Absence of Relationship Among Termite (Insecta: Isoptera) Richness, Functional Groups and Environmental Variables in Southern Brazil

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Abstract. In the temperate zones, termites play a minor ecological role, while, in the tropics, they dominate among the decomposing invertebrates, corresponding to about 10% of the total animal biomass and up to 95% of the soil insect biomass. At the same time, the tropical zones have more productive environments, lower climatic variation, greater ecological stability, and are richer in species. In this study, we evaluated termite species richness, composition, and trophic groups in 14 sites at different altitudes distributed in the State of Rio Grande do Sul, Southern Brazil from previous published surveys. We tested whether there would be a pattern linking those three variables to altitude and bioclimatic factors. We found no significant correlation between species richness and altitude. Bioclimatic variables did not explain the differences in species composition neither in functional group. However, species number, though not statistically different, and composition varied among sampling sites. We suggest that further surveys should be conducted along with greater collection effort and number of sampled sites as to provide a better understanding of the factors affecting the termite fauna of Southern Brazil.

Keywords: Bioclimatic variables; Biodiversity; Species composition; Trophic groups.

Ausência de Relação Entre Riqueza, Grupo Funcional e Variáveis Ambientais para Térmitas (Insecta: Isoptera) no Sul do Brasil

Resumo. Nas zonas temperadas, os térmitas têm um papel ecológico reduzido, enquanto que, nos trópicos, dominam entre os invertebrados decompositores e correspondem a cerca de 10% do total da biomassa animal e quase 95% da biomassa de insetos de solo. Ao mesmo tempo, as zonas tropicais possuem ambientes mais produtivos, menor variação climática, maior estabilidade ecológica e riqueza de espécies. No presente trabalho, avaliamos a riqueza, composição e os grupos funcionais dos térmitas de 14 localidades em diferentes altitudes no Rio Grande do Sul, sul do Brasil, a partir de dados já publicados. Testamos se existiria um padrão relacionando essas três variáveis à altitude e aos fatores bioclimáticos. Os resultados não mostraram correlação significativa entre riqueza de espécies e altitude, assim como os fatores bioclimáticos não explicaram a variação na composição de espécies e dos grupos funcionais. No entanto, o número, embora não significativo, e a composição de espécies foram diferentes entre os locais de coleta. Sugerimos a ampliação dos levantamentos, com maior esforço amostral e maior número de pontos amostrados, para identificar os fatores ambientais que influenciam a termitofauna do sul do Brasil.

Palavras-Chave: Composição de espécies; Biodiversidade; Grupos tróficos; Variáveis bioclimáticas.

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While in temperate zones, isopterans play a minor ecological role; in the tropics, they are the most important invertebrate decomposer (Bignell & Eggleton 2000; Bignell *et al.* 2011). They make up approximately 10% of the total animal biomass and 95% of the soil insect biomass (Bignell & Eggleton 2000). Del Grosso *et al.* (2008) suggest that the increase in species richness in the tropical areas is due to the higher productivity of the environment as a consequence of more stable climatic factors.

In general, altitude and species richness correlates negatively for several organisms (Rahbek 2005; McCain 2009; for a review see Sundqvist *et al.* 2013). For example, in tropical and subtropical zones, altitude alters the correlation between latitude and richness of ant species. At latitudes lower than 30° S and below 500 m a.s.l., richness and altitude correlates positively, while correlating negatively at greater latitudes and altitudes (Kusnezow 1957; Ward 2000).

For instance, termite richness and composition is affected by altitude in a study conducted in the Indonesian rain forest (Gathorne-Hardy *et al.* 2001). The authors found that a 100

m increase in the elevation gradient produced significant decrease in species richness. Cancello *et al.* (2014) found that both richness and abundance correlates negatively to latitude in the Brazilian Atlantic Forest, but whether altitude has been accounted in the final statistical model of this important and pioneer study is unknown. The species feeding group was also taken into account by Cancello *et al.* (2014), and that yielded interesting results. Feeding (or functional) groups are defined mainly on their different diet requirements, which, briefly, vary from soil, fresh wood to different stages of decomposition of the wood (De Souza & Brown 1994; Eggleton *et al.* 1995, 1997; Jones & Brendell 1998; Jones 2000; Bignell & Eggleton 2000).

Given that altitude and several bioclimatic factors are a determinant or proxy for species richness of different taxa, our aim was to test whether a similar pattern could exist for termites collected in the State of Rio Grande do Sul, Southern Brazil, of which the species richness and composition have been recently published in our previous study (Diehl *et al.* 2014).

MATERIAL AND METHODS

Species richness and composition, elevation and geographical location on termites sampled in 14 sites distributed in four geomorphological units of Rio Grande do Sul (Central Depression, Coastal Plain, Southern Plateau, and Sul-Riograndense Shield) (Figure 1) were gathered from our previously published study (Diehl *et al.* 2014).

Sampling and identification. Briefly, a transect (100 m x 3 m) divided into 20 sections (15 m²) was established at each site. Samples were taken in ten non-contiguous sections along the transect, alternating left/right sites in each section. During 60 minutes, each section was surveyed for termites on the ground and on the trees. A termitrap bait was randomly placed sixty days before sampling at 15 cm deep into the soil for each section (Almeida & Alves 1995) and ten blocks (340 cm³) of soil at horizon A were extracted per each section.

Termites were stored in individual amber glass with 80% ethanol. Specimens were identified to the genus level and, whenever possible, to the species level or morphospecies, using Emerson (1952), Krishna & Araujo (1968), Araujo (1977), Mathews (1977), Fontes (1985, 1992, 1995, 1998), Cancello (1989), and Constantino (1994, 1998, 1999, 2002, 2013). Taxonomists verified species identification. Specimens are deposited at the Collection of Social Insects (Isoptera and Formicidae) of the University of Vale do Rio dos Sinos, São Leopoldo, Rio Grande do Sul, Brazil.

Functional group classification. For the present study, we grouped termites according to the functional grouping system of Rezende (2012), who studied the feeding habits of South American termites of the family Termitidae based on worker mandible morphology and gut content analysis, resulting in four functional groups: wood-feeders, humus-feeders, grass-litter feeders, and intermediate. For Kalotermitidae, we followed Constantino (1999, 2002) and Cancello *et al.* (2014).

Bioclimatic data. Climatic variables (n = 19) related to temperature (BIO_1, BIO_2, BIO_3, BIO_4, BIO_5, BIO_6, BIO_7, BIO_8, BIO_9, BIO_{10}, BIO_{11}) and precipitation (BIO_{12}, BIO_{13}, BIO_{14}, BIO_{15}, BIO_{16}, BIO_{17}, BIO_{18}, BIO_{19}) were gathered for each sampled site from the database WorldClim (Hijmans *et al.* 2005). We conducted Principal Component Analysis (PCA) to reduce the dimensionality of the climatic variables, as they are highly correlated. Broken stick model selected for the meaningful principal components (Legendre & Legendre 2012) and retained two orthogonal axes that explained 85% of the variation of the data. We calculated the Euclidean distance of these orthogonal axes as the bioclimatic variables used in Mantel tests.

Statistical analysis

Species richness and altitude. Linear regression was used to test for correlation between species richness and altitude (Legendre & Legendre 2012), performed with R Core Team package vegan (Oksanen *et al.* 2013).

Species composition, functional groups and bioclimatic variables. Mantel test was used to check if the variation in species composition and functional groups among sampling sites was explained by bioclimatic variables. We translated the matrix of site coordinates (latitude and longitude) into spatial predictors with distance based in Moran Eigenvector Maps (dbMEM), formerly called Principal Coordinates of Neighbor Matrices (PCNM) analysis (Dray *et al.* 2006, 2012). We used the Euclidean distance between the sampled sites. Then, computed the threshold value and constructed a truncated distance matrix. To construct the truncated matrix, we kept the original distance values that were lower than the threshold value, and multiplied by four the values higher than the threshold value. We then performed a Principal Coordinate Analysis (PCoA) of the truncated distance matrix to obtain vectors used as spatial

predictors in Mantel tests.

To analyze the impact of bioclimatic variables (predictor) on species composition while controlling for the effect of spatial variables we used partial Mantel test. The test controlled for the effect of spatial autocorrelation on species distribution, i.e., the phenomenon by which sites closer to each other have more similar species composition than farther ones, regardless of environmental variation (Dray *et al.* 2006, 2012; Legendre & Legendre 2012). Here, we transformed the species composition into a dissimilarity matrix using the Bray-Curtis distance against bioclimatic dissimilarity obtained above, while controlling for the effect of spatial distance (Euclidean distance) (Legendre & Legendre 2012). Permutations (n = 999) of rows and columns of species dissimilarity matrix estimated the significance of the correlation (Legendre & Legendre 2012). We tested separately with partial Mantel tests for each functional group (wood-feeder, humus-feeder, grass-litter feeder, and intermediate). Analysis were conducted in R Core Team (2013) using the packages vegan (Oksanen *et al.* 2013) and labdsv (Roberts 2013).

RESULTS

In our previous study, we recorded 16 taxa of termites from two families. Kalotermitidae was represented by a single morphospecies of *Rugitermes*, while we found 12 genera, seven species, and eight morphospecies from four subfamilies (Apicotermitinae, Nasutitermitinae, Syntermitinae, and Termitinae) of Termitidae (Table 1).

The most frequent species were *Anoplotermes* sp. and *Aparatermes* sp., occurring in ten (71.4%) and nine (64.3%) sampled sites, respectively. *Cornitermes cumulans* (Kollar) and *Cortaritermes fulviceps* (Silvestri) were found in half of the sites. *Neocapritermes* sp. and *Rugitermes* sp. were found in four (28.6%) sites, while *Nasutitermes jaraguae* (Holmgren) and *Termes* sp. were found in three (21.4%). Four species [*Dihoplotermes inusitatus* Araujo, *Grigiotermes bequaerti* (Snyder & Emerson), *Nasutitermes aquilinus* (Holmgren), and *Nasutitermes* sp.] were present in only two (14.3%) sites. The remaining species [*Araujotermes caissara* (Fontes), *Grigiotermes* sp., *Ruptitermes* sp., and *Tetimatermes* sp.] occurred in only one (7.1%) of the 14 sampled sites (Figure 2).

Most of the 16 taxa were either wood- (31.2%) or humus-feeders (31.2%). Four species were grass-litter feeders (25%) and two species were classified as intermediates (12.5%). The majority of sites (57.1%) had two to three functional groups, while 14.3% had a single functional group (Figure 2).

Species composition varied between sites, as well as species number per site, from one to 14 (Figure 2). Species richness and altitude were not correlated [F (1, 12) = 0.009, P = 0.924]. Bioclimatic variables did not explain the differences in species composition (r = -0.09107, P = 0.67) neither functional group differences (r = -0.1116, P = 0.64).

DISCUSSION

Species number was low, varying from one to 14 species per site and only the species composition differed greatly among sites, similar to previously registered for temperate and subtropical regions (Eggleton 2000; Eggleton & Tayasu 2001). However, in the temperate regions of Argentina, species number differs from southern Brazil and termite richness can reach up to 81 species (Laffont *et al.* 1998, 2004; Torales *et al.* 2005). Nevertheless, Cancello (2002) recorded from two to eight morphospecies in the Brazilian Atlantic Forest located in a subtropical region (State of Santa Catarina), but also found that in the State of Bahia, in the tropical region, an average of 30 morphospecies were recorded.

Invertebrates diversity pattern remain poorly unknown (Diniz-Filho *et al.* 2010), and in the case of termites, several studies on

Table 1. Termites recorded in 14 sites in Rio Grande do Sul, Southern Brazil, classified into functional groups.

Family/Subfamily	Taxon	Functional group
Kalotermitidae	*Rugitermes* sp.	wood-feeder
Termitidae		
Apicotermitinae	*Anoplotermes* sp.	humus-feeder
	Aparatermes sp.	intermediate
	Grigiotermes bequaerti (Snyder & Emerson)	humus-feeder
	Grigiotermes sp.	humus-feeder
	Ruptitermes sp.	grass-litter feeder
	Tetimatermes sp.	humus-feeder
Nasutitermitinae	*Araujotermes caissara* (Fontes)	intermediate
	Cortaritermes fulviceps (Silvestri)	grass-litter feeder
	Nasutitermes aquilinus (Holmgren)	wood-feeder
	Nasutitermes jaraguae (Holmgren)	wood-feeder
	Nasutitermes sp.	wood-feeder
Syntermitinae	*Cornitermes cumulans* (Kollar)	grass-litter feeder
Termitinae	*Dihoplotermes inusitatus* Araujo	humus-feeder
	Neocapritermes sp.	wood-feeder
	Termes sp.	intermediate
Total	**16**	**4**
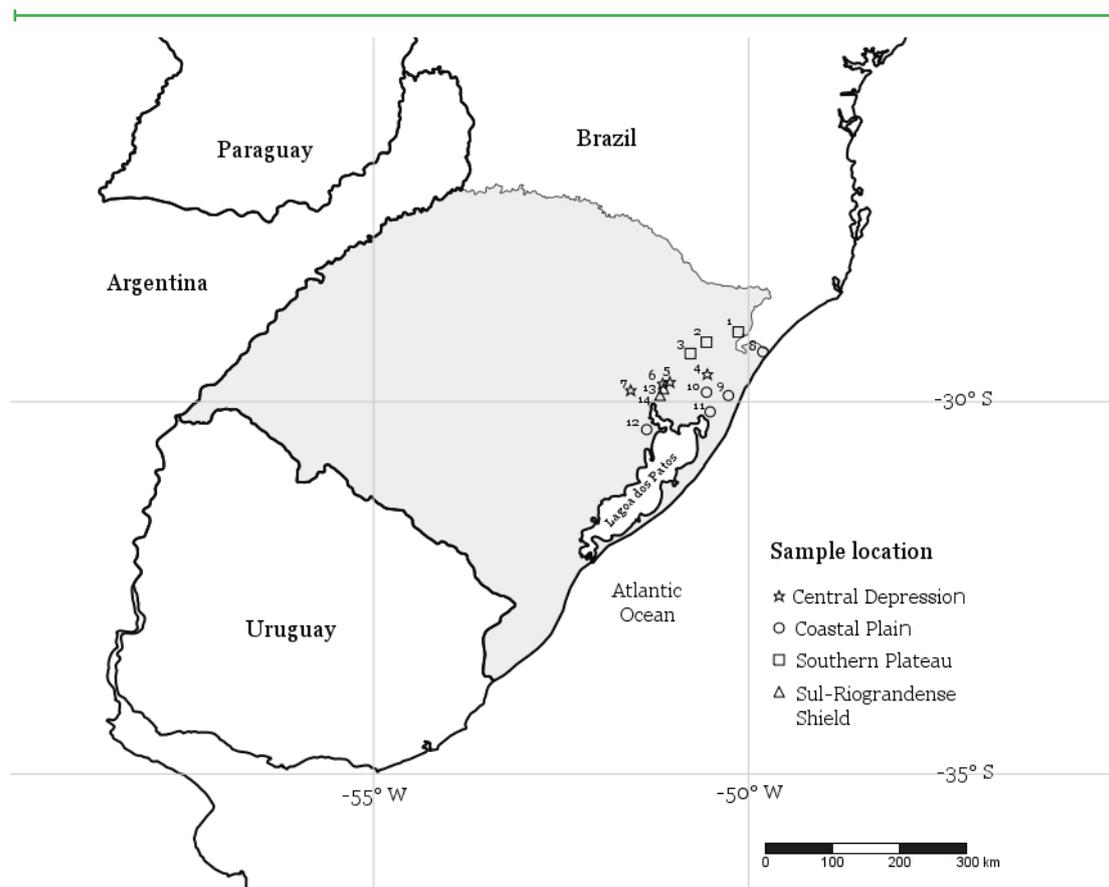
Figure 1. Termite sampling sites distributed in four geomorphological units of Rio Grande do Sul, Southern Brazil. [Sampling sites: 1, Cambará do Sul (29°10'S, 50°05'W); 2, São Francisco de Paula (29°23'S, 50°25'W); 3, Canela (29°21'S, 50°49'W); 4, Rolante (29°36'S, 50°31'W); 5, São Leopoldo (29°45'S, 51°08'W); 6, Novo Hamburgo (29°41'S, 51°04'W); 7, Triunfo (29°53'S, 51°23'W); 8, Torres (29°20'S, 49°44'W); 9, Passinhos (30°01'S, 50°23'W); 10, Santo Antônio da Patrulha (29°54'S, 50°33'W); 11, Capivari do Sul (30°08'S, 50°30'W); 12, Barra do Ribeiro (30°17'S, 51°18'W); 13, Sapucaia do Sul (29°49'S, 51°08'W); 14, Canoas (29°55'S, 51°11'W)].

the effects of environmental factors, such as fire, deforestation, and forest fragmentation on the community structure have been conducted (Eggleton *et al.* 1995, 1996; Davies 2002). However, it is clear that local environmental factors, such as altitude, temperature, rainfall, and vegetation influences the richness of termite communities (Eggleton 2000; Donovan *et al.* 2002; Inoue *et al.* 2006). Moreover, Collins (1980, 1981) reported a reduction in species abundance with increasing altitude. Among Termitidae, Inoue *et al.* (2006) found that Nasutitermitinae species richness and abundance tend to increase in higher altitudes, while elevation had not effect on Rhinotermitidae. This trend was not found in our study, probably due to our reduced sample size and collection effort.

Cancello *et al.* (2014) were pioneers in describing, for the South America region, the diversity pattern, abundance and species composition of the termite functional groups along a latitudinal gradient (from 7°S to 27°S) in the Brazilian Atlantic Forest. Along this gradient, termite species richness and abundance negatively correlates to latitude. Latitude influenced termite diversity through variation in rainfall, in the evapotranspiration potential, and temperature, the later with greater influence. Another important study has been conducted by Palin *et al.* (2011) in the Peruvian Amazon-Andes along an elevation gradient. From the 49 species registered, in general, the diversity declined with increased elevation. The functional groups responded differently to the upper distribution limit: for the soil-feeding it was between
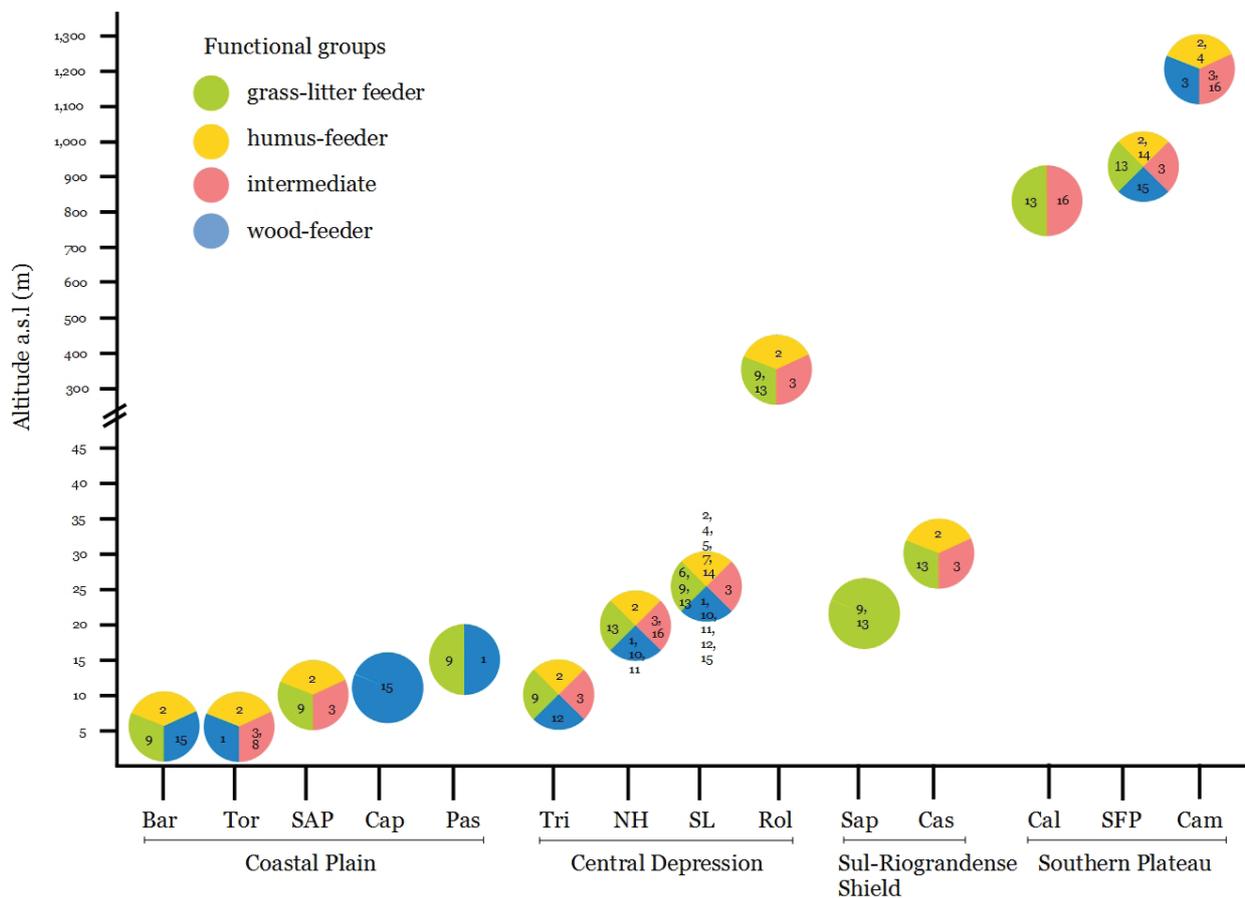
Figure 2. Richness, composition and functional groups of termite species collected in four geomorphological units of Rio Grande do Sul, Southern Brazil. [(Species: 1, *Rugitermes* sp.; 2, *Anoplotermes* sp.; 3, *Aparatermes* sp.; 4, *Grigiotermes bequaerti*; 5, *Grigiotermes* sp.; 6, *Ruptitermes* sp.; 7, *Tetimatermes* sp.; 8, *Araujotermes caissara*; 9, *Cortaritermes fulviceps*; 10, *Nasutitermes aquilinus*; 11, *Nasutitermes jaraguae*; 12, *Nasutitermes* sp.; 13, *Cornitermes cumulans*; 14, *Dihoplotermes inusitatus*; 15, *Neocapritermes* sp.; 16, *Termes* sp.). (Sampling sites: Bar, Barra do Ribeiro; Tor, Torrers; SAP, Santo Antônio da Patrulha; Cap, Capivari do Sul; Pas, Passinhos; Tri, Triunfo; NH, Novo Hamburgo; SL, São Leopoldo; Rol, Rolante; Sap, Sapucaia do Sul; Cas, Canoas; Cal, Canela; SFP, São Francisco de Paula; Cam, Cambará do Sul)].

925 and 1,500 m a.s.l., while the wood-feeding termites was between 1,550 and 1,850 m a.s.l. And this differential response led the authors to suggest that the energy requirements for each group are a key factor in shaping their occurrence associated with the altitude and temperature.

Small differences in species richness and composition among sampled sites in Rio Grande do Sul could be due to several factors such as the diversity of habitats and vegetation, altitude, and local climatic factors. However, the analysis showed no significant correlation between species richness or functional groups with the parameters (altitude and climatic variables). Thus, we suggest that the greatest influence, especially in species richness per site, has elapsed from insufficient sampling effort and the lack of repetitions, especially when the results are compared to other close regions as Argentina. There are more than 2,800 termite species in the world, of which ca. 550 species occur in the Neotropics (CONSTANTINO 2013). Estimates of termite richness for Brazil are not yet accurate, ranging from 250 to more than 360 species (CANCELLO & SCHLEMMERMEYER 1999; CONSTANTINO 1999, 2013; FONTES & ARAUJO 1999). However, the estimated species richness should increase with termite sampling in other areas of the country and, we expect, in the State of Rio Grande do Sul.

In South America, there is not enough data to support a strong diversity pattern of termites, mainly because surveys are not evenly distributed and have been carried out in regions of Guiana and Brazil, including the states of Amazon, São Paulo and Mato Grosso (EGGLETON 2000), except for some recent and significant studies (PALIN *et al.* 2011; CANCELLO *et al.* 2014). For instance, we would expect a reduction in termite richness in lower latitudes of South America based on the temperate climate of the region and on recent evidence (CANCELLO *et al.* 2014).

There must be other forces driving the termite diversity and richness apart from the latitudinal and the altitudinal gradient *per se*, for example, that the phylogenetic structure might be involved the process, especially in the temperate forests, as suggested for ants (MACHAC *et al.* 2011). Intriguing results have been found for termite in other temperate zones, as in Argentina. For example, LAFFONT *et al.* (1998) surveyed a commercial eucalyptus forest in northwestern Argentina and recorded seven genera and ten species. The same authors, in 2004, reported 15 genera and 22 species in three nature reserves in northwestern Argentina, while TORALES *et al.* (2005) recorded 31 genera and 81 species in a total of 214 locations, almost covering the entire country, which ranges from (from 22° S to 55° S).

Our results clearly differ from other published studies for temperate zones of South America. The reduced number of termite species as well the absence of relationship among the factors tested could be due to lack of taxonomists and reduced sampling effort in the region (DIEHL *et al.* 1995). Termite richness in Argentina is a good indicator of the need to increase the area surveyed, the number of sampling sites and the collection effort in the State of Rio Grande do Sul.

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