphospecies found at each site.

Termite diversity was characterized using estimated species number based on coverage rarefaction (Chao & Joost, 2012). We obtained estimated richness (q0) and the estimators Shannon (q=1) and Simpson (q=2) with a 95% confidence level. To test the hypothesis of differences in termite species composition among sites, we performed a Permutacional Analysis of Variance (PERMANOVA; α:0,05) based on Bray–Curtis dissimilarity (Anderson, 2005). All the analyses were performed with the software R (R Development Core Team, 2014), using the vegan package (Oksanen et al., 2012) and iNEXT (Hsiech et al., 2016). To test the hypothesis of differences in termite abundance or richness among sites regarding feeding guilds and to compared tree size, canopy light and Organic matter accumulation among sites we performed a one-way ANOVA using SPSS (IBM SPSS version 20).

Results

Termites from 24 genera and approximately 38 species were found in a total of 278 samples (Table 1) and 199 encounters. Most species and morphospecies (81.2%) belonged to the family Termitidae (and to the subfamilies

Table 1. Termite diversity, relative abundance, and feeding guilds of termites found in gallery forests. X: xylophagous, H: humivorous, L: litter feeder, I: intermediate; C: Caño Claro, HLG: Caño Huerta La Grande, M: Caño Los Micos.

Taxon	Claro	Huerta La Grande	Los Micos	Total	Feeding group	Feeding habits references
Rhinotermitidae	**12**	**10**	**11**	**33**		
Coptotermitinae	0	0	1	1		
Coptotermes testaceus (Linnaeus, 1758)	0	0	1	1	X	Constantino, 1999; Donovan *et al*. 2001
Heterotermitinae	**11**	**9**	**10**	**30**		
Heterotermes tenuis (Hagen, 1858)	7	8	7	22	X	Constantino, 1999; De Souza & Brown, 1994
Heterotermes convexinotatus (Snyder, 1924d)	4	1	3	8	X	Constantino, 1999; De Souza & Brown, 1994
Rhinotermitinae	**1**	**1**	**0**	**2**		
Rhinotermes marginalis (Linnaeus, 1758)	1	1	0	2	X	Constantino, 1999; De Souza & Brown, 1994
Termitidae	**60**	**39**	**67**	**166**		
Apicotermitinae	**7**	**8**	**19**	**34**		
Anoplotermes parvus Snyder,1923	2	0	1	3	H	Constantino, 1999; De Souza & Brown, 1994
Apicotermitinae sp. 1	1	0	1	2	H	Constantino, 1999; De Souza & Brown, 1994
Apicotermitinae sp. 2	0	1	1	2	H	Constantino, 1999; De Souza & Brown, 1994
Apicotermitinae sp. 3	0	2	1	3	H	Constantino, 1999; De Souza & Brown, 1994
Apicotermitinae sp. 4	0	3	4	7	H	Constantino, 1999; De Souza & Brown, 1994
Apicotermitinae sp. 5	3	1	1	5	H	Constantino, 1999; De Souza & Brown, 1994
Patawatermes turricola (Silvestri, 1901)	1	1	7	9	H	Bourguignon *et al*., 2016
Ruptitermes sp. 1	0	0	2	2	H	Constantino, 1999; De Souza & Brown, 1994
Ruptitermes sp. 2	0	0	1	1	H	Constantino, 1999; De Souza & Brown, 1994
Nasutitermitinae	**26**	**17**	**29**	**72**		
Angularitermes nasutissimus (Emerson, 1925)	0	0	1	1	I	Constantino, 1999
Atlantitermes raripilus (Emerson, 1925)	1	0	0	1	I	Constantino, 1999
Coatitermes clevelandi (Snyder, 1926,d)	1	2	0	3	I	Constantino, 1999
Nasutitermes banksi Emerson, 1925	5	4	6	15	X	Constantino, 1999; De Souza & Brown, 1994
Nasutitermes cf. *ephratae*	6	3	3	12	X	Constantino, 1999; De Souza & Brown, 1994
Nasutitermes cf. *gaigei*	0	0	1	1	X	Constantino, 1999; De Souza & Brown, 1994
Nasutitermes cf. *guayanae*	5	4	7	16	X	Constantino, 1999; De Souza & Brown, 1994
Nasutitermes cf. *similis*	7	3	8	18	X	Constantino, 1999; De Souza & Brown, 1994
Nasutitermes cf. *surinamensis*	0	1	0	1	X	Constantino, 1999; De Souza & Brown, 1994
Rotunditermes bragantinus (Roonwal & Rathore)	0	0	3	3	X	Constantino, 1999
Subulitermes sp.1	1	0	0	1	H	Constantino, 1999; De Souza & Brown, 1994

Table 1. Termite diversity, relative abundance, and feeding guilds of termites found in gallery forests. X: xylophagous, H: humivorous, L: litter feeder, I: intermediate; C: Caño Claro, HLG: Caño Huerta La Grande, M: Caño Los Micos. (Continuation)

Taxon	Claro	Huerta La Grande	Los Micos	Total	Feeding group	Feeding habits references
Syntermitinae	**11**	**2**	**10**	**23**		
Cyrilliotermes angulariceps (Mathews,1977)	1	0	0	1	H	Constantino, 1999
Embiratermes neotenicus (Holmgren,1906)	2	1	6	9	I	Constantino, 1999
Labiotermes labralis (Holmgren,1906)	0	0	3	3	H	Constantino, 1999; Donovan *et al*. 2001
Mapinguaritermes cf. *grandidens* (Silvestri,1901)	1	0	0	1	I	Constantino, 1999
Silvestritermes cf. *euamignathus* (Silvestri,1901)	3	0	0	3	I	Constantino, 1999
Syntermes sp.1	4	1	1	6	L	Constantino, 1999; Donovan *et al*. 2001
Termitinae	**16**	**12**	**9**	**37**		
Crepititermes verruculosus Emerson, 1925	1	0	0	1	H	Constantino, 1999
Cylindrotermes flangiatus (Holmgren, 1906)	1	1	1	3	X	Constantino, 1999
Cylindrotermes parvignathus (Holmgren, 1906)	3	0	1	4	X	Constantino, 1999
Microcerotermes cf. *exiguus* (Hagen,1858)	5	5	4	14	X	Constantino, 1999
Neocapritermes cf. *pumilis* Constantino,1991c	1	0	0	1	X	Constantino, 1999
Neocapritermes cf. *talpoides* Krishna & Araujo, 1968	0	1	0	1	X	Constantino, 1999
Neocapritermes cf. *taracua* Krishna & Araujo, 1968	0	0	1	1	X	Constantino, 1999
Termes sp.1	5	5	2	12	I	Constantino, 1999; De Souza & Brown, 1994
Total morphospecies	**25**	**20**	**27**	**38**		
Relative abundance	**72**	**49**	**78**	**199**		

Apicotermitinae [23.7%], Nasutitermitinae [31.4%], Termitinae [21.0%], and Syntermitinae [15.8%]); the remaining (11.4%) belonged to the family Rhinotermitidae.

Termites were found in 98% of the 45 plots and in 17% of the 180 soil samples examined. Seventy-five per cent of the 198 encounters were with termites of the genera *Nasutitermes*, *Heterotermes*, *Anoplotermes*, *Microcerotermes*, *Termes* and *Embiratermes*. The most abundant species found was *Heterotermes tenuis* followed by *Nasutitermes similis, N*. cf. *guayanae* and *N. banksi*. Approximately 30% of the morphospecies were found only once.

In the three sampling sites, richness ranged from 20 (52.6% of the total number of morphospecies) to 27 (71%), and abundance (number of encounters) ranged from 49 (24.6%)

Table 2. Relative abundance (%) of termite samples according to foraging substrate.

Collection substrate	Claro	Los Micos	Huerta La Grande	Total
Arboreal	3.3	0.7	2.9	6.9
Dead wood	28.7	17.1	30.9	76.7
Mound	1.8	1.5	2.9	5.5
Soil sample	2.2	4.0	4.7	10.9
Total	36.0	23.3	41.5	100

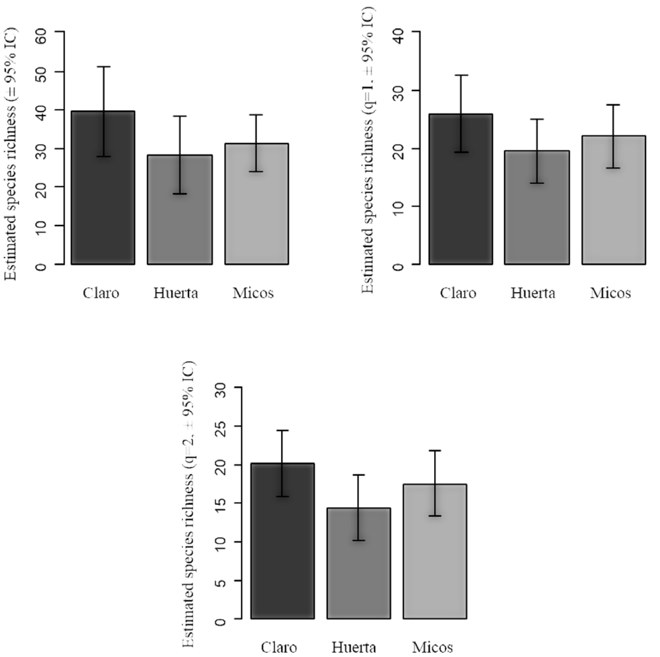

Fig 1. Estimated termite species richness by coverage - based rarefaction in Caño Claro, Huerta La Grande and Los Micos gallery forests. Estimates are based on 0.86 coverage. Error bars correspond to 95% confidence intervals.

of the total number of encounters to 78 (39.2%). The maximum percentage of total morphospecies and species found in each site was 70%; about 30% of the species we sampled were singletons or doubletons.

Although, at the Huerta La Grande numerically lower number of species and encounters were found, estimated species richness (q^0) based on coverage rarefaction including 95% confidence intervals indicates no significant differences among sampling sites, therefore, neither significant differences were estimated regarding Shanon (q^1) or Simpsom (q^2). As observed in Figure 1, confidence intervals overlap among sampling sites.

Sampling coverage curve including interpolation and extrapolation values for each sampling site, averaged 82% of completeness, and indicates a trend towards stabilization, suggesting the sampling appropriately represent the termite diversity in the area (Figure 2).

The 38 termite species and morphospecies found were assigned to four feeding guilds as follows: xylophages 42.47%, humivores 34.2%, intermediate feeders 18.4% and litter feeders 2.6%. Xylophagous dominated (61.8% on average) the encounters per site (Figure 2). Most termites (76.7%) were collected foraging in deadwood (Table 3). The sampling sites were also similar regarding termite richness or abundance of feeding guilds (Figure 3).

Size of the trees (expressed by height and diameter) was higher in Caño Claro (Table 4). However, we did not find any structural variable related with diversity as indicated by the PERMANOVA analysis based on Bray-Curtis dissimilarity and including the structural variables (Table 5).

Discussion

In this study, *Angularitermes*, *Crepititermes*, *Mapinguaritermes* and *Subulitermes* were recorded for the first time in Colombia, and *Rhinotermes*, *Coptotermes*,

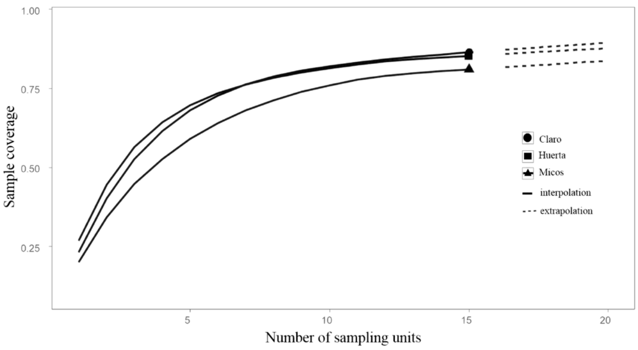

Fig 2. Sample coverage curve as indicative of sampling completeness at Caño Claro, Huerta La Grande and Los Micos gallery forests.

Table 3. Summary of One-way ANOVA of structural and environmental variables.

Site	Trees per transect	DAP (cm)	Tree height (m)	Organic matter accumulation (cm)	Canopy light (%)	Organic Carbon (%)	pH	Soil moisture (%)
Claro	8 ± 2.5	24.2 ± 8.4 a	15.3 ± 3.3 a	3.7 ± 1.4 a,b	13.7 ± 5.6 a	3.0	4.4	29
Huerta La Grande	23 ± 7.2	13.6 ± 3.4 b	10.2 ± 4.7 b	4.6 ± 1.6 b	16.0 ± 5.3 a	1.2	4.5	9
Los Micos	18 ± 6.1	11.7 ± 6.3 b	11.1 ± 2.5 b	3.1 ± 1.3 a	15.8 ± 6.0 a	4.3	4.3	22.3
df.		2	2	2	2			
p		0,000	0.001	0,018	0,46			
f		***	***					

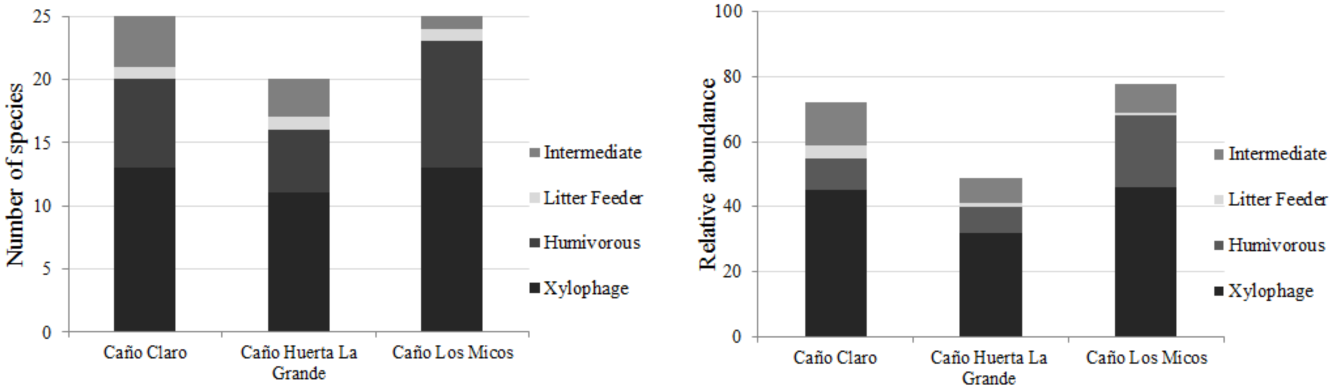

Fig 3. Richness (a) and abundance (b) of termites by trophic guild in Caño Claro, Huerta La Grande and Los Micos. Relative number of species (top left), relative number of encounters (below, left.)

Table 4. Summary of PERMANOVA of termite composition including sampled sites and forest structural variables.

Sources of variation	df	SS	Mean SS	F Model	R^{2**}	*p* value
DAP (cm)	1	0,288	0,288	0,741	0,017	0,795
Tree height (m)	1	0,390	0,390	1,003	0,023	0,443
Canopy light (%)	1	0,290	0,290	0,747	0,017	0,768
Organic matter acum. (cm)	1	0,313	0,313	0,804	0,018	0,679
Residuals	39	15,169	0,388	0,909		
Total	44	16,685	1			

** Variance explained by each source of variation.

Cyrilliotermes, *Coatitermes* and *Termes* were recorded for the first time in the Orinoco region of Colombia. Consequently, our findings increase to 27, the number of genera and to 40 the number of (morpho) species of termites known to occur in the Orinoco region (Vargas-Niño et al., 2005; Morales-Castaño & Medina, 2009; Pinzón et al., 2012).

Unfortunately, was impossible to compare the diversity and abundance found in our study with those of other Colombian studies because there have been no previous reports of inventories from Colombian gallery forests. However, unpublished data (Pinzon personal communication) found only 21 morphospecies from 18 genera in a gallery forests and 10 genera in a commercial rubber plantation (Pinzon et al., 2012) in Pto. Lòpez, a nearby location to the study site from the present study. Sampled sites in the current study kept 40% more species.

Although primary Amazonian forests may substantially differ from the forest of our study, only in order to have a reference, a recent study, using the sampling protocol, revealed eighteen more species than our study in a primary no flooding forest in central Amazonia (Ackerman et al., 2009). The same study reported humivorous to account for 50% of the encounters (we found 20%), and the dominance of Nasutitermitinae, as well as *Nasutitermes*. In another study in tropical forests, Jones et al. (2003) found fewer number of species than reported here, in a primary forest (34 species), with substantial dropping of termite diversity and encounters when progressive degree of land use disturbance was compared; a trend that appear to be consistent when natural forest is replaced by agricultural activities.

Seventeen species of termites (61.8%) belonging to the xylophagous feeding guild were found in the areas. As indicated in a study of a gallery forest in the Cerrado (Oliveira et al., 2013), we also expected to find more representatives of this guild than the others, given the easy availability of wood and cellulosic resources derived from fallen branches, palm leaves and mulch at the sites sampled in this study (most of the xylophagous were collected in dead wood pieces in the forest floor). Species of *Heterotermes* and *Nasutitermes* were the main removers of wood and leaf litter in the study areas. Contrary to Oliveira et al. (2013), xylophage species in our study were found foraging within the niches explored in this sampling method and predominated in the samples, while humivorous where the second more important group.

Structural and environmental variables of forests have been used to attempt to explain termite diversity (Davies et al., 2003; Apolinario & Martius, 2004; Vasconcellos et al., 2010; Dahlsjö et al., 2015). In particular, leaf litter accumulation depth and the basal area of woody plants may correlate with termite abundance (Gillison et al., 2013), and tree size may correlate with the abundance of some Termitidae, particularly those that build arboreal termitaria (Gillison, 2003; Jones et al., 2003; Gonçalves et al., 2005). In this study, the site Claro had more well-developed trees (with greater trunk diameter and height) than Los Micos and Huerta La Grande, however, these structural differences in the habitat did not influenced the termite diversity; neither the abundance or richness of any feeding group differed significantly between sites as have been reported in some tropical forest (Jones et al., 2003).

Our results are similar to recent observations in some Brazilian forest fragments (Oliveira et al., 2013; Almeida et al., 2016), in which termite diversity is not directly explained by the structural/environmental variables of the vegetation included in those studies. Besides vegetation structure and environmental conditions, understanding termite plasticity and habitat requirements as well as quality and availability of food (Kirton et al,. 1999; Araujo et al., 2011; Almeida et al., 2016) or predation (Dambros et al., 2016) may contribute to better explain termite diversity association in these particular habitats.

The low soil moisture content (9%) at Huerta La Grande, due to the fact that sampling was done in a relatively drier period at this site, may explain the lower numerical values of richness and abundance of termites at this site compared to the other two sites, which were sampled in a more humid period. It is known how the frequency of encounters, especially with subterranean termites, decreases during dry times. Under these conditions, termites migrate to deeper soil layers, because high temperatures and low humidity in the surface layers of wood strongly limit superficial foraging (Nobre et al., 2009). Decreases in termite abundance and richness in rubber tree plantations during the dry period have been reported in areas close to our sampling site (Pinzón et al., 2012).

Despite the fact that the gallery forest relicts included in this study are subject of anthropocentric pressure derived from the surrounding forested and pasture matrix, diversity of termites found in this study are considerable, and besides adding to our knowledge about local and regional termite fauna in Colombia, also highlights the importance of gallery forest fragments as reservoirs for these key arthropods. Termites are of clear conservation interest; therefore, other forest fragments with lower or no human influence in the Orinoco region should be surveyed to obtain a better representation of the termite diversity of the region.

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