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*Dendrofloristic and structural heterogeneity in discontinuous fragments of an evergreen forest in the Ecuadorian Amazon*

*Heterogeneidad dendroflorística y estructural en fragmentos discontinuos de un bosque siempreverde en la amazonía ecuatoriana*

*Heterogeneidade dendroflorística e estrutural em fragmentos descontínuos de um bosque sempreverde na Amazônia Equatoriana*

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## ABSTRACT

This study aimed to compare the structural characteristics, diversity, and floristic composition of two discontinuous fragments of a lowland evergreen forest in the northern Ecuadorian Amazon, located in the province of Sucumbíos. The hypothesis was that changes in tree diversity in relation to structure and floristic composition vary at a small scale. Data were analyzed based on diameter at breast height (DBH) measurements of trees, tree ferns, and palms 10 cm or greater. Ten 10 m x 50 m transects were established in each of the forest remnants. The results indicate that structurally, the ecosystems of the remnants did not show significant differences in richness, density, families, genera, basal area, or diversity ( $p > 0.05$ ). However, regarding floristic composition, only 12 of the 89 species found were shared (ANOSIM  $p = 0.0001$ ). These results demonstrate that differences in floristic composition are linked to the influence of primarily edaphic and anthropogenic environmental factors on the local scale. Furthermore, it can be inferred that spatial configuration may be influenced by other surrounding human activities that limit biological dispersal processes, as well as by forest enrichment practices based on the importance of species to wildlife.

**Keywords:** biodiversity; ecological connectivity; Lago Agrio ecological and recreational park; Nueva Loja tourist park.

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## RESUMEN

El presente estudio tuvo como objetivo comparar las características estructurales, diversidad y composición florística de dos fragmentos discontinuos de un bosque siempreverde de tierras bajas de la Amazonía norte de Ecuador, ubicados en la provincia de Sucumbíos; bajo la hipótesis de que los cambios de diversidad arbórea con relación a la estructura y composición florística varían a pequeña escala. Los datos se analizaron con base a la medición del diámetro a la altura de pecho (DAP) en árboles, helechos arbóreos y palmas mayores o iguales a 10 cm. En cada uno de los relictos boscosos se establecieron 10 transectos de 10 m x 50 m. Los resultados indican que estructuralmente los ecosistemas de los relictos no presentaron diferencias significativas en riqueza, densidad, familias, géneros, área basal o diversidad ( $p > 0.05$ ). Sin embargo, para la



composición florística mostró que, de las 89 especies encontradas, solo 12 fueron compartidas (ANOSIM  $p = 0.0001$ ). Estos resultados demuestran que las diferencias de la composición florística están ligadas a la influencia de factores ambientales principalmente edáficos y antropogénicos a escala local. Además, se puede deducir que la configuración espacial puede estar influenciada por otras actividades antrópicas circundantes que limitan procesos biológicos de dispersión, y a las prácticas de enriquecimiento del bosque en función de la importancia que tienen las especies para la fauna silvestre.

**Palabras clave:** biodiversidad; conectividad ecológica; parque ecológico recreacional Lago Agrio; parque turístico Nueva Loja.

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## RESUMO

Este estudo teve como objetivo comparar as características estruturais, a diversidade e a composição florística de dois fragmentos descontínuos de uma floresta perene de terras baixas na Amazônia setentrional do Equador, localizada na província de Sucumbíos. A hipótese foi que as mudanças na diversidade arbórea em relação à estrutura e à composição florística variam em pequenas escalas. Os dados foram analisados com base nas medições do diâmetro à altura do peito (DAP) em árvores, samambaias e palmeiras maiores ou iguais a 10 cm. Dez transectos medindo 10 m x 50 m foram estabelecidos em cada um dos remanescentes florestais. Os resultados indicam que, estruturalmente, os ecossistemas dos remanescentes não apresentaram diferenças significativas na riqueza de espécies, densidade, famílias, gêneros, área basal ou diversidade ( $p > 0,05$ ). No entanto, em relação à composição florística, apenas 12 das 89 espécies encontradas foram compartilhadas (ANOSIM  $p = 0,0001$ ). Esses resultados demonstram que as diferenças na composição florística estão ligadas à influência de fatores ambientais, principalmente edáficos e antropogênicos, em nível local. Além disso, pode-se deduzir que a configuração espacial pode ser influenciada por outras atividades antropogênicas circundantes que limitam os processos de dispersão biológica e por práticas de enriquecimento florestal baseadas na importância das espécies para a vida selvagem.



**Palabras-chave:** biodiversidade; conectividade ecológica; Parque Ecológico Recreativo Lago Agrio; Parque Turístico Nueva Loja.

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## INTRODUCTION

The Amazon basin comprises 50% of the world's forests and plays a strategic role in providing ecosystem services (Wang *et al.*, 2014). Approximately 52% of the world's forests are concentrated in the tropics, and these are precisely the areas that suffer the highest rate of deforestation due to land-use change. (Brown *et al.*, 1996. This reality is evidenced by the conversion of pristine areas into areas for livestock grazing (Hecht, 1993); (Aide *et al.*, 2000) and although, forest loss has decreased considerably in South America, to approximately half the extent in 2010-2020 (2.6 million ha) compared to 2000-2010 (5.2 million ha) (FAO, 2016-2020), the causes linked to this phenomenon still persist (Butchart) *et al.*, 2010), Shi *et al.*, (2025).

In Ecuador, the problems of degradation and loss of native vegetation are due to land-use change for grazing and agriculture; this reality is no different from what occurs regionally, with an annual forest loss rate of 0.6% calculated for the period 1990–2015. Ecuadorian forests are among those with the highest rates of deforestation in South America (Ordoñez & Iglesias-Quintana, 2024). Despite this, Ecuador is considered one of the 20 most biodiverse countries per unit area (National Biodiversity Institute, 2020), with floristic diversity across its territory resulting from distribution patterns, the interaction of associated ecological factors, and geodynamic processes reported in recent decades (Quizhpe *et al.*, 2019).

In this context, the Ecuadorian Amazon contains 54.86% of the country's total native forest area; specifically, the province of Sucumbíos ranks fourth in terms of the area covered by native vegetation, with 1,411,432 hectares of forest (Ministry of the Environment of Ecuador, 2015). However, anthropogenic pressures, such as changes in land use and deforestation, make forest ecosystems one of the most threatened ecosystems and a high priority for conservation and study (Rodríguez-Echeverry, 2023).



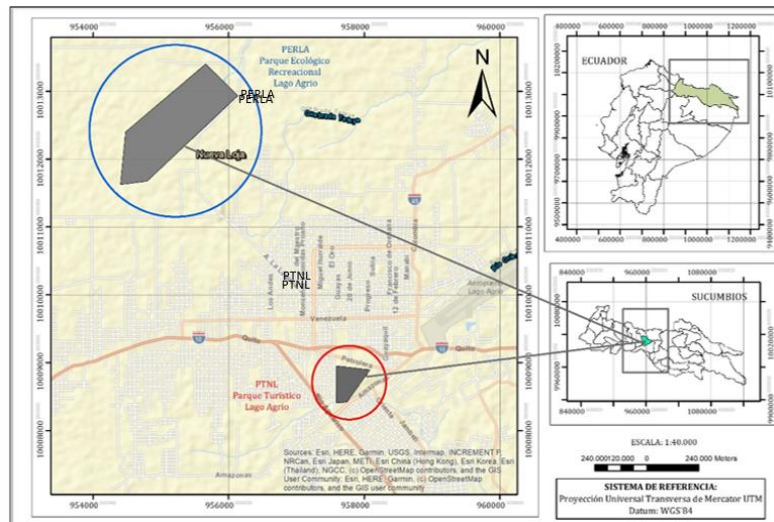
Under this premise, the objective of the present study was to compare the structural characteristics of two forest patches, the first called Nueva Loja Tourist Park (PTNL) and the second Lago Agrio Ecological Recreational Park (PERLA); in order to analyze the level of structural homogeneity of the patches in relation to their tree vegetation, and to determine the variations at the level of floristic composition and diversity, under the hypothesis that changes in tree diversity in relation to the structure and floristic composition are influenced by external factors on a small scale.

### **MATERIALS AND METHODS**

The ecosystems being compared consist of two multi-layered forest patches in a secondary successional state. The Lago Agrio Ecological Recreational Park, located under the influence of a mosaic of secondary vegetation, crops, and pastures resulting from human activity (UTM 287584; 13378) at 315 m asl; and the Nueva Loja Tourist Park, immersed within a completely human-modified ecosystem surrounded by urban infrastructure (UTM 289757; 8619) at 312 m asl (Figure 1). These ecosystems represent remnants of vegetation characteristic of the study area, wildlife refuges, carbon sinks, and providers of ecosystem goods and services (Cabrera *et al.*, 2018).

According to the characterization of ecosystems of continental Ecuador (Ministry of the Environment of Ecuador, 2012), both study sites are located within a lowland evergreen forest ecosystem of the Aguarico Putumayo-Caquetá region, characterized by tall, multi-layered, closed-canopy forests with heights of up to 35 m, except for some exceptions in dominant trees, with predominant bioclimatic conditions that vary between humid and hyperhumid. The average annual temperature range is between 24 °C and 26.5 °C, with annual rainfall between 2800 and 4500 mm (Harris, 2020).





**Figure 1.** - Study area Lago Agrio Ecological Recreational Park (PERLA) and Nueva Loja Tourist Park (PTNL)

#### *Data collection*

Data were collected based on measurements of trees, tree ferns, and palms with a diameter greater than or equal to 10 cm at a height of 1.3 m. (Jadán *et al.*, 2016a). In each study area, 10 quantitative sampling units were established using transects (10 m. x 50 m.), which were separated at intervals of 100 m. linear (Lozano *et al.*, 2013).

At each site, plants were counted and taxonomically identified to the genus and species level with the assistance of forestry specialists from the Ministry of Environment, Water and Ecological Transition, and local ethnobotanical experts. Unidentified species were collected, pressed, and processed to herbarium standards; identified using specialized botanical literature and classified according to the Angiosperm classification system. Phylogeny Group – APG IV (Chase *et al.*, 2016).

#### *Floristic composition and structure*

Floristic composition was analyzed based on the richness of families, genera, and species (Lozano *et al.*, 2013). Horizontal structure was evaluated in terms of density ( $N/0.05 \text{ ha}^{-1}$ ), basal area ( $G/0.05 \text{ m}^2 \text{ ha}^{-1}$ ), and relative frequency. These parameters were used to determine the Importance Value Index (IVI) (Equation 1, Table 1), which denotes the relative ecological importance of species in plant communities according to the



horizontal structure of an ecosystem (Cottam & Curtis, 1956; Soler *et al.*, 2012). A distribution analysis was also performed for the density and basal area of woody biotypes according to diameter classes (Ramos & Plonczak, 2007).

The evaluation of the vertical structure was based on the previously proposed standard methodology (Camacho & Plonczak, 2012). Saplings, trees, and palms were considered to provide a description of the ground cover naturally occupied by the species within the forest stand. (Jadan) *et al.*, 2016a). The sum of the sociological values of the tree stratum (Equation 2, Table 1) allowed the determination of the value per sub-stratum, represented by the number of trees contained within certain altitudinal classes. Likewise, it allowed the calculation of the absolute sociological position index per species (Equation 3, Table 1), and the relative sociological position index (Equation 4, Table 1). (Melo & Vargas, 2003).

Finally, to calculate the expanded importance value index (IVIA) (Equation 5, Table 1), the values of the relative sociological position (vertical structure) and the importance value index (horizontal structure) were combined, in order to explain the phytosociological importance of each species in each of the ecosystems of the study. (Camacho & Plonczak, 2012; Jadán *et al.*, 2016b).

**Table 1.** - Variables and equations for calculating the vertical structure, importance value index (IVI) and expanded importance value index (IVIA)

Variable	Equation	Description	Equation
Importance Value Index (IVI) for each species	$IVIr = (Ar + Dr + Fr)$	IVIr: Relative Importance Value Index (%). Ar: Relative abundance (%). Dr: Relative dominance (%). Fr: Relative frequency (%).	Ec 1
Sociological value - per species (VFi)	$VFi \frac{ni \text{ ha}^{-1}}{N \text{ ha}^{-1}} \times 100$	VFi: Phytosociological value of a species in the i- th sub-stratum.  $ni \text{ ha}^{-1}$ = number of individuals per hectare of a species in the i- th sub-stratum.	Ec 2



		$N \text{ ha}^{-1}$ = Number of individuals per hectare, present in all strata.  i: lower (i), middle (m) or upper (s) sub-stratum.	
Index of absolute sociological position - by species (Psa)	$PSa = VFi * ni \text{ ha}^{-1} + VFm * nm \text{ ha}^{-1} + VFs * ns \text{ ha}^{-1}$	PSa: Absolute sociological position  VFi: Phytosociological value of a species in the i- th sub-stratum.  $ni \text{ ha}^{-1}$ : Number of individuals in the i- th sub-stratum.  i: lower (i), middle (m) or upper (s) sub-stratum.	Ec 3
Index of relative sociological position of each species (PSr)	$PSr = \frac{PSa}{\sum PSa} \times 100$	PSr: Relative sociological position.  Psa: Absolute sociological position of each species.  $\sum PSa$ : Sum of the sociological positions of all species.	Ec 4
Expanded Importance Value Index (IVIA) for each species	$IVIA = IVIr + PSr$	IVIA: Expanded Importance Value Index (%).  Ar: Relative abundance.  Dr: Relative dominance (according to basal area).  PSr: Sociological position (%).  IVIr = relative IVI (%).	Ec 5

### Alpha diversity

To determine the tree diversity of the ecosystems, the standard Shannon (H') and Simpson (1-D) indices were used, considering trees, tree ferns and palms (Moreno, 2001).

### Information analysis

Sampling efficiency was assessed using non-parametric richness estimators based on abundance (Chao 1), and species accumulation curves were calculated using EstimateS

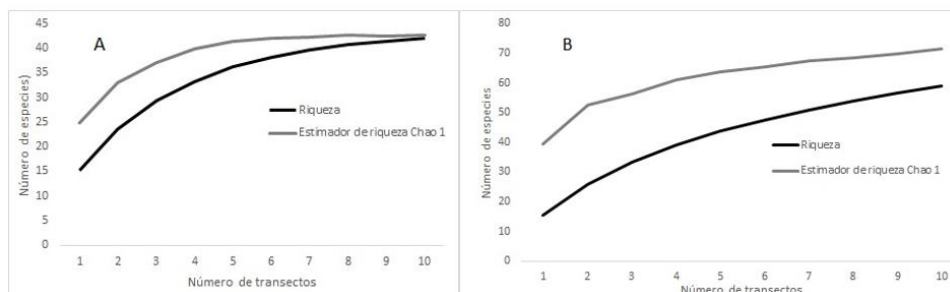


9.1 software. (Colwell & Elsensohn, 2014), with respect to the data on richness, Shannon and Simpson alpha diversity indices and abundance were analyzed and compared between the two forests, for this the non-parametric Mann-Whitney U method was used. To compare the biotic communities, it was done using the PAST 2.0 program (Hammer *et al.*, 2001; AE Magurran, 1988; Spellerberg, 2005). Finally, using a similarity analysis (ANOSIM), the similarity between the different transects was determined based on the floristic composition and abundance of each species. In the case of species dissimilarity between forests, a non-metric multidimensional scaling (NMS) analysis was performed using the Sorensen distance measure (Bray-Curtis). (Jadan *et al.*, 2016a).

## RESULTS AND DISCUSSION

### Sampling efficiency

In the PERLA forest, 98% efficiency was achieved, with 42 species recorded out of the 43 expected (Figure 2A). In contrast, for the PTNL forest, 84% efficiency was achieved (59 species recorded out of the 70 expected species), according to the Chao 1 species richness estimator (Chao & Lee, 1992). Figure 2AB shows the curve with a tendency to stabilize from transect 9 onward in the case of the PERLA ecosystem (Figure 2A), while in the case of the PTNL ecosystem, the stabilization is less pronounced, but with a slight stabilization expected from transect 10 onward (Figure 2B). These results demonstrate that the number of sampling units for both forests (PTNL and PERLA) was sufficient to characterize the floristic richness of the study area.



**Figure 2A-B.** - Accumulation of tree species as a function of the number of transects (0.05 ha) and number of species. (A) Accumulation curve of PERLA. (B) Accumulation curve of PTNL.

Lago Agrio Ecological Recreational Park (A) and Nueva Loja Tourist Park (B)



*Floristic composition and abundance*

Lowland Amazonian forests are more diverse than those found at the base of the Andes Mountains, exhibiting a pattern characterized by high species richness and low abundance (Freitas *et al.*, 2019; Gentry, 1990). However, in the study areas, a total of 36 families, 71 genera, and 89 species were recorded; 42 species in the PERLA forest and 59 in the PTNL forest, represented in 672 and 538 trees ha<sup>-1</sup>, respectively. No significant differences were found between the two forests in species richness, density, or basal area (Table 2).

In contrast, the total species richness of the two ecosystems represents lower values than those previously reported (Valencia *et al.*, 1994) in a one-hectare plot located in the northern Amazon of Ecuador, indicating a total richness of 473 spp. ha<sup>-1</sup>. Similarly, the values previously reported by Quizhpe *et al.* (2019) in forests of the Amazonian mountain range in southeastern Ecuador, with a total richness of approximately 430 spp. ha<sup>-1</sup>, were also high for the Sumaco Napo Galeras National Park, with a total richness of 220 species ha<sup>-1</sup>. (Jadan) *et al.*, 2016a). These results are 2–3 orders of magnitude higher than those presented in this study. This demonstrates a decrease in total richness in the assessed ecosystems, presumably due to their successional stage and the pressures to which these ecosystems are subjected. However, seven of the genera found are included in the list of the 20 most abundant tree species in the Amazon (Table 3) (Ter Steege *et al.*, 2013); and presents a pattern characteristic of the recovering Amazonian forest, evidenced by the presence of many species with low abundance and characteristic distribution patterns (García *et al.*, 2020). From this, one can infer the tendency of these ecosystems to recover their functionality and dynamics.

The structural characteristics between the two ecosystems are homogeneous; there were no statistically significant differences between their variables (Table 2).



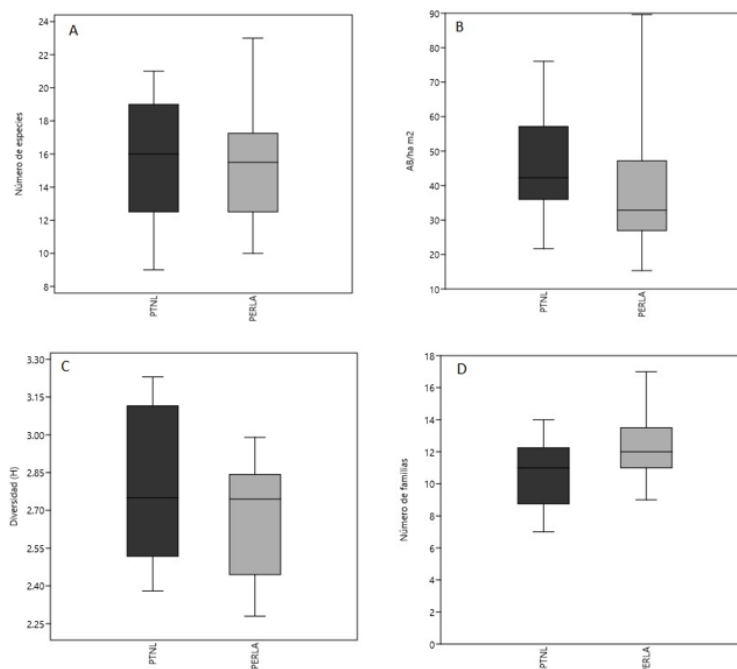
**Table 2.** - Structure, richness and diversity in the forests of PTNL and PERLA (average  $\pm$  STD)

Variable	PTNL	PEARL	F value	p
Wealth (S)	15.5 $\pm$ 3.89 a	15.3 $\pm$ 3.71 a	0.014	0.91
Density (0.5 ha <sup>-1</sup> )	269 $\pm$ 7.23 a	336 $\pm$ 13.9 a	1.82	0.19
Families	10.8 $\pm$ 2.2 a	12.5 $\pm$ 2.22 a	2.95	0.10
Genres	14.2 $\pm$ 3.15 a	14.7 $\pm$ 3.19 a	0.12	0.73
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	45.5 $\pm$ 15.3 a	39.4 $\pm$ 20.3 a	0.57	0.43
Shannon H' (0.05 ha <sup>-1</sup> )	2.77 $\pm$ 0.30 a	2.67 $\pm$ 0. 24 a	0.62	0.44
Simpson 1-D (0.05 ha <sup>-1</sup> )	0.93 $\pm$ 0.028 a	0.92 $\pm$ 0.036 a	0.99	0.33

The basal area is comparable to that found in the evergreen forests of the foothills of the northeastern Andes mountain range 37.7 m<sup>2</sup> ha<sup>-1</sup> (Jadán *et al.*, 2016a) and 34.52 m<sup>2</sup> ha<sup>-1</sup> (Torres *et al.*, 2020). The abundance is 605 trees ha<sup>-1</sup>, similar values reported by (Ter Steege *et al.*, 2013), which is indicative of a restored horizontal and vertical structure that can be compared to that of secondary forests.

In the PERLA forest, the families with the highest number of individuals were Fabaceae (16.1%), Meliaceae (15.5%), Lauraceae (15.2%), Myristicaceae (8.0%), and Moraceae (6.3%). Together, these families represent 61.0% of the total species in this forest. In the PTNL forest, the families with the highest number of individuals were Moraceae (20.8%), Arecaceae (15.2%), Fabaceae (10.4%), Meliaceae (7.8%), and Euphorbiaceae (6.3%). Together, these families comprise 60.6% of the total species in the forest (Figure 3).





**Figure 3.** - Variation in the structure and diversity of tree vegetation in the PTNL and PERLA ecosystems. (A) represents floristic richness, (B) represents basal area, (C) represents floristic diversity, (D) represents taxonomic families.

#### Structural characteristics

The results indicate that the species with the greatest ecological importance in PERLA were represented by *Guarea kunthiana* A. Juss, *Nectandra* sp., *Inga* spp. and *Chrysophyllum argenteum* Jacq. In the PTNL, they were *Ficus maxima* Mill. and *Ficus insipida* Willd., followed by species such as *Ocotea* sp., *Sapium* sp. and *Miconia* sp., (Table 3). The structure of these forest relicts generates conditions of vegetation cover and height that facilitate interaction between species as a result of the gradual recovery of diversity at different levels (Cabrera *et al.*, 2018).



**Table 3.** - Values of the ecological importance index (IVI) and expanded importance value index (IVIA) of the 10 most important species in the PERLA and PTNL ecosystems (0.5 ha)

	SPECIES	Dr (%)	Dor (%)	Fr %	IVIr (%)	PSA	PsR (%)	IVIA (%)
	<i>Guarea Kunthiana</i>	15.2	14.3	6.5	12	23.8	16.2	14.1
	<i>Nectandra</i> sp.	11.6	6.7	5.9	8.1	17.8	12.1	10.1
	<i>Inga</i> spp.	11	8.5	5.9	8.5	16.1	11	9.7
	<i>Chrysophyllum argenteum</i>	4.2	2.7	4.6	3.8	6.5	4.4	4.1
	<i>Miconia</i> sp.	4.5	2.2	2.6	3.1	6.5	4.5	3.8
	<i>Ferrules elongate</i>	3.3	3.5	3.9	3.6	5.2	3.6	3.6
PEARL	<i>Pourouma minor</i>	3.3	7	3.9	4.7	3.1	2.1	3.4
	<i>Virola duckei</i>	3.3	4.5	2.6	3.5	5	3.4	3.4
	<i>Sloanea grandiflora</i>	3.3	0.8	4.6	2.9	5.5	3.8	3.3
	<i>Simarouba amara</i>	3.0	3.3	3.3	3.2	5	3.4	3.3
	Other	38.1	45.5	56.2	46.6	54.3	37	41.8
	Total	100	100	100	100	146.7	100	100
	SPECIES	Dr (%)	Dor (%)	Fr %	IVIr (%)	PSA	PsR (%)	IVIA (%)
	<i>Ficus maxima</i>	7.8	21.2	4.5	11.2	6.1	5.6	8.4
	<i>Ficus insipida</i>	5.9	22.4	4.5	10.9	3.5	3.3	7.1
	<i>Ocotea</i> spp.	5.6	3.6	4.5	4.6	6	5.5	5.0
PTNL	<i>Sapium</i> sp.	5.2	2.6	3.9	3.9	6.2	5.7	4.8
	<i>Miconia</i> sp.	4.5	1.3	3.9	3.2	5.3	4.9	4.0
	<i>Iriartea deltoidea</i>	4.5	1.8	3.2	3.2	5.3	4.9	4.0
	<i>Guarea Kunthiana</i>	4.1	0.9	3.2	2.7	4.8	4.4	3.6
	<i>Socrates exorrhiza</i>	4.1	1	3.2	2.8	4.9	4.5	3.6
	<i>Inga</i> sp.	3.7	1.7	3.9	3.1	4.1	3.8	3.4
	<i>Guarea macrophylla</i>	3.3	0.8	3.9	2.7	3.6	3.3	3.0
	Other	51.3	42.9	61.3	51.8	58.5	54.1	53
	Total	100	100	100	100	108.2	100	100

Dr: relative density; Dor: relative dominance; Fr: relative frequency; IVI: importance value index; Psa.r : absolute sociological position ; IVIA: expanded importance value index.

Species with the lowest IVIA in PERLA included the *Pourouma species minor* Benoist, *Virola duckei*, *Sloanea grandiflora* Sm, *Simarouba amara* Aubl. Meanwhile, the IVIA in the PTNL were *Pourouma cecropiifolia* Mart., *Ochroma pyramidale* Urb., *Minquiartia guianensis*, *Cyathea* sp., *Aparisthmium cordatu*. (Table 3).



Among the forest fragments evaluated, the most ecologically important species differ, with the exception of *Inga*. sp. and *Miconia* sp. that are common on both study sites. This difference is attributable to the influence of edaphic and anthropogenic factors on the local scale (Mosquera & Piedra, 2020). Furthermore, the spatial configuration of species distribution in the study areas demonstrates that biological processes such as dispersal limitation are mechanisms that control the distribution of canopy tree species at the local scale; in addition to this, the capacity of species to compete with others for resource availability (Duivenvoorden & Duque, 2010; Duque *et al.*, 2003; Ruokolainen) *et al.*, 2007; Svenning, 2001; Valencia *et al.*, 2004)

The results for species abundance distributed across diameter classes (Table 4) showed no statistically significant differences between forests, with the exception of the  $\geq 60$  cm diameter class ( $p = 0.00001$ ) (Figure 4A). Regarding basal area distribution in each diameter class, an irregular pattern was observed, with no statistically significant differences between individuals in classes I through V ( $p > 0.05$ ). Significant differences were observed for species in the  $\geq 60$  cm class (Figure 4B). These differences are evident due to the varying abundance and dominance of individuals in this class (Figure 4B). Furthermore, the management of these areas includes the application of active restoration practices based on the existing wildlife (Cabrera *et al.*, 2018).

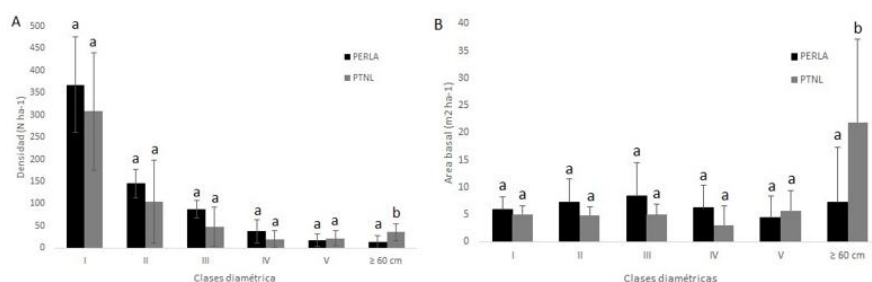
Meanwhile, the distribution of individuals resulted in an inverted J characteristic of tropical forests (García *et al.*, 2020); which denotes that the largest number of individuals is located in the lower diameter classes (10-30 cm DBH  $\geq 1.3$ m) (Figure 4A) typical of heterogeneous native forests in advanced succession stage that denotes the natural dynamics typical of natural tropical forests (Freitas *et al.*, 2019; Santos, 2013; Sardinha, 2017); and as is the case of the forest fragments under study, after having undergone selective harvesting processes. (García *et al.*, 2020) This is an indicator of the heterogeneity of individuals due to natural processes or the degree of intervention that the forest ecosystems under study have suffered.



**Table 4.** - Averages and standard deviation of the abundance of individuals by diameter class considering trees with a  $DBH_{1.30m} \geq 10$  cm in 0.05 ha transects

Diametric class	PTNL	PEARL	<i>p</i>
Yo	308±77 <sup>a</sup>	368±95 <sup>a</sup>	0.28
II	104±23 <sup>a</sup>	146±66 <sup>a</sup>	0.19
III	48±13 <sup>a</sup>	88±45 <sup>a</sup>	0.07
IV	20±18 <sup>a</sup>	38±15 <sup>a</sup>	0.11
V	22±10 <sup>a</sup>	18±14 <sup>a</sup>	0.62
≥ 60cm	36±11 <sup>a</sup>	14±13 <sup>b</sup>	0.00001*

\*Statistically significant

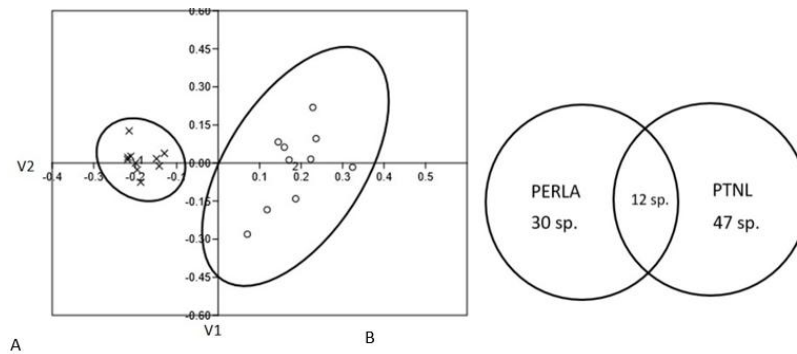


**Figure 4.** - Diameter distributions for density ( $N\ ha^{-1}$ ) (A) and basal area (B) ( $m^2\ ha^{-1}$ ) in the PTNL and PERLA ecosystems. Vertical bars represent the standard deviation. Diameter class ranges: I: 9.5–20 cm; II: 20.1–30.6 cm; III: 30.7–41.2 cm; IV: 41.3–51.8 cm; V: 51.9–60 cm; VI:  $\geq 60$  cm

The results of the spatial ordination of the forests between the study sites suggest a low similarity index ( $I_s = 0.18$ ). This corresponds to 47 species exclusive to PTNL and 30 species exclusive to PERLA, with a total of 12 species shared between the two forests (Figure 5A), denoting floristic dissimilarity between the two forests (Figure 5B). The number of species in the study area is indicative of its ecological quality, since this factor, combined with disproportionate abundance, is characteristic of forest relicts in a successional state. secondary factors include the levels of disturbance to which they have been subjected (García *et al.*, 2020; Yepes & Villa, 2010). This demonstrates the ecological requirements of certain species to be able to develop in different stages of succession.



Significant differences in floristic composition and abundance were also observed. In particular, the analysis of floristic composition similarities significantly separated ( $p = 0.0001$ ) the two areas represented in the NMS. The PTNL forest differed floristically from the PERLA forest. This can be seen on the first axis (Figure 5-B), with plots located in PTNL grouped to the right and those in PERLA to the left.



**Figure 5 AB.** - Exclusive and shared species, non-metric multidimensional scaling (Bray-Curtis) for measuring similarity in floristic composition between PERLA and PTNL in 0.05 ha transects

## CONCLUSIONS

The ecosystems studied are in an advanced state of succession with a group of dominant species that include *Ficus maxima* and *Ficus insipida* in the PTNL, and *Guarea kunthiana*, *Nectandra sp.*, and *Inga spp.* in the PERLA. These species are indicators of the state of forest succession.

There is no variation in terms of structural characteristics between ecosystems, although there is a difference with respect to floristic composition. This is the result of the spatial configuration influenced by surrounding activities that limit biological dispersal processes (subsistence agriculture and livestock farming in the case of PERLA, and activities typical of urban areas in the case of PTNL).

The indices based on density, dominance, frequency, and phytosociological position constitute structural indicators of the potential of both ecosystems to provide ecosystem services. They represent relict habitats of paramount importance for the conservation of



associated resources and the dynamics of what was once the area's landscape matrix. The results highlight the importance of maintaining these conservation areas. It is recommended that the entities responsible for local environmental management implement stricter controls on the pressures caused by surrounding human activities that are not in harmony with the natural environment in the case of PERLA, nor with its carrying capacity in the case of PTNL.

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***Conflicts of interest:***

The authors declare no conflicts of interest.

***Authors' contribution:***

The authors have participated in the writing of the work and analysis of the documents.



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