

## Taxonomic diversity of ant (Hymenoptera: Formicidae) assemblages in forest remnants in the Northeast of Argentina

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**ABSTRACT.** Argentina is among the ten countries in the world with loss of large areas of forests in recent years. Deforestation leads to an inevitable loss of biodiversity and the fragmentation of natural environments, with increased extinctions of species in small patches. Ants are present in all terrestrial ecosystems and play key ecological roles. This study aimed to analyse how ant assemblages vary in different forest remnants of the Northeast Argentina (NEA) from the approach of taxonomic diversity, which involve the linnean classifications relationships of the taxa. The ants were collected by hand collecting and pitfall trapping techniques in the forests of 15 NEA localities during the warm months in 2015-2018. In total, 600 samples, 10741 individuals and 94 ant species were obtained. In this way, 94 species distributed in 41 genera, 14 tribes and 9 subfamilies were obtained. Myrmicinae, Formicinae and Ponerinae presented the highest specific richness. The results of taxonomic distinctness ( $\Delta+$ ) and average taxonomic variation ( $\Lambda+$ ) demonstrated that all localities fell within the expected average for estimated models. The beta diversity, measured by the species dissimilarity ( $1-\beta J$ ) and taxonomic dissimilarity ( $1-\Delta T$ ), reflected in the NMDS and cluster analyses, proved that the localities in the Iberá Reserve (Corrientes), differ from the rest both in the specific composition and in the phylogenetic relationships between them. This could indicate a typical ant microfauna of the Iberá Reserve.

[Keywords: taxonomic diversity, forests, Argentina]

**RESUMEN. Diversidad taxonómica de los ensambles de hormigas (Hymenoptera: Formicidae) en remanentes de bosque del noreste argentino.** La Argentina se encuentra entre los diez países del mundo con pérdida de grandes extensiones de bosques en los últimos años. Esta deforestación conduce a una pérdida inevitable de biodiversidad y a la fragmentación de los entornos naturales, con una mayor extinción de especies en pequeños parches. Las hormigas están representadas en todos los ecosistemas terrestres y cumplen papeles ecológicos relevantes. Este estudio tuvo como objetivo analizar cómo varían los ensambles de hormigas en diferentes remanentes de bosque del noreste argentino (NEA), desde el enfoque de la diversidad taxonómica, que involucra las relaciones de clasificación linneana de los taxones. Las hormigas fueron recolectadas mediante técnicas de recolección manual y trampas *pitfall* en los bosques de 15 localidades del NEA durante los meses cálidos de 2015-2018. Se obtuvo un total de 600 muestras, 10741 individuos y 94 especies de hormigas, distribuidas en 41 géneros, 14 tribus y 9 subfamilias. Myrmicinae, Formicinae y Ponerinae presentaron la mayor riqueza específica. Los resultados de distinción taxonómica ( $\Delta+$ ) y variación taxonómica promedio ( $\Lambda+$ ) demostraron que todas las localidades se ubicaron dentro del promedio esperado. La diversidad beta medida por la disimilitud de especies ( $1-\beta J$ ) y disimilitud taxonómica ( $1-\Delta T$ ), reflejada en los análisis NMDS y *cluster*, demostró que las localidades de la Reserva Iberá (Corrientes) difieren de las demás tanto en la composición específica como en las relaciones filogenéticas entre ellos. Esto podría indicar una microfauna de hormigas típica de la Reserva Iberá.

[Palabras clave: diversidad taxonómica, bosques, Argentina]

## INTRODUCTION

The growth of human societies to the detriment of natural areas mainly due to the devastation of large areas for cultivation, livestock or construction of urban structures, is progressing unfailingly. In this context, Argentina ranks among the ten countries in the world with loss of large areas of forest between 2010-2015 (FAO 2016), with the Gran Chaco being one of the most deforested regions in the last three decades (Hoyos et al. 2012; Zak et al. 2008). This area is located in the Chaco biogeographic province, which extends through southern Bolivia, western Paraguay, southern Brazil and central northern Argentina (Morrone 2000, 2006). In addition, other provinces such as the Pampean Region, the Paraná Forest and the Araucaria Forest also converge in the Northeast Argentina (NEA) (Arana et al. 2017). Deforestation leads to an inevitable loss of biodiversity and the fragmentation of natural environments. This last phenomenon influences population dynamics by reducing the potential for dispersal and colonization of isolated populations, which are mostly extinguished in small patches (Granados-Sánchez et al. 1999). Thus, several studies show the negative effect of the fragmentation and the loss of habitat on birds, mammals and insects (Barbosa and Marquet 2002; De Angelo et al. 2011; Stratford and Stouffer 2015).

Among invertebrates, ants stand out for their abundance, high diversity and for being well represented in all terrestrial ecosystems, fulfilling important ecological roles (Agosti et al. 2000; Hölldobler and Wilson 1990). They are of great functional importance, sensitive to environmental change, and easily sampled (Majer et al. 2007; Philpott et al. 2010). Likewise, they are considered good indicators of environmental quality in monitoring programs and diversity studies (Agosti et al. 2000; Kaspari and Majer 2000).

Biodiversity has traditionally been studied using neutral diversity indices that give equal importance to all species. However, there are other possible approaches which address diversity from a functional, taxonomic, phylogenetic, genetic, evolutionary or ecological perspectives (Castro et al. 2020; Devictor et al. 2010; Schweiger et al. 2008; Silvestre et al. 2003; Villéger et al. 2011). These approaches are known as non-neutral measures of diversity (Chao et al. 2010; Laliberte et al. 2014) and allow the incorporation of some

additional aspects to the identity of the species for a more complete analysis.

Taxonomic diversity is a non-neutral measure of diversity which considers supraspecific taxonomic levels and incorporates species richness as well as information about the degree of higher-order taxonomic structure between species plot communities (Bacaro et al. 2007). According to this approach, a community will have greater taxonomic diversity if its species belong to different genera, and even more if the genera belong to different families than if they were made up of co-generic species closely related phylogenetically (Clarke and Warwick 1998; Ricotta et al. 2012). This diversity approach makes it possible to incorporate information about evolutionary history to assess the alpha and beta diversity of a community (Bacaro et al. 2007; Clarke and Warwick 1998). Taxonomic alpha diversity represents the level of relatedness between species in a community taking into account the taxonomic structure (Bacaro et al. 2007; Clarke and Warwick 1998). On the other hand, taxonomic beta diversity (taxonomic dissimilarity) is the degree of differentiation in the composition of supraspecific taxa between communities (Bacaro et al. 2007).

Although ecological factors are of vital importance in structuring communities (Bestelmeyer and Wiens 1996; Pianka 1973; Wiens 1977), this structure is also influenced by the phylogenetic relationships among taxa that make up a community, reflecting past interactions between species and their evolutionary history (Losos 1994; Webb et al. 2002). In this sense, several researchers have evaluated the influence of phylogeny on the composition of communities of different taxa (Bellini et al. 2015; Colston et al. 2010; Mesquita et al. 2006; Werneck et al. 2009), suggesting the need to consider natural history, genetic, taxonomic, and functional aspects altogether in community analyses. However, studies that evaluate taxonomic diversity of insects with the indices described are scarce in the Neotropics (García de Jesús et al. 2016) and nonexistent in Argentina. We can highlight the surveys carried out in the provinces of Corrientes (Arbino and Godoy 2001; Calcaterra et al. 2010, 2021; Larrea et al. 2022a), Chaco (Calcaterra et al. 2021; Gómez Lutz and Godoy 2010), Formosa (Calcaterra et al. 2021; Leponce et al. 2004; Theunis 2005) and Misiones (Calcaterra et al. 2021; Hanisch et al. 2015, 2017, 2018) between the most

recent studies about ant diversity in natural environments of the NEA. Likewise, surveys in the forest monocultures in Corrientes and Misiones also stand out (Santoandré et al. 2019) and citrus crops in Corrientes (Larrea et al. 2022b).

The aim of this study was to evaluate how ant assemblages vary in different forest remnants of the NEA from the approach of taxonomic diversity, which involves the Linnean classifications relationships of taxa. We hoped to get different results using both measures, traditional and taxonomic diversity indices, in the analyses of the ant assemblies. Besides we aimed to evaluate how geographical distance influence the similarity of the ant assemblages from the forests studied. We asked the following questions: 1) is there a relationship between the results obtained using measures of neutral diversity with those of taxonomic diversity?, and 2) how does geographical distance influence the similarity of the forests studied?

## MATERIALS AND METHODS

### *Field of study*

The NEA region encompasses the provinces of Misiones, Corrientes, Chaco and Formosa, with an area of 289699 km<sup>2</sup>. The forests in this region present vertical stratification, with a predominance in the woody stratum (10-12 m) of *Aspidosperma quebracho-blanco* (Apocynaceae), *Schinopsis balansae* and *S. lorentzii* (Anacardiaceae), *Vachellia caven*, *Prosopis alba*, *P. affinis* and *P. nigra* (Fabaceae); a shrub stratum (2-4 m) with a predominance of *Sarcomphalus mistol* (Rhamnaceae), *Geoffroea decorticans*, *Parkinsonia praecox*, *Vachellia aroma* and *V. caven* (Fabaceae), and an herbaceous stratum (1 m) with a predominance of Bromeliaceae (*Bromelia hieronymii*), Cactaceae (*Stetsonia coryne* and *Cereus forbesii*) and Poaceae (*Elionorus muticus* and *Bromus catharticus*) (Arana et al. 2021). These environments are currently threatened by conversion processes caused by human activities, generating the loss of forested areas and the fragmentation of natural habitats (Dinerstein et al. 1995; Volante and Seghezzo 2018).

In this region, we can observe a pluviometric gradient with significant rainfall in the east (1800 mm per year), decreasing towards the west (600 mm per year). Associated with this pattern, a thermal gradient is presented with

annual average temperatures between 18-20 °C in the east and 22 °C or higher in the west of the region (Arana et al. 2021; Ginzburg and Adamoli 2006). These gradients regulate the distribution of vegetation type and define a wide variety of environments such as palm groves, grasslands, estuaries, ravines and wooded areas (Cabrera and Willink 1980; Carnevali 1994). This complexity of the landscape provides multiple habitats that are colonized by a varied fauna of vertebrates and invertebrates. Ant collections were carried out in forest formations of 15 NEA localities (Figure 1, Table 1), included in the provinces of Chaco, Corrientes, Formosa and Misiones.

### *Ant sampling and identification*

The samplings were conducted during the months of December-February in the period 2015-2018. In the 15 localities, 200 m transects were drawn and 20 points were located along the transects, with a distance of 10 m from each other. At each point, the collection of ants was carried out using the following capture techniques: A) pitfall (it consisted of 500 mL plastic containers with 1/3 of preservative solution [propylene glycol:water, in 1:1 ratio]; traps were placed at ground level and remained active for 48 h) and B) hand collecting (an exhaustive search was executed in the soil and in vegetation at a height of 1.5 m; it was carried out by 2 people for 30 minutes). A total of 600 samples was obtained ([20 pitfall+20 hand collecting] x 15 localities).

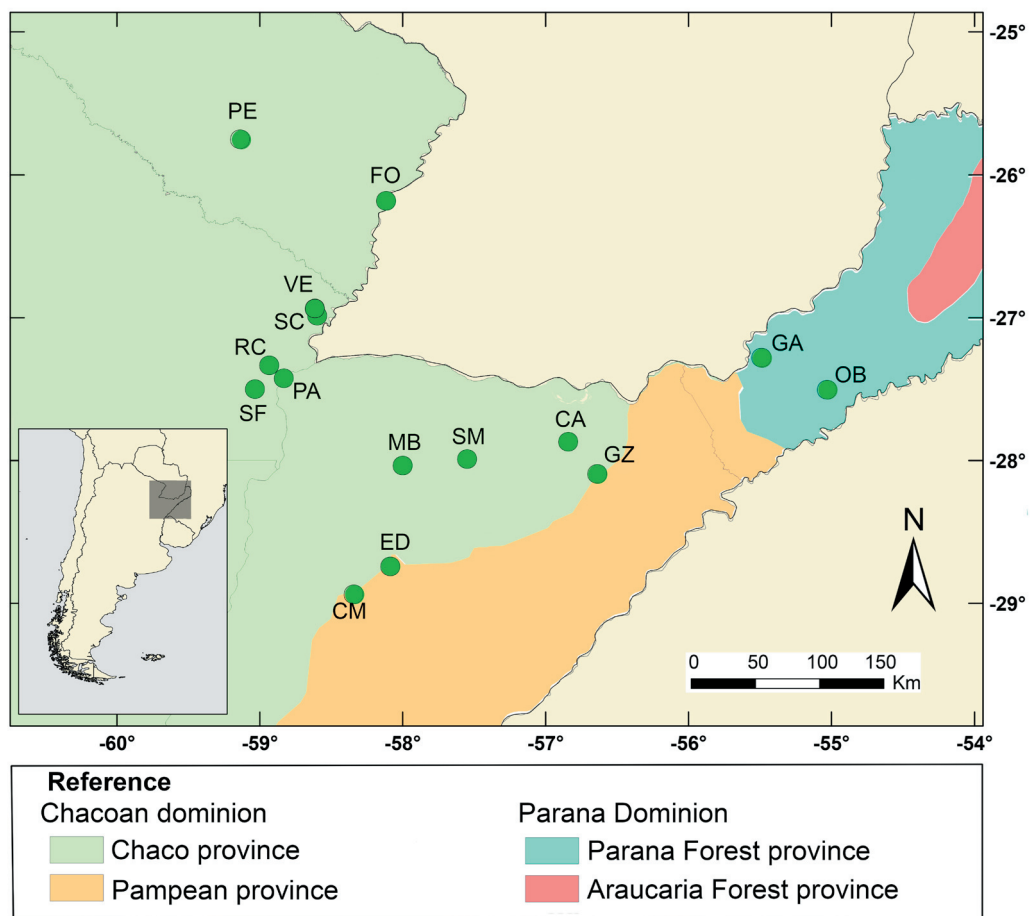
The ants were identified at a specific level through available taxonomic keys (see Supplementary Material) and by comparison with reference specimens deposited at Cátedra de Biología de los Artrópodos, Universidad Nacional del Nordeste, Corrientes, Argentina (CARTROUNNE). Voucher specimens are housed at CARTROUNNE. The catalog of ants from Argentina and Uruguay was used for the preparation of the matrices with different supra-specific taxonomic levels (subfamily, tribe, and genus) (Bolton 2022; Cuzzo and Larrea 2022).

### *Data analysis*

**Alpha diversity.** Species richness was used as a measure of neutral diversity. On the other hand, taxonomic diversity was measured with two indices. 1) The average taxonomic distinctness ( $\Delta^+$ ). This index is a measure of the degree to which the species in a sample are related taxonomically to each other, and

**Table 1.** Georeferences of the studied localities in the NEA.**Tabla 1.** Georreferencias de las localidades estudiadas en el NEA.

Province	Locality	Latitude	Longitude
Misiones	Garupá (GA)	27°17'10.1" S	55°31'25.9" W
	Oberá (OB)	27°30'22.5" S	55°04'17.3" W
Corrientes	El Dorado (ED)	28°44'25.4" S	58°07'36.4" W
	Galarza (GZ)	28°06'07.5" S	56°40'46.6" W
	Capitá Mini (CM)	28°56'23.1" S	58°22'22.6" W
	San Miguel (SM)	27°59'42.7" S	57°35'25.9" W
	Cambyretá (CA)	27°52'06.3" S	56°52'49.6" W
	Mburucuyá (MB)	28°02'25.09" S	58°02'36.2" W
	Reserva Los Chaguares (RC)	27°20'07.1" S	58°57'57.0" W
Chaco	Puerto Antequera (PA)	27°25'43.7" S	58°51'58.1" W
	San Francisco (SF)	27°30'30.2" S	59°04'53.2" W
	San Carlos (SC)	26°57'46.8" S	58°38'12.5" W
	General Vedia (VE)	26°47'33.6" S	58°44'02.2" W
	Pirané (PE)	25°45'39.08" S	59°10'03.11" W
Formosa	Formosa (FO)	26°11'23.28" S	58°09'21.1" W

**Figure 1.** Map of the Argentine Northeast. The different sampling locations (green circles) period 2015-2018. Biogeographic regions of Arana et al. (2017). See reference of acronyms in Table 1.**Figura 1.** Mapa del noreste argentino. Los diferentes lugares de muestreo (círculos verdes), periodo 2015-2018. Regiones biogeográficas de Arana et al. (2017). Ver referencia de siglas en la Tabla 1.

is defined mathematically as (Clarke and Warwick 1998):

$$\Delta^+ = \frac{\sum \sum_{i < j} \omega_{ij}}{[S(S-1)/2]}$$

where S is the number of species present and, for the double summation, i and j range over these S species. 2) The variation in taxonomic distinctness ( $\Lambda^+$ ), that is mathematically defined as:

$$\Lambda^+ = \left[ \sum_{i \neq j} (\omega_{ij} - \bar{\omega})^2 \right] / [s(s-1)]$$

This index reflects the variability of the full set of pairwise distinctness weights making up the average (Clarke and Warwick 2001). Both indices ( $\Delta^+$  and  $\Lambda^+$ ) include in their calculation the distances between the phylogenetic lineages as well as they are independent of the sample size. Besides, these can be related to functional diversity and possible anthropogenic impacts on the ecosystem (Clarke and Warwick 1998, 2001; Leonard et al. 2006). The PRIMER-E version 5 software was used to calculate these two indices of taxonomic diversity using a presence/absence matrix (Clarke and Gorley 2001).

**Beta diversity.** Dissimilarity ( $1-\beta J$ ), based on the Jaccard similarity index ( $\beta J$ ), was used for beta diversity analyses. This index takes the incidence to compare species composition between 2 communities. Jaccard similarity index ( $\beta J$ ) is defined mathematically as:

$$\beta J = \frac{a}{b + c - a}$$

Taxonomic dissimilarity was measured as  $1-\Delta T$ , where  $\Delta T$  is the taxonomic similarity index described by Bacaro et al. (2007). This last index measures the level of similarity in the taxonomic classification of two communities, including the supraspecific taxa. 'T' is defined mathematically as:

$$\Delta T = \frac{T_a}{T_b + T_c - T_a}$$

where 'T' is a normalized measure of taxonomic similarity,  $T_a$  is the number of taxonomic categories shared between 2 communities,  $T_b$  is the number of taxonomic categories in the taxonomic structure of one

community, and  $T_c$  is the number of categories in the taxonomic structure of the second community (Bacaro et al. 2007). Values of  $1-\beta J$  and  $1-\Delta T$  were used to compare the relative position of each community.

Pearson correlation analyses were performed with a significance level of 0.05. These were done to assess the existence of significant differences between taxonomic richness and diversity, and between species dissimilarity and taxonomic dissimilarity.

The specific composition of the studied environments was explored with a Nonmetric Multidimensional Scaling (NMDS) analysis. The distortion of the resolution of the two-dimensional arrangement is represented by a voltage value (stress).

The relationship between species similarity ( $\beta J$ ) and taxonomic similarity ( $\Delta T$ ) with the average linear distance in kilometers between pairs of communities was calculated to assess the influence of geographic distance on dissimilarity. The Mantel correlation was used for this analysis, with a significance level of 0.05. Pearson and Mantel correlation analyses, Jaccard similarity index and NMDS, were performed using the Past 3.0 statistical program (Hammer et al. 2001).

## RESULTS

The total of ants obtained from the samplings was 10741, belonging to 94 species distributed in 41 genera, 14 tribes and 9 subfamilies (Supplementary Material-Table S1). The subfamily with the highest species richness was Myrmicinae (33 species), followed by Formicidae (14 species) and Ponerinae (14 species).

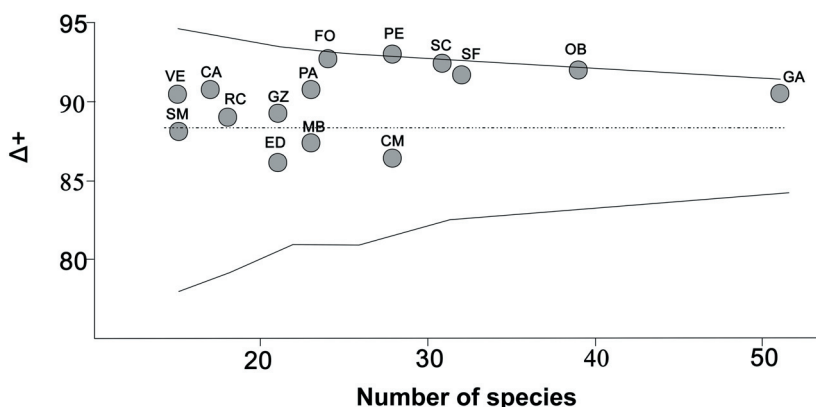
### *Alpha diversity*

Garupa presented the highest values of species richness (39 species) followed by Oberá (34 species) and San Francisco (23 species). The other areas presented lower richness values (10-34 species). These results demonstrate localities with species richness values much higher than the general average and others with much lower extreme values (Table 2). Regarding the average taxonomic distinctness values ( $\Delta^+$ ), all the localities are within the average expected by the model. Besides, most localities of Misiones, Formosa and Chaco provinces are positioned above the expected average (Figure 2), while all the

**Table 2.** Species richness (S), average taxonomic distinctness ( $\Delta+$ ) and variation in taxonomic distinctness ( $\Lambda+$ ) of the Formicidae assemblies of the studied localities in the NEA.

**Tabla 2.** Valores de riqueza de especies (S), distinción taxonómica promedio ( $\Delta+$ ) y variación en la distinción taxonómica ( $\Lambda+$ ) de los ensambles de Formicidae de las localidades estudiadas en el NEA.

Province	Locality	S	$\Delta+$	$\Lambda+$
Misiones	Garupá (GA)	39	90.67	451.12
	Oberá (OB)	34	92.17	377.33
Corrientes	El Dorado (ED)	15	86.07	570.88
	Galarza (GZ)	15	89.07	337.87
	Capita Mini (CM)	21	87.98	418.14
	San Miguel (SM)	10	87.78	461.73
	Cambyretá (CA)	12	85.61	569.33
Chaco	Mburucuyá (MB)	16	87.29	499.96
	Reserva los Chaguares (RC)	13	83.33	587.61
	Puerto Antequera (PA)	17	86.95	652.27
	San Francisco (SF)	23	92.29	360.55
	San Carlos (SC)	23	90.71	486.85
Formosa	Vedia (VE)	14	92.03	424.16
	Pirané (PE)	22	93.51	309.57
	Formosa (FO)	20	91.32	358.80
General average		19.60	89.08	457.74



**Figure 2.** Average taxonomic distinctness ( $\Delta+$ ) of the Formicidae assemblies for all the localities analyzed in NEA, with 95% confidence limits. See reference of acronyms in Table 1.

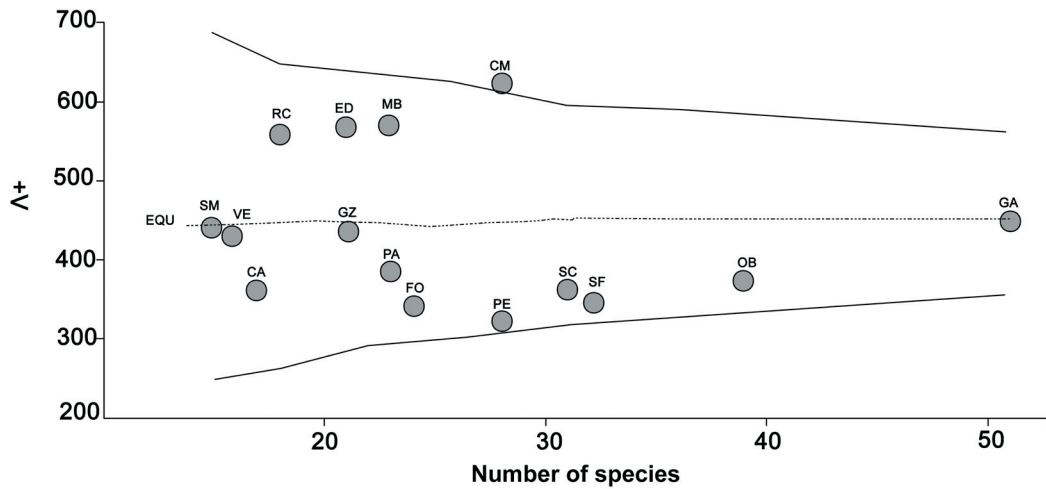
**Figura 2.** Distinción taxonómica promedio ( $\Delta+$ ) de los ensambles de Formicidae para todas las localidades analizadas del noreste argentino, con límites de confianza del 95%. Ver referencia de siglas en Tabla 1.

localities of Corrientes showed values below it, except for Galarza and Cambyretá, that presented a value slightly higher than average. In terms of values of the variation in taxonomic distinctness ( $\Lambda+$ ), all localities fell within the value expected by the model (Figure 3), except for Capitá Mini, that presented a value slightly higher. On the other hand, it was observed that in General Vedia and San Carlos, besides a high  $\Delta+$  value, the  $\Lambda+$  values were also high, above the expected average (Figures 2, 3). The correlation between species richness and  $\Delta+$  values was not statistically significant ( $r=0.29$ ;  $P>0.05$ ).

It is also noticeable in Table 2, where the community with the highest species richness (Garupa) showed low  $\Delta+$  values. It was also observed that the communities with species richness highly contrasting (S: San Miguel=10; Capitá Mini=21) registered very similar values of taxonomic diversity ( $\Delta+$ : San Miguel=87.78; Capitá Mini=87.98).

#### Beta diversity

The analysis of species dissimilarity ( $1-\beta J$ ) for the studied communities showed values

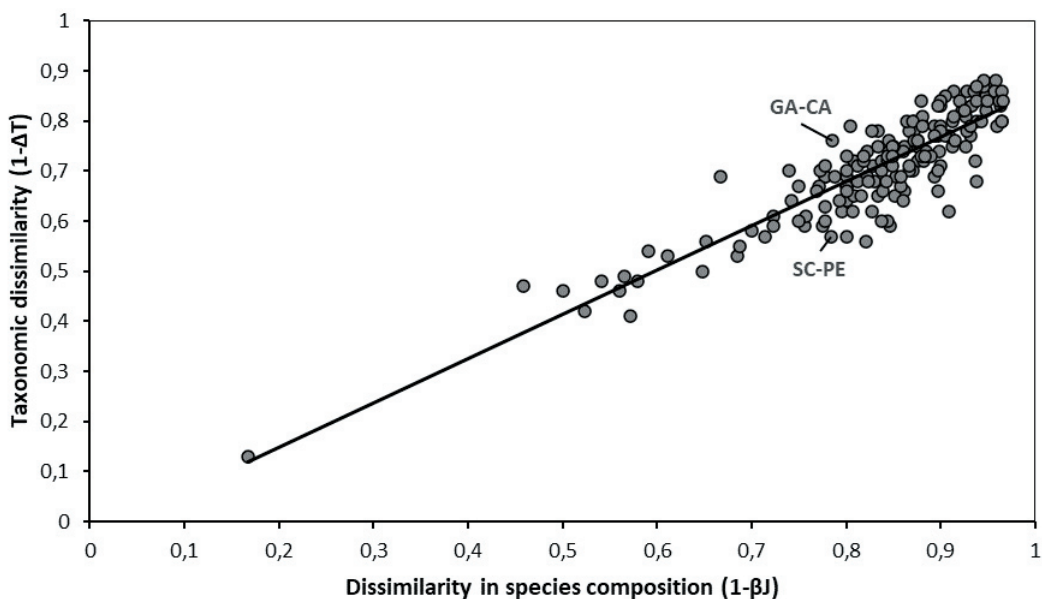


**Figure 3.** Variation in taxonomic distinctness ( $\Lambda^+$ ) of the Formicidae assemblages for all the localities analyzed in NEA, with 95% confidence limits. See reference of acronyms in Table 1.

**Figura 3.** Variación en la distinción taxonómica ( $\Lambda^+$ ) de los ensambles de Formicidae para todas las localidades analizadas del NEA, con límites de confianza del 95%. Ver referencia de siglas en Tabla 1.

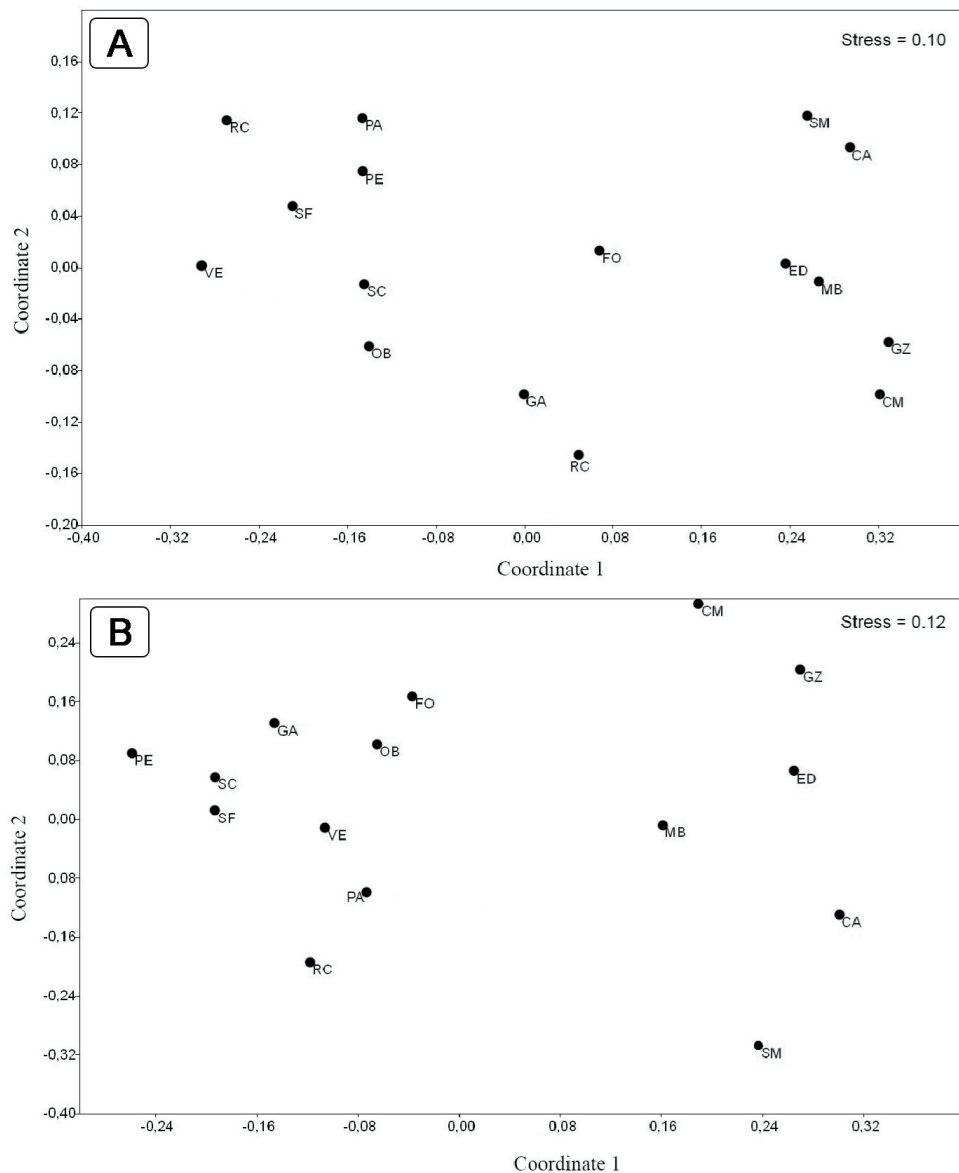
between 17 and 97%. On the other hand, the taxonomic dissimilarity ( $1-\Delta T$ ) ranged from 13 to 88%. The correlation analysis between  $1-\beta J$  and  $1-\Delta T$  was statistically significant ( $r=0.89$ ;  $P<0.05$ ) (Figure 4). Likewise, pairs of communities were observed with equal

values of  $1-\beta J$  (e.g., Garupá-Cambyretá and San Carlos-Pirané, with 78%). However, they differ in values of  $1-\Delta T$  (e.g., Garupá-Cambyretá=77%; San Carlos-Pirané=57%). NMDS analysis for  $1-\beta J$  organized three groups with a stress value of 0.1 (Figure 5A).



**Figure 4.** Relation between the dissimilarity values at the species level ( $1-\beta J$ ) and taxonomic dissimilarity ( $1-\Delta T$ ) between pairs of Formicidae communities in the NEA ( $r=0.89$ ;  $P<0.05$ ). Two pairs of communities are shown with the same species dissimilarity value but with different taxonomic dissimilarity values. Garupá (GA) and Cambyretá (CA), San Carlos (SC) and Pirané (PE).

**Figura 4.** Relación entre los valores de disimilitud a nivel de especie ( $1-\beta J$ ) y disimilitud taxonómica ( $1-\Delta T$ ) entre pares de comunidades de Formicidae en el NEA ( $r=0.89$ ;  $P<0.05$ ). Se muestran dos pares de comunidades con el mismo valor de disimilitud de especies, pero con diferentes valores de disimilitud taxonómica. Garupá (GA) y Cambyretá (CA), San Carlos (SC) y Pirané (PE).



**Figure 5.** Composition of NMS species of the ant community A) as a function of species dissimilarity (1-βJ) and B) as a function of taxonomic dissimilarity (1-ΔT) for the localities analyzed in the NEA. See reference of acronyms in Table 1.

**Figura 5.** Composición de especies NMS de la comunidad de hormigas A) en función de la disimilitud de especies (1-βJ) y B) en función de la disimilitud taxonómica (1-ΔT) para las localidades analizadas en el NEA. Ver referencia de siglas en Tabla 1.

One of them was formed by ant community of Capitá Miní, Galarza, Mburucuyá and El Dorado; another well-defined was formed by San Miguel and Cambyretá communities, and the last one was formed by the other communities (localities with greater distances between points) (Figure 5A). In the NMS analysis for 1-ΔT, two groups with a stress value of 0.12 can be observed (Figure 5B). This analysis suggests that the communities belonging to Corrientes province (Capitá Miní,

Galarza, Mburucuyá, Cambyretá, San Miguel and El Dorado) form a well-defined group. The second group is composed by the other localities. Moreover, it was observed that the taxonomic structure of several localities of Misiones was similar to those from Chaco and Formosa (Figure 5B). When comparing both NMS analyses, it is interesting to observe that some localities that were distant in terms of their specific composition presented a very similar taxonomic structure. On the other



hand, very close localities in terms of specific composition were very distant based on their taxonomic structure (Figure 5). Mantel tests showed a decrease in similarity in relation to geographic distance at species level ( $r=0.09$ ;  $P<0.05$ ) and at level of taxonomic composition ( $r=0.15$ ;  $P<0.05$ ).

If we consider the contributions of the two diversity approaches applied in this study (neutral diversity indices and taxonomic diversity indices), we can recognize three areas of interest for conservation: AREA I (characterized by presenting the localities with the highest species richness [Misiones: Garupa and Oberá]), AREA II (areas with the highest values of taxonomic diversity [Formosa: Pirané, Formosa; Chaco: San Francisco and General Vedia]), and AREA III (the localities with the most similar communities [Corrientes: Mburucuyá, San Miguel, Cambyretá, Galarza, El Dorado and Capitá Miní]).

## DISCUSSION

This is the first study that analyzes the taxonomic diversity of ant in the NEA. The number of registered species represents 13.64% of the known species for the country and 48.18% known for the Argentine Northeast (Cuezzo and Larrea 2022). The pattern of specific richness observed with high values for the Myrmicinae, Formicinae and Ponerinae subfamilies is consistent with those obtained in other studies in the region (Calcaterra et al. 2010; Hanisch et al. 2018; Leponce et al. 2004). This is due to the fact that they are the most common families with more known species to the country and the region (Cuezzo and Larrea 2022; Fernández and Sendoya 2004).

Regarding the first question asked in this study, our results indicate that there is no relationship between species richness and average taxonomic distinctness. The absence of correlation between species richness and average taxonomic distinctness found in this study correlates with the data obtained in other studies (Anu and Sabu 2007; García de Jesús et al. 2016). In this sense, average taxonomic distinctness analyses function as complementary measures for biodiversity and conservation studies. This is mainly because it takes into account the degree of relationship between species and reflects in some way their phylogenetic diversity (Clarke and Warwick 1998; Ricotta et al. 2012).

If we analyze the taxonomic structure, both showed values close to the general

average. At the same time, localities with less richness, presented greater average taxonomic distinctness such as Vedia in Chaco, San Miguel in Corrientes, Oberá in Misiones and Pirané in Formosa. Although, these sites are not conservation areas, have a greater number of representatives of high levels in taxonomic hierarchy. As a case in point, we can mention the Amblyoponinae subfamily, which was registered for Pirané, and the Heteroponerini tribe, which was registered for Oberá. Likewise, Capitá Mini, with a richness above the average of all the localities, presented low value of average taxonomic distinctness ( $\Delta^+$ ) and high value of variation in taxonomic distinctness ( $\Lambda^+$ ). Moreno et al. (2009) explain that a low  $\Delta^+$  value is due to the presence of many closely related species at a low taxonomic level (e.g., several species belonging to the same genus or family) and a high  $\Lambda^+$  to an over or under-representation of some taxonomic groups.

In this sense, in Capitá Miní, the genus *Pheidole* presented the highest number of species, which leads to its low taxonomic diversity. Similarly, the low values of average taxonomic distinctness in areas with high species richness could be attributed to the greater number of species collected in hyper diverse genera such as *Camponotus* and *Pheidole* (Pérez-Sánchez et al. 2018; Wilson 2003). We believe the low of average taxonomic distinctness in Capitá Miní is possibly due to forest degradation. This can be affirmed considering that this property was previously a purely cattle ranch until 2002 and that a few years of cattle exclusion had elapsed by the time the ants samples were taken. Likewise, some common genera in forest environments such as *Cephalotes* were not collected in Capitá Miní. This could be due to its sensitivity of these ants to the environment fragmentation and the reduction of the tree stratum. Several authors highlighted these environments are threatened by conversion processes caused by human activities (Dinerstein et al. 1995; Volante and Seghezzo 2018). These processes reduce the recovery capacity of environments and generate irreversible effects on the biodiversity of flora and fauna, affecting the provision of ecosystem goods and services (Correa Ayram et al. 2017; Pavlacky et al. 2012; Sanderson et al. 2002).

Regarding the second question asked in this study, our results indicate a correlation between species and taxonomic dissimilarity. The dissimilarity observed between the

localities was high at the species level and at the taxonomic level. These results would indicate that the proportion of shared species between the assemblies is similar to the proportion of shared supra-specific taxa. Similar patterns have been reported for other invertebrate groups (García de Jesús et al. 2016; Terlizzi et al. 2009) and for vascular plants (Qian et al. 2013). Communities with the same dissimilarity in species composition have been recorded in this study, but with a different taxonomic dissimilarity. This is because the first index ( $1-\beta_J$ ) only takes into account the species while the second also includes taxonomic levels (i.e., genus, tribe and subfamily) in its calculation and this gives it a greater advantage (Izsak and Price 2001).

The results of beta diversity showed that the localities of the Corrientes province differ from the others both in the composition of species and in the taxonomic structure. From a geological perspective, this system evidences characteristic tectonic and sedimentary processes (Orfeo 2005). These processes configured a depressed area with a slight slope where herbaceous formations predominate (APN 2017). The use of methods such as NMDS allows to obtain the first evidence of an ant microfauna of the province of Corrientes, Argentina. This reflects the need to expand the studies by means of analyses that contemplate species phylogeny more precisely (such as cladistics biogeography or phylogenetic diversity), as well as studies that reveal whether the observed patterns are due to evolutionary history, adaptations, current conditions or a combination of both. Nonetheless, it should be pointed out that although the clusters obtained in the NMDS reflect the differences between communities due to environmental gradients and spatial variations in habitats, this test is not enough. It is not able to distinguish if these differences are presented due to ecological similarity between the studied localities or if they reflect a common geological history. Apart from that, it was observed that geographical distance is a factor that influenced the dissimilarity at the species level and at the level of the taxonomic structure, on the spatial scale of this study.

This variation in similarity along a spatial gradient has already been reported in other similar studies (Bacaro et al. 2009; Bishop et al. 2015; Fisher 1999; Vasconcelos et al. 2010). The decrease in similarity in species composition may be due to a decrease in environmental similarity with distance, that is, a change in the available niches (Calderón-Patrón et al. 2012; Nekola and Brown 2007). Another possible explanation for this decrease in similarity may be due to special barriers between environments that produce isolation (Bacaro et al. 2012; Nekola and White 1999; Nekola and Brown 2007). For his part, Hubbell (2011) proposes random dispersion and ecological drift as an answer for this decrease in similarity respect to distance. Recognizing these variations in the alpha and beta diversity of the assemblages provides us with essential information for the definition of areas of interest for conservation (Brooks et al. 2006; Pereira Gomes et al. 2020; Winter et al. 2013). It was suggested that taxonomic and phylogenetic diversity is relevant for conservation objectives since it may reflect processes such as extinction, biotic invasion, taxon rarity and even ecosystem services (Dubois 2003; Forest et al. 2007; Srivastava et al. 2012; Winter et al. 2013). In this study, taxonomic diversity made it possible to recognize areas that are not evident with other approaches to diversity (e.g., AREA II). This demonstrates the importance of using non-neutral indices, such as taxonomic diversity, that can be used to define priority areas for conservation. As taxonomic diversity provides additional information about taxa, not only the species richness or composition, but also about the family relations, and the taxonomic structure between among species plots.

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