

Research Article

Bird community diversity in three habitat types in an ecological corridor in the Atlantic Forest of Misiones province, Argentina

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Abstract

The Atlantic Forest is one of the most threatened biodiversity hotspots in the world due to habitat fragmentation. Restoration and connectivity of forest fragments are crucial to maintain viable populations of forest-dependent species. During winter and summer, we studied the bird diversity, its components and composition (including specialist and generalist species) in three different vegetation types: mature forest (MF), secondary forest (SF) and grassland (G) of an ecological corridor in Misiones, Argentina. We determined the influence of alpha diversity (of each habitat) and beta diversity (species turnover between habitats) on gamma diversity (regional diversity in the corridor), to provide conservation management recommendations. MF showed the highest values of bird diversity, richness, evenness and abundance, followed by SF and G, in both seasons. Only MF showed a possible seasonal variation in diversity and richness. The species composition of SF was similar to MF. However, G, where pasture specialist and edge species were the most common species recorded (70% of its avifauna), had very low similarity to MF, where the most forest specialist species were found (53%). As alpha diversities were higher than beta values, the bird diversity in the studied corridor mainly resulted from the diversity in each vegetation type, in both studied seasons. We therefore recommend preservation of both MF and recovering SF due to their high bird diversity and the presence of forest-dependent, threatened and endemic bird species. We also urge the creation of ecological corridors between protected forest remnants of the Atlantic Forest.

Keywords: alpha, beta and gamma diversity, ecological restoration, South America.

Resumen

El Bosque Atlántico es uno de los hotspots de diversidad más amenazados mundialmente debido a la fragmentación del hábitat. Por ello, la restauración y la conectividad de fragmentos de bosques mantienen poblaciones viables de especies dependientes de bosques. Durante invierno y verano, estudiamos la diversidad de aves, sus componentes y composición (especies especialistas y generalistas) en tres tipos de vegetación: bosque maduro (BM), bosque secundario (BS) y pastizal (P) de un corredor biológico de Misiones, Argentina. Determinamos la influencia de las diversidades alfa (de cada hábitat) y beta (recambio de especies entre hábitats) sobre la diversidad gama (diversidad del corredor), para proveer recomendaciones de manejo para la conservación. BM mostró valores altos de diversidad, riqueza, equitatividad y abundancia de aves, seguido por BS y P, en ambas estaciones. Solo BM presentó una posible variación temporal en su diversidad y riqueza. La composición de especies del BS fue similar al BM, sin embargo P, donde las especies especialistas de pastizales y de borde fueron las más registradas (70% de su avifauna), tuvo una muy baja similitud con BM, donde gran parte de las especies encontradas fueron especialistas de bosques (53%). Como la diversidad alfa fue mayor que la de beta, la diversidad de aves del corredor (gama) resultó principalmente de la diversidad de cada tipo de vegetación. Por lo tanto, recomendamos la preservación de BM y BS en recuperación debido a su alta diversidad de aves y a la presencia de especies dependientes de bosques, endémicas y amenazadas. Además, recomendamos la creación de corredores biológicos que conecten los parches remanentes del Bosque Atlántico.

Palabras clave: diversidad alfa, beta y gama, restauración ecológica, Sudamérica.

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Introduction

The Atlantic Forest ecoregion in southeast Brazil, eastern Paraguay, and northeastern Argentina, is one of the biogeographic regions with the highest diversity in the world [1-3]. However, it is now critically threatened by increased anthropogenic pressure, such as selective logging and agricultural expansion (the most important human activities in this region) [2-4]. This ecoregion includes the Upper Paraná Atlantic Forest, which originally covered an area of 81 million hectares in southern Brazil, eastern Paraguay, and northeastern Argentina (province of Misiones). At present, only 5% of the original forest remains intact, and the degree of forest conservation and fragmentation differs among countries. Brazil and Paraguay are critically affected, while 50% of the original area remains in Argentina [5, 6]. Nevertheless, this scenario is changing rapidly in the Argentine province of Misiones, where the Paranaense Forest (*sensu* Cabrera [7]) has undergone intense deforestation in recent decades [4, 2], fragmenting the landscape with forest patches in different degrees of alteration [2, 5, 8]. A major forest nucleus in the Atlantic Forest is formed by the connected protected areas of Iguacu National Park in Brazil, Iguazú National Park, and Uruguá-í Provincial Park in Argentina (Fig. 1). At the southeast of this nucleus an ecological corridor links Uruguá-í Provincial Park to Horacio Foerster Provincial Park (hence forth ECU-F) (Fig. 1). This corridor was created to preserve or restore the connectivity between the provincial parks because the site is crossed by several roadways, bringing associated urbanization, deforestation, fragmentation and resource extraction [6]. The goal of ECU-F is to restore the structure and functioning of native humid forests in areas that were converted to pasture or cropland and then abandoned, as well as in deforested stream margins and selectively logged forests, and to provide bridge habitat between the large forest areas of the provincial parks. These ecological restoration practices contribute to biodiversity conservation through the regeneration of the original habitats supporting biodiversity [9-10]. As modification and restoration of vegetation structure can cause changes in some populations of animal species, particularly in birds, assessing the contribution of different habitats to regional diversity is important [11-13].

Misiones (particularly the Atlantic Forest of Argentina) is one of the areas of highest bird diversity in Argentina [14], providing suitable habitat for several endemic species [15-16] that are of major conservation concern, at both global and national levels [17-18]. Nevertheless, research involving birds has been primarily descriptive (point records of species distribution, checklists, and scattered natural

history data), and only a few studies evaluate bird diversity patterns and their underlying causes in this region and in tropical forest [2, 6, 19-20]. Among them, some studies analyzed the effects on bird communities of forest fragmentation and habitat loss caused by human activity [21-25] and general patterns of land use [11-13, 26-31]. These studies showed that the loss of structural components of old-growth forest (such as old living trees and logs) reduces bird richness and changes the composition of bird communities [11, 13, 31], which is related to species' dependency on forested habitats [25, 31]. Therefore, the most transformed habitat would have low bird richness and a composition of generalist bird species or non-forest-dependent bird species. Forest-dependent, endemic and threatened bird species are strongly affected by fragmentation [26, 31]. Their vulnerability to fragmentation creates a need to conserve large remnants of native forest to preserve the high biodiversity of Atlantic Forest birds [26]. Ecological corridors are a useful conservation strategy to provide functional connectivity between forest remnants and increase their biodiversity, but there have not been many studies of biodiversity in ecological corridors in the tropics and subtropics [32-33].

As at a regional scale, the ecological corridor has a variable number of habitat types that combine into a heterogeneous landscape. The study of alpha, beta and gamma components of the diversity are useful for measuring and monitoring the effects of human activities on biodiversity, such as fragmentation [34-36]. Studying the relationships and the factors that determine the structure and composition of bird communities provides helpful information about the alteration of the environment and species populations by human activities [37]. The study of bird community attributes can reveal the variation of local diversity (alpha diversity) and the complement of species composition among sites within the region (beta diversity), and how these diversities contribute to regional diversity (gamma diversity) [35, 37]. The influence of alpha and beta diversities on gamma diversity is an essential aspect of local and landscape level conservation plans [38]. The relationship of alpha and beta diversities with gamma diversity in a modified landscape depends on its homogeneity [35, 38]. In fragmented or heterogeneous tropical landscapes the number of species (related to gamma diversity) is superior to that observed in the richest of these habitats (alpha diversity), due to a strong complement between different habitat types (beta diversity) [35, 38].

In this study, we provide a thorough description of the bird community in the ECU-F, based on its main attributes (specific composition, richness, abundance, and evenness), taking into account the concept of alpha, beta and gamma diversity [34-35]. Our objectives were to compare how well the main habitat types in the ecological corridor provide habitat suitable for bird diversity, and the influence of alpha and beta diversities on gamma diversity. We evaluate the composition of each habitat by determining the number of generalist and specialist species. The study includes contrasting climate conditions (winter and summer), to determine whether there is a seasonal variation in alpha, beta and gamma diversities, mainly from the presence of bird migrant species. Finally, we provide management recommendations for preserving biodiversity in the studied corridor and in the surrounding area.

Methods

Study area

The Ecological Corridor Urugua-í – Foerster (ECU-F) covers an area of 1,500 ha, located in the northeast of the province of Misiones, Argentina (25° 53'S and 53° 56'W) (Fig.1). The climate is subtropical, with annual mean temperatures ranging between 16 and 22 °C and high annual variation, where frost is common during winter [4]. The mean precipitation is between 1,000 and 2,000 mm, distributed throughout the year [4]. The ECU-F is composed of a mosaic of populated areas with small cultivated plots of cassava, citrus fruits, and yerba mate, pasture lands, and public and private protected areas. Thus, the ECU-F consists mainly of three habitats or vegetation types in different stages of restoration.

About 63% of the area is covered by a well-conserved mature forest (MF), characterized by four tree strata: the upper one has trees of 20-30 m in height such as Rosewood (*Aspidosperma polyneuron*), Copperpod (*Peltophorum dubium*) and Cedar (*Cedrela fissilis*) and a dense understory of bamboos and ferns [7, 18]. Palm trees (e. g. Queen palm tree (*Syagrus romanzoffiana*) and Assani palm tree (*Euterpe edulis*)) and epiphytes are also important vegetation components. The secondary forest (SF), an intermediate succession stage, occupies 7.5% of the area. It is characterized by typical pioneer tree species of the Atlantic Forest, such as Woolly nightshade (*Solanum granulosum-leprosum*) and Florida trema (*Trema micrantha*), approximately 80% of bare soil, and a second lower stratum of shrubs (e. g. "Chilca" (*Baccharis* sp) and "Mata-campo" (*Mikania cordifolia*)). Finally, the grassland (G) occupies 11% of the area and shows the highest degree of anthropogenic transformation, dominated by the exotic Giant star grass (*Cynodon plectostachyus*). The remaining part of the corridor (18.5%) is an artificial lake and populated areas.



Fig. 1: Geographic location of the studied Ecological Corridor Urugua-í – Foerster (box), between the Provincial Parks of Urugua-í (84,000 ha) and Foerster (5,000 ha) in Misiones province, Argentina.

Sampling design and data collection

We used the point-counts technique [39] to carry out field surveys based on sightings and audio recordings of birds [40-42] during the first four hours after dawn, and the two hours before sunset [43, 44]. Counts were made during two contrasting seasons: winter (July 2012) and summer (January 2013), in the predominant vegetation types: G, SF and MF. In total, sixty sampling sites were randomly selected based on the surface area occupied by each vegetation type ($N=41$ for MF, $N= 9$ for SF and $N= 10$ for G), separated by a distance of at least 250 m to ensure independence among observations. Because most of the contacts in Atlantic Forest ecosystems are heard but not seen due to dense vegetation [45], all birds seen and heard during 10 minutes, in an unlimited radius both in MF and SF and within a fixed radius of about 25 m in G, were recorded [39, 41, 46] once per season. Bird species were identified following bird field identification guides, such as Narosky and Yzurieta [47], Ridgely and Tudor [48] and Rodríguez Mata et al. [49]. At each sampling station, bird songs were tape-recorded, using a Zoom H1 recorder, to identify unidentified bird

vocalizations, mainly in forested areas [42, 43, 50]. Only diurnal species were recorded, and birds that were flying over or through the survey area were not counted.

Estimation of community attributes

We considered the diversity components alpha, beta and gamma to analyze changes in bird diversity related to landscape structure [34, 35]. At alpha level, first we calculated the expected number of species with the rarefaction method using EstimateS 8.2 [51], to compare qualitatively bird richness among vegetation types at different sample sizes.

Second, we estimated the mean alpha diversity per vegetation type using the series of diversity numbers of Hill, which transform the values of diversity indices of Shannon-Wiener (H') and Simpson (λ) in unit of number of species [52]. The numbers $N1$ and $N2$ are a measure of the number of species in the sample (the number of abundant species and very abundant species in the sample, respectively) where each species is weighted by its abundance, giving a clear idea of dominance and/or evenness of the community [34]. Therefore, they are highly recommended as the easiest to make comparisons and interpret ecologically [34, 52]. We estimated the mean alpha diversity in conjunction with the mean specific richness, mean evenness (estimated by the Hill's ratio), and mean abundance of species (estimated as the average number of individuals observed in each habitat type).

To analyze the bird composition of the studied ecological corridor, we classified the species by their forest and grassland dependence in four categories: 1) forest specialist (species that are mostly found in the interior of native forest); 2) generalist (species that are found in many forest types and disturbed forest); 3) edge species (species adapted to borders and open areas); and 4) grassland specialist (species that are found only in pasture areas), following Marini [53], Aleixo [54] and Marino [55].

Beta diversity was calculated using the Jaccard's similarity index (qualitative) and Sørensen's index (qualitative and quantitative) [34, 52], in order to determine the degree of differentiation of diversity or species turnover among vegetation types, including both the species abundance and the presence-absence of species.

Regional diversity (gamma) was estimated through the indices proposed by Lande [56], based on diversity indices of Shannon-Wiener and Simpson. These indices divide gamma diversity in two additive components: the diversity of each vegetation type or habitat (alpha) and diversity between vegetation types or habitats (beta) [34, 56].

Data analysis

The community attributes at alpha level ($N1$ and $N2$ diversity, richness, evenness, and abundance) were statistically compared for each vegetation type in each season using a variance analysis with General Linear Models (GLM) [57-58]. The global statistical model, which has vegetation types, seasons, and their interaction as fixed effect, and sampling sites as random effect, were used for each community attribute to analyze statistically: 1) a possible seasonal variation in each vegetation type; 2) a probable variation among vegetation types; and 3) a probable seasonal variation. We compared different types of this model, modeling its variance indifferent ways (heteroscedasticity modeling). Akaike Information Criterion (AIC) was used to choose the "optimal" model, since it is the criterion commonly used in ecology [59-60]. Also, the likelihood ratio test was used to compare statistically the "optimal" model with the variance homogeneous model (similar to a classic ANOVA). In all cases, assumptions of normality and homogeneity of variances were checked using QQ-plots and Pearson's conditional residuals [59]. When results of the optimal statistical analysis were significantly different ($p < 0.05$), comparisons among vegetation types

within and between seasons were made by Fisher's least significant difference (LSD) test. All analyses were performed using the InfoStat software [61] via an interface with the statistical software package R [62].

Results

We recorded a total of 1,207 individual birds (representing 123 species). A total of 104 species were found in MF, 45 in SF and 20 in G (Appendix 1). The rarefaction curves showed that the expected bird richness, at the same sampling size, present a pattern where MF has the highest bird richness, with expected species numbers of 42.6 and 48.8 during summer and winter respectively, followed by SF, with expected species numbers of 27 and 32. G has the lowest bird richness with expected species numbers of 15.7 and 12.6 (Fig. 2). The mean alpha diversity and its components (mean richness, mean evenness and mean abundance) showed a similar pattern as well in both seasons, with MF reaching the highest values, followed by SF and G (Figs. 3–4).

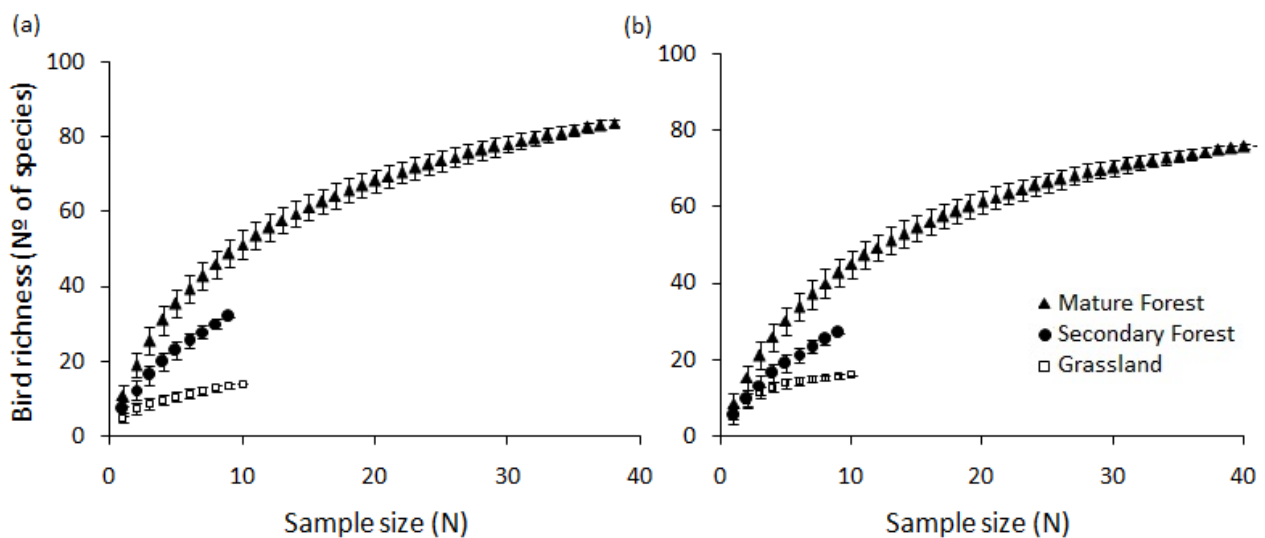


Fig. 2: Rarefaction curves based on the expected number of bird species for the three studied vegetation types \pm SD during winter (a) and summer (b), in the Ecological Corridor Urugua-í – Foerster, Argentina.

The “optimal” model selected with GLM (Appendix 2) found significant differences, mainly between MF and G in N1 and N2 diversities (AIC = 608.83, $F_{2,56} = 3.95$, $p = 0.0248$ and AIC = 692.72, $F_{2,38} = 3.26$, $p = 0.0300$, respectively) and mean richness (AIC = 639.75, $F_{2,56} = 3.57$, $p = 0.0348$), in both studied seasons (Fig. 3). The mean evenness was relatively high in each vegetation type, and significant differences were found between MF and G (AIC = 245.66, $F_{2,54} = 4.87$, $p = 0.0118$), regardless of the season (Fig. 4a). Fifty-seven species were forest specialist species (55 of them were found in MF and 15 in SF), 48 generalist (44 were found in MF, 25 in SF, and six in G), 11 edge species (five were found in MF, five in SF and seven in G) and seven grassland specialist species (all of them in G) (Appendix 1). The mean abundance presented significant differences between MF and the other two studied vegetation types (AIC = 767.03, $F_{2,57} = 3.81$, $p = 0.0281$) (Fig. 4b).

A possible seasonal variation in bird diversity was obtained (AIC = 608.83, $F_{2,56} = 3.95$, $p = 0.0248$ and AIC = 692.72, $F_{2,38} = 3.26$, $p = 0.0300$ to N1 and N2 respectively), but this variation was observed only in the most diverse vegetation type, MF, which had high values during winter (Fig. 3a–3b). The same result was

obtained for the mean bird richness (AIC = 639.75, $F_{2,56} = 3.57$, $p = 0.0348$), in which SF showed a possible temporal variation as well (AIC = 639.75, $F_{2,56} = 3.57$, $p = 0.0348$) (Fig. 3c). Nevertheless, the bird mean evenness and mean abundance did not show a seasonal variation (AIC = 245.66, $F_{2,37} = 2.08$, $p = 0.1392$ and AIC = 767.03, $F_{2,56} = 0.98$, $p = 0.3818$, respectively).

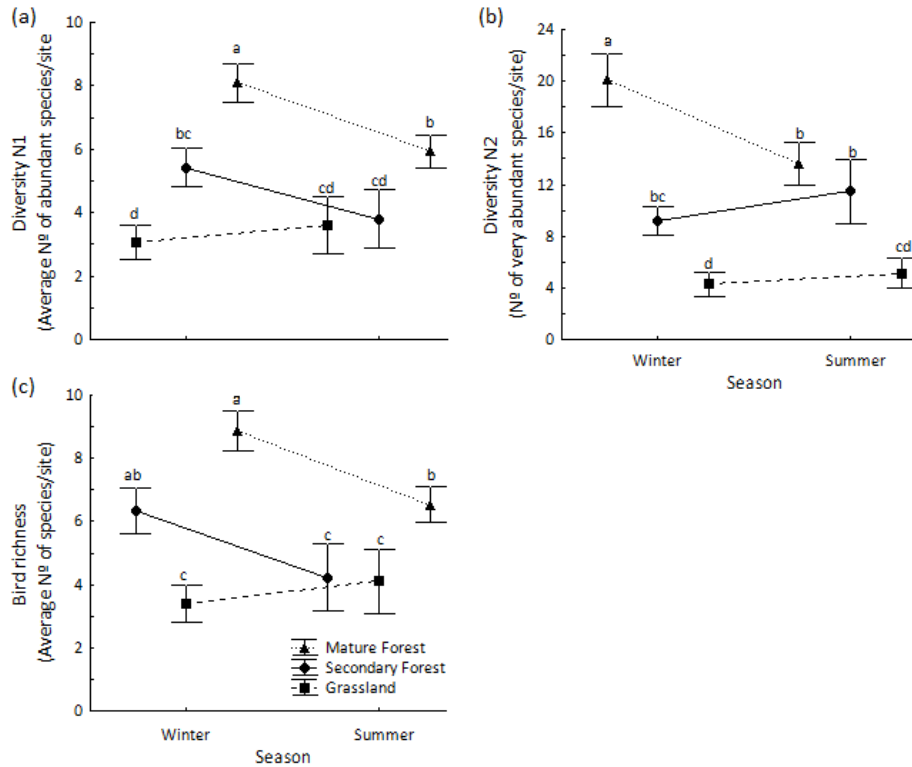


Fig. 3: Values of mean alpha diversities N1 (a) and N2 (b), and mean bird richness (c) ± SE estimated in each studied vegetation type in each contrasting season: winter and summer, in the Ecological Corridor Urugua-í – Foerster, Argentina. Means with same letter are not significantly different ($p > 0.05$).

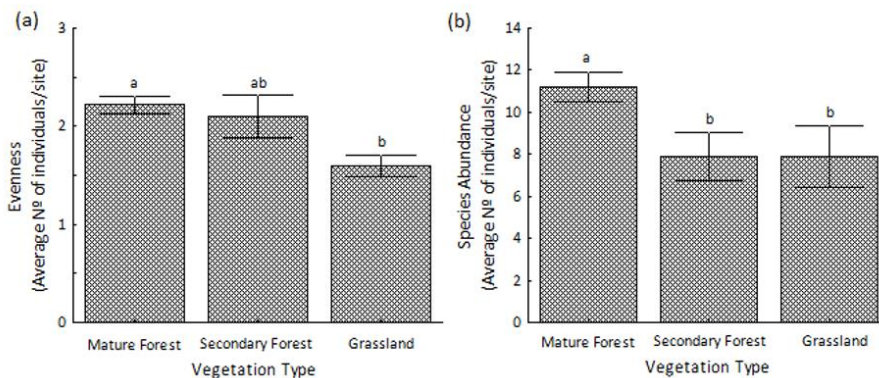


Fig. 4: Values of community attributes at alpha level of mean evenness (a) and mean species abundance (b) ± SE, estimated for each studied vegetation type regardless of the season, in the Ecological Corridor Urugua-í – Foerster, Argentina. Means with same letter are not significantly different ($p > 0.05$).

At beta level, G and MF were the vegetation types with highest difference, or lowest degree of similarity in bird species and relative abundance, in all coefficients of similarity estimated in both seasons (Table 1). G shared 4.2% of species (five out of 119 species) with MF, and 10.2% of species (six out of 59 species) with SF, regardless of season. Otherwise, the most similar vegetation types were MF and SF, though not markedly, sharing 35.4% of species (39 out of 110 species), regardless of season (Table 1).

Table 1. Coefficients of similarity estimated, as beta diversity, among the three studied vegetation types: mature forest (MF), secondary forest (SF) and grassland (G), for the two contrasting seasons, in the Ecological Corridor Uruguay-í – Foerster, Argentina.

Season	Vegetation type	Jaccard	Sørensen qualitative	Sørensen quantitative
Winter	G – SF	0.125	0.222	0.074
	G – MF	0.020	0.040	0.017
	SF – MF	0.258	0.410	0.254
Summer	G – SF	0.048	0.093	0.102
	G – MF	0.033	0.065	0.058
	SF – MF	0.303	0.466	0.213

At landscape level (gamma), we found higher values in alpha diversity than beta diversity in both seasons (Table 2). The Shannon index suggested that gamma diversity is particularly affected by alpha diversity (about 85%), and to a lesser extent, by beta diversity (15%) in both winter and summer. Simpson index values showed a similar trend, with alpha and beta diversity contributing 98% and about 2% to gamma diversity, respectively (Table 2). Seasonal variation in alpha, beta and gamma diversities apparently was not observed (Table 2).

Table 2. Values of alpha, beta and gamma diversities based on Shannon index (H') and Simpson index (λ'), for the two studied contrasting seasons, in the Ecological Corridor Uruguay-í – Foerster (Misiones, Argentina). Also, the contribution of alpha and beta diversities to gamma diversity is shown in percentage for each index estimated.

Season	Diversity	H'	H' (%)	λ'	λ' (%)
Winter	Alpha	3.01	84.79	0.92	97.87
	Beta	0.54	15.21	0.02	2.13
	Gamma	3.55		0.94	
Summer	Alpha	3.17	86.38	0.95	98.96
	Beta	0.50	13.62	0.01	1.04
	Gamma	3.67		0.96	

Discussion

The bird diversity pattern that we found in the Ecological Corridor Urugua-í– Foerster (ECU-F) is congruent with the gradient of vegetation conditions, determined by the three characteristic vegetation types described. These vegetation types, or habitat types for birds, represent different levels of anthropogenic disturbance or successional stages of the mature forest under restoration: mature forest (MF), secondary forest (SF) and grassland (G). This pattern is caused by variation in bird specific richness and evenness. The structure and heterogeneity of vegetation, as well as its vertical stratification in the different vegetation types, seem to be the most important factors influencing the diversity pattern of birds, as some authors propose [63–65]. In the ECU-F, this is reflected mainly in the differences between G and MF, with the latter showing the highest internal heterogeneity not only by its greater variety in types and composition of components, but also by its functional and structural relationships both vertically and horizontally, providing greater structural complexity [4, 6] and higher bird diversity.

However, the differences in diversity mainly between MF and SF probably are best explained by the loss of structural components that reduce complexity. The loss of bird richness is mainly due to the loss of specialist or forest-dependent species, which are the most sensitive to the replacement of natural forest [54]. The most forest specialist species were found in the MF (53% of its avifauna), whereas the bird assemblage of SF was composed mainly of generalist species (55% of its avifauna) and forest specialist species (33%) (Appendix 1). Similarly, other studies in the Atlantic Forest of Argentina [26, 31] showed that the observed decline in bird richness was related to species dependence in forested habitats to differences among forest habitat types [31], and to different area sizes of native forest fragments [26]. We recorded 33 endemic species, of which 27 are forest specialist and three are endemic and globally threatened: Helmeted woodpecker (*Dryocopus galeatus*), Blackish-Blue Seedeater (*Amaurospiza moesta*) and Southern Bristle-Tyrant (*Phylloscartes eximius*) [66].

The evenness contributes to the diversity pattern obtained, as stated above. We found high values of this community attribute in MF and in second place in SF, where two or more species co-dominate in the community (e. g. White-rimmed Warbler (*Basileuterus leucoblepharus*) and Plush-crested Jay (*Cyanococorax chrysops*)). In contrast, G had a lower value, and few bird species dominate in this habitat (e. g. Smooth-billed Ani (*Crotophaga ani*)) (Appendix 1).

The possible seasonal variation in alpha diversity (N1 and N2), mainly in the MF, reflects a potential dependence on the diversity with the season. In other words, the values of bird diversity vary between winter and summer, showing high values during winter in the mature forest. This variation is probably due to changes in richness, which showed a temporal variation as well. However, this change in richness is not due to the presence of migrant species. When the species composition is analyzed, it shows that migrant species, such as Greater Ani (*Crotophaga major*), Black-crowned Tityra (*Tityra inquisitor*), Fork-tailed Flycatcher (*Tyrannus savanna*) and Boat-billed Flycatcher (*Megarhynchus pitangua*) are relative few compared to resident species. These birds nest in spring-summer and migrate north during autumn. In contrast, we found high values of richness during the most unfavorable season, perhaps because in winter many species search for the favorable shelter conditions provided by a more forested or dense vegetation type. Moreover, in winter they congregate in mixed-species flocks for foraging, concentrating more species in one sample.

At beta level, first of all, we found that results coincide with those found at alpha level or local scale. Thus, the highest difference in species composition was between MF and G, suggesting that each habitat has its

own bird species composition, while SF and MF were the most similar, regardless of the season. Second, because beta diversity is related to environmental heterogeneity, we expected higher values in tropical fragmented landscapes because of the dissimilarity of habitats [35, 38]. On the contrary, we found lower values (compared with alpha diversity), which are probably because there are more forest-dependent than forest-generalist bird species [37]. In addition, the mature forest is a large fragment of continuous forest that is in contact with the Horacio Foerster and Urugua-í Provincial Parks, providing a more homogeneous area for birds in the studied ecological corridor.

The gamma diversity of birds seemed to be more affected by alpha diversities than by the beta component, contrary to other studies [35, 37] in which regional or landscape diversity of tropical or fragmented forests was mainly determined by beta diversity both in birds [37] and in some mammals [35]. However, as some authors propose [35, 37, 38], this relationship seems to depend not only on the scale, but in the response to habitat variability and to the dispersal capacity of the studied taxonomic group. For example, a study of bats conducted in a fragmented landscape of Latin American rainforest found that regional diversity depends on local diversity [38], as in our study. Thus, the MF, with higher richness, was likely to make the greatest contribution to regional diversity, followed by SF and finally by G. In SF we found the some but not all of the same species as in MF. The G showed species totally different from the most preserved habitat, which would increase the regional bird diversity as well. This result is expected in homogeneous landscapes or where anthropogenic changes have impoverished the original habitat type [38]. Therefore, the studied ecological corridor, an area with different vegetation types or habitats, is in fact a homogeneous area for birds.

Although it was not statistically tested, this trend appeared to be similar in both winter and summer. Consequently, the MF (like other types of recovered forests) provides habitat suitability, potentially including connectivity, to the largest number of birds. Although this study was conducted at a local level and represents a small area of the Atlantic Forest, our results have implications for future conservation plans in other areas of the Atlantic Forest ecoregion.

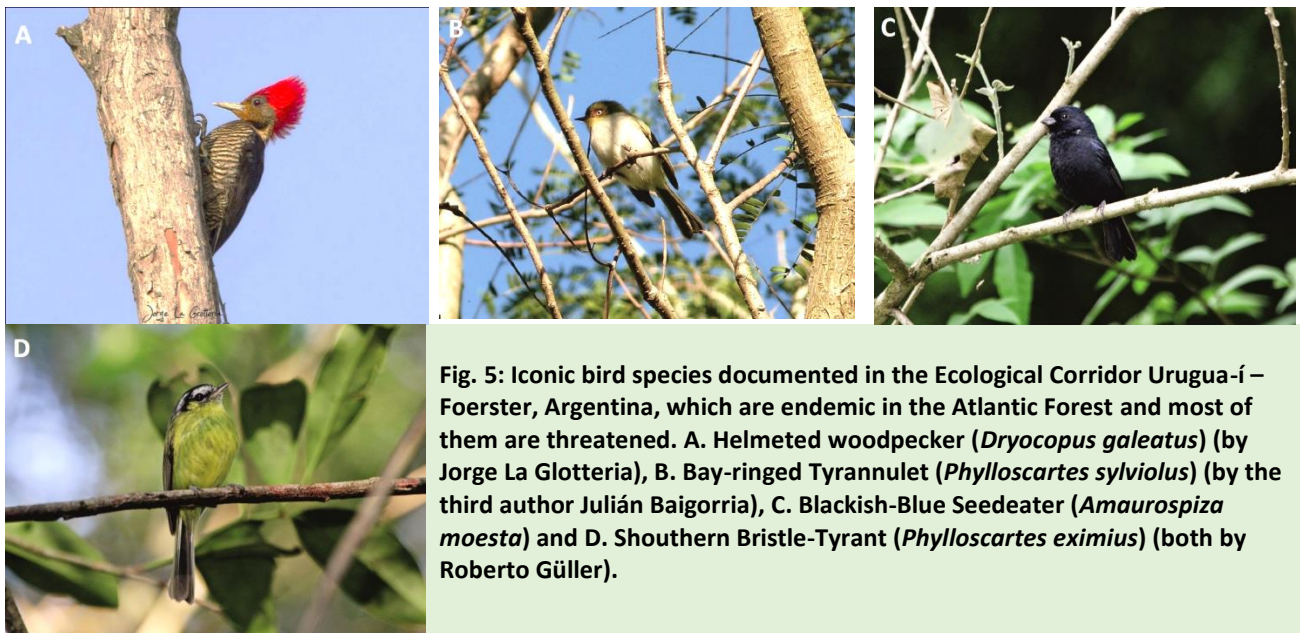


Fig. 5: Iconic bird species documented in the Ecological Corridor Urugua-í – Foerster, Argentina, which are endemic in the Atlantic Forest and most of them are threatened. A. Helmeted woodpecker (*Dryocopus galeatus*) (by Jorge La Glotteria), B. Bay-ringed Tyrannulet (*Phylloscartes sylviolus*) (by the third author Julián Baigorria), C. Blackish-Blue Seedeater (*Amaurospiza moesta*) and D. Shouthern Bristle-Tyrant (*Phylloscartes eximius*) (both by Roberto Güller).

Implication for conservation

The ECU-F showed a high richness of birds, including an important number of endemic species of the Atlantic Forest, some of which are forest specialists and globally threatened (e. g. Helmeted woodpecker (*Dryocopus galeatus*), Blackish-Blue Seedeater (*Amaurospiza moesta*) and Southern Bristle-Tyrant (*Phylloscartes eximius*)) (Fig. 5). Our results confirm the great need for conservation of both secondary and native forest in this area and other tropical forest fragments of Atlantic Forest subjected to anthropogenic activities such as selective logging and agriculture.

Our results point to alpha diversity as the main component to be preserved for maintaining species diversity in the ECU-F, with particular focus on the MF due to its high values in this parameter and in bird richness. Furthermore, MF (and other degrees of recovered forests) should be especially considered in management plans for the Atlantic Forest, first because it has several forest specialist bird species, most of them endemic and some threatened. Second, it is the most threatened environment due to past and current anthropogenic activities.

Ecological corridors increase the functional connectivity between protected remnants of habitats, a benefit to forest dependent species (also species of other taxa), increasing the mobility of individuals between habitat patches in constantly changing landscapes. Ecological restoration should therefore continue in the studied corridor and in other areas of the Atlantic Forest, creating new corridors between reserves, which will effectively enhance conservation of biodiversity at the macro-regional scale. We also recommend proper management of native forests, with the identification of suitable indicator bird species for natural habitats, to monitor the success of ecological restoration measures in the region. Proper design of ecological corridors, with suitable habitat conditions and free circulation of wildlife and native vegetation [67-71], may ensure the preservation of biodiversity in the Atlantic Forest and its environmental services in the medium and long term.

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APPENDIX 1

List of bird species recorded in the Ecological Forest Urugua-í – Foerster, Argentina in the three vegetation types studied: mature forest (MF), secondary forest (SF) and grassland (G). Mean abundances observed per site in each vegetation type, during summer (As) and winter (Aw) are shown. The degree of dependence of each species is shown with the following initials: FD: forest-dependent or specialist species; G: forest-generalist species; ED: edge or open area species; GD: grassland-dependent species. Species marked with ¹ are endemic of Atlantic Forest and ² are migrant species.

Family and species	Common name	MF		BS		G	
		As	Aw	As	Aw	As	Aw
Tinamidae							
<i>Crypturellus obsoletus</i> (FD)	Brown Tinamou	0.10		0.11			
<i>Crypturellus tataupa</i> (G)	Tataupa Tinamou	0.10		0.11			
<i>Crypturellus parvirostris</i> (ED)	Small-billed Tinamou				0.11		
<i>Rhynchotus rufescens</i> (GD)	Red-winged Tinamou					0.10	0.30
Rallidae							
<i>Aramides ypecaha</i> (G)	Giant Wood-Rail		0.05		0.11		
<i>Aramides saracura</i> (FD) ¹	Slaty-breasted Wood-rail	0.10	0.10	0.22	0.44		
Charadriidae							
<i>Vanellus chilensis</i> (GD)	Southern Lapwing					0.60	0.90
Columbidae							
<i>Columba cayennensis</i> (G)	Pale-vented Pigeon	0.19		0.22			
<i>Columba picazuro</i> (G)	Picazuro Pigeon	0.71	0.40	0.56	0.33		0.10
<i>Leptotila verreauxi</i> (G)	White-tipped Dove	0.12	0.17	0.44	0.11		
Psittacidae							
<i>Aratinga leucophthalma</i> (G)	White-eyed Parakeet	0.05					
<i>Pyrrhura frontalis</i> (FD) ¹	Reddish-bellied Parakeet	0.27	0.10				
<i>Pionus maximiliani</i> (G)	Scaly-headed Parrot	0.12	0.22		0.33		
Cuculidae							
<i>Crotophaga ani</i> (G)	Smooth-billed Ani	0.10				1.60	1.90
<i>Crotophaga major</i> (FD) ²	Greater Ani	0.15	0.05				
<i>Guira guira</i> (ED)	Guira Cuckoo					0.70	0.20
<i>Dromococcyx pavoninus</i> (FD)	Pavonine Cuckoo		0.07				
<i>Tapera naevia</i> (G) ²	Striped Cuckoo	0.05	0.02	0.11	0.11		
<i>Piaya cayana</i> (G)	Squirrel Cuckoo		0.17	0.11			
Strigidae							
<i>Ciccaba huhula</i> (FD)	Black-banded Owl				0.11		
<i>Aegolius harrisii</i> (G)	Buff-fronted Owl		0.02				
<i>Pulsatrix koeniswaldiana</i> (FD)	Tawny-browed Owl	0.07					
Trochillidae							
<i>Phaetornis eurynome</i> (FD) ¹	Scale-throated Hermit	0.05	0.10				
<i>Thalurania glaucopis</i> (G)	Violet-capped Woodnymph	0.05	0.02		0.11		
<i>Stephanoxis lalandi</i> (FD) ¹	Green-crowned Plovercrest	0.02					
<i>Hylocharis chysura</i> (G)	Gilded Sapphire		0.02				
<i>Chlorostilbon aereoventris</i> (GD)	Glittering-bellied Emerald	0.07					
Trogonidae							

<i>Trogon rufus</i> (FD)	Black-throated Trogon	0.02			
<i>Trogon surrucura</i> (FD) ¹	Surucua Trogon	0.05	0.35		
Ramphastidae					
<i>Ramphastos dicolorus</i> (G) ¹	Red-breasted Toucan	0.12	0.07		0.22
<i>Ramphastos toco</i> (G)	Toco Toucan		0.02		
Bucconidae					
<i>Nonnula rubecula</i> (FD)	Rusty-breasted Nunlet		0.02		
Picidae					
<i>Colaptes campestris</i> (GD)	Field Flicker				0.50
<i>Colaptes melanochloros</i> (G)	Green-barred Woodpecker	0.07	0.02		
<i>Celeus flavescens</i> (G)	Blond-crested Woodpecker	0.10	0.02	0.11	0.11
<i>Melanerpes flavifrons</i> (FD) ¹	Yellow-fronted Woodpecker	0.05			
<i>Veniliornis spilogaster</i> (G) ¹	White-spotted Woodpecker	0.02	0.02		
<i>Picumnus temminckii</i> (FD) ¹	Ochre-collared Piculet	0.02	0.20		
<i>Dryocopus galeatus</i> (FD) ¹	Helmeted Woodpecker		0.02		
<i>Dryocopus lineatus</i> (G)	Lineated Woodpecker	0.02	0.12		
<i>Campephilus robustus</i> (FD) ¹	Robust Woodpecker	0.05			
Dendrocolaptidae					
<i>Dendrocolaptes platyrostris</i> (FD)	Planalto Woodcreeper	0.02			
<i>Sittasomus griseicapillus</i> (G)	Olivaceous Woodcreeper	0.37	0.52	0.11	0.22
Furnariidae					
<i>Furnarius rufus</i> (ED)	Rufous Hornero			0.11	0.60 1.30
<i>Sclerurus scansor</i> (FD) ¹	Rufous-breasted Leafscraper	0.02	0.05		
<i>Synallaxis ruficapilla</i> (FD) ¹	Rufous-capped Spinetail	0.05			
<i>Synallaxis spixi</i> (G)	Chicli Spinetail				0.10
<i>Synallaxis cinerascens</i> (FD) ¹	Gray-bellied Spinetail	0.05	0.15		0.22
<i>Syndactyla rufosuperciliata</i> (FD)	Buff-browed Foliage-gleaner		0.15		
<i>Philydor lichtensteini</i> (FD) ¹	Ochre-breasted Foliage-gleaner	0.10	0.40		
Formicariidae					
<i>Batara cinerea</i> (FD)	Giant Antshrike		0.02		0.11
<i>Mackenziaena leachii</i> (G) ¹	Large-tailed Antshrike				0.11
<i>Mackenziaena severa</i> (FD) ¹	Tufted Antshrike		0.12		
<i>Hypoedaleus guttatus</i> (FD) ¹	Spot-backed Antshrike	0.27	0.45	0.11	0.11
<i>Thamnophilus caerulescens</i> (G)	Variable Antshrike	0.27	0.17	0.22	0.67
<i>Pyriglena leucoptera</i> (FD) ¹	White-shouldered Fire-eye	0.34	0.12	0.11	
<i>Dysithamnus mentalis</i> (FD)	Plain Antivireo	0.32	0.25	0.11	
<i>Drymophila rubricollis</i> (FD) ¹	Bertoni Antbird	0.02	0.05		
<i>Drymophila malura</i> (FD) ¹	Dusky-tailed Antbird	0.05	0.05	0.22	
<i>Herpsilochmus rufimarginatus</i> (FD)	Rufous-winged Antwren	0.34	0.35		
<i>Chamaeza campanisona</i> (FD)	Rufous-tailed Anthrush	0.27	0.25	0.22	
<i>Grallaria varia</i> (FD)	Variiegated Antpitta	0.05	0.05		
<i>Grallaria ochroleuca</i> (FD)	Speckle-breasted Antpitta		0.02		
<i>Conopophaga lineate</i> (G) ¹	Rufous Gnateater	0.07	0.02		
Rhinocryptidae					
<i>Scytalopus speluncae</i> (FD) ¹	Mouse-colored Tapaculo	0.02	0.12		
Cotingidae					
<i>Pyroderus scutatus</i> (FD) ¹	Red-ruffed Fruitcrow	0.02	0.05		

Pipridae						
<i>Schiffornis virescens</i> (FD) ¹	Greenish Manakin	0.12	0.05	0.11		
Tyrannidae						
<i>Pachyramphus polychopterus</i> (G) ²	White-winged Becard	0.17	0.1	0.11		
<i>Pachyramphus viridis</i> (G)	Green-backed Becard		0.02			
<i>Tityra inquisitor</i> (G) ²	Black-crowned Tityra	0.15				
<i>Myiodynastes maculatus</i> (G) ²	Streaked Flycatcher	0.17			0.11	0.10 0.10
<i>Capsiempis flaveola</i> (G)	Yellow Tyrannulet		0.05			
<i>Pitangus sulphuratus</i> (ED)	Great Kiskadee	0.34	0.12	0.44	0.22	0.90 0.40
<i>Megarhynchus pitangua</i> (G) ²	Boat-billed Flycatcher					0.10
<i>Tyrannus savana</i> (ED) ²	Fork-tailed Flycatcher					0.40
<i>Sirystes sibilator</i> (FD)	Sirystes	0.12	0.02			
<i>Lathrotriccus euleri</i> (G)	Euler's Flycatcher	0.05				
<i>Corythopis delalandi</i> (FD)	Southern Antpipit	0.07	0.02			
<i>Tolmomyias sulphurescens</i> (FD)	Yellow-olive Flycatcher		0.05			
<i>Platyrinchus mystaceus</i> (FD)	White-throated Spadebill		0.05			
<i>Hemitriccus diops</i> (FD) ¹	Drad-breasted Pygmy-tyrant		0.10	0.11		
<i>Todirostrum plumbeiceps</i> (G)	Ochre-faced Tody-flycatcher	0.02	0.05			
<i>Phylloscartes eximius</i> (FD) ¹	Southern Bristle-tyrant	0.05	0.10			
<i>Phylloscartes sylviolus</i> (FD) ¹	Mottled-cheeked Tyrannulet	0.05				
<i>Elaenia obscura</i> (FD)	Highland Elaenia	0.05	0.17			
<i>Elaenia flavogaster</i> (G)	Yellow-bellied Elaenia		0.02			0.20
<i>Myiopagis caniceps</i> (FD)	Gray Elaenia		0.17			
<i>Leptopogon amaurocephalus</i> (FD)	Sepia-capped Flycatcher	0.02	0.02			
<i>Camptostoma obsoletum</i> (ED)	Southern Beardless-tyrannulet		0.02			
<i>Myiopagis auriculatis</i> (FD) ¹	Eared Pygmy-tyrant		0.15			
Corvidae						
<i>Cyanocorax chrysops</i> (G)	Plush-crested Jay	0.41	0.42	0.56	1.67	
Troglodytidae						
<i>Troglodytes aedon</i> (ED)	House Wren				0.11	0.80 1.30
Mimidae						
<i>Turdus leucomelas</i> (G)	Pale-breasted Thrush	0.02	0.32		0.22	
<i>Turdus rufiventris</i> (G)	Rufous-bellied Thrush		0.05			
<i>Turdus albicollis</i> (FD)	White-neckaed Thrush	0.12	0.40		0.33	
Vireonidae						
<i>Vireo olivaceus</i> (G) ²	Red-eyed Vireo	0.07				
<i>Cyclarhis gujanensis</i> (G)	Rufous-browened Peppershrike	0.05	0.17	0.11	0.22	
Parulidae						
<i>Basileuterus leucoblepharus</i> (G) ¹	White-rimmed Warbler	0.68	1.12	0.56	1.78	
<i>Basileuterus culicivorus</i> (G)	Golden-crowned Warbler	0.41	0.65	0.11	0.44	
<i>Parula pitaiayumi</i> (G)	Tropical Parula	0.19	0.50		0.22	
<i>Geothlypis aequinoctialis</i> (ED)	Masked Yellowthroat		0.05			
Coerebidae						
<i>Conirostrum speciosum</i> (FD)	Chestnut-vented Conebill		0.05			
Thaupidae						
<i>Euphonia musica</i> (G)	Golden-rumped Euphonia	0.12	0.05			
<i>Euphonia chlorotica</i> (G)	Purple-throated Euphonia	0.15	0.02			
<i>Euphonia violacea</i> (FD)	Violaceous Euphonia		0.22			

<i>Euphonia pectoralis</i> (FD)	Chestnut-bellied Euphonia	0.05			
<i>Chlorophonia cyanea</i> (FD)	Blue-naped Chlorophonia		0.12		
<i>Hemithraupis guira</i> (FD)	Guira Tanager	0.02			
<i>Cissopis levariana</i> (G)	Magpie Tanager	0.05		0.22	
<i>Trichothraupis melanops</i> (FD)	Black-goggled Tanager	0.07	0.22		0.11
<i>Tachyphonus coronatus</i> (G) ¹	Ruby-crowned Tanager	0.29	0.17	0.22	0.67
<i>Thraupis sayaca</i> (G)	Sayaca Tanager	0.02	0.02		
<i>Habia rubica</i> (FD)	Red-crowned Ant-tanager	0.10			
<i>Pyrrhocomma ruficeps</i> (FD) ¹	Chestnut-headed Tanager		0.15		
Emberizidae					
<i>Saltator similis</i> (G)	Green-winged Saltator	0.10	0.20		0.11
<i>Amaurospiza moesta</i> (FD) ¹	Blackish-Blue Seedeater		0.02		
<i>Sporophila caerulescens</i> (GD)	Double-collared Seedeater				0.40
<i>Sicalis luteola</i> (GD)	Grassland Yellow-finch				0.10
<i>Coryphospingus cucullatus</i> (ED)	Red-crested Finch	0.02		0.44	0.30
<i>Zonotrichia capensis</i> (ED)	Rufous-collared Sparrow				0.60 0.20
<i>Ammodramus humeralis</i> (GD)	Grassland Sparrow				0.30
Icteridae					
<i>Cacicus haemorrhous</i> (G)	Red-rumped Cacique		0.82		
<i>Sturnella supercilialis</i> (GD)	White-browed Blackbird				0.70

APPENDIX 2

AIC values of the statistical models used to choose the “optimal” model to analyze statistically each attribute of bird community of the Ecological Corridor Urugua-í – Foerster, in Argentina. In each model, the variance was modeled in different ways: variances homogeneous, variances as an exponential function of co-variable, variances as a potential function of co-variable and a different variance for each group or treatment (identity), which was used only when a data group differs from all other. In some cases, exponential and potential models were not done because the co-variable could not be estimated. Also, p values of the likelihood ratio test between the best model (*italic*) and the homogeneous variance model were shown.

	Homogeneous	Exponential	Potential	Identity	p value
Richness	648.65	<i>639.75</i>	--	--	0.001
Diversity N1	621.32	<i>608.83</i>	--	--	0.0001
Diversity N2	735.75	<i>692.72</i>	703.52	--	< 0.0001
Evenness	255.83	<i>245.66</i>	247.52	--	0.0005
Abundance	266.97	--	--	<i>767.03</i>	0.1636*

*Although significant differences were not found between models of homogeneity and identity, we used this last to analyze the abundance because the assumptions of normality and homogeneity of variance were corroborated.