Research Article

Floristic Composition, Structure, and Diversity of a Fragmented Forest Remnant in the Ecuadorian Chocó: The Case of 'La Montaña enclave'

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Abstract | Floristic composition is a key indicator of a region's biodiversity, as it helps identify the species present, their interactions, and the special distribution of plant communities. The objective of this study was to assess the floristic composition, structure, and diversity of vegetation units at the 'La Montaña enclave' (210 ha), circumscribed at the Estación Experimental Tropical Pichilingue, Instituto Nacional de Investigaciones Agropecuarias (INIAP), Los Ríos province, Ecuador. Thirty-one temporary sampling plots, each measuring 20 m × 20 m (400 m^2) were established to evaluated the presence of plants, the diameter and height of trees. The importance value index (IVI) was calculated based on abundance, frequency and dominance relative. The plant units were grouped according to floristic and structural similarities. The floristic inventory encompassed a total of 23 botanical families, 55 species and 366 individuals. The families with the most representatives were: Moraceae, Malvaceae, Fabaceae, Mimosaceae, and Arecaceae. The study identified three vegetation units: forest, flood and swamp zone. *Anacardium excelsum* was the dominant species in the forest zone, while *Erythrina glauca* and *Cecropia peltata* were the dominant species in the swamp and flood zones, respectively. The forest zone had the highest diversity of species (H_{SD}= 0.906, H'= 3.015 y D_{mg}= 7.913), followed by the flood zone (H_{SD}= 0.861, H'= 2.392 y D_{mg}= 4.348) and the swamp zone (H_{SD}= 0.666, H'= 1.258 y D_{mg}= 1.228). The floristic inventory provides information about plant biodiversity which helps to understand its structure and arboreal composition. The findings provide a baseline for prioritizing restoration actions in lowland evergreen forests of the Ecuadorian Chocó.

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Introduction

Biodiversity is the ecosystem's biological richness on which humanity depends (Suárez *et al*., 2018; Aguirre, 2019; Chimarro *et al*., 2023). Forests are the largest land ecosystems, occupying 31% of the land surface; the ecosystem services provided by biodiversity are climate regulation, preventing erosion, recycling CO_2 from the air, reducing global warming, regulating rainfall, contributing refilling to aquafers, soil fertility and water purification, crucial for human well-being (FAO, 2020; Rathoure and Kumar, 2024).

Climate change possess challenges for biodiversity, particularly for freshwater ecosystems in high latitudes (He *et al*., 2019; Reid *et al*., 2019). The effects of raising temperatures on biodiversity have varied extensively between regions (O'Gorman *et al*., 2019). In forests, temperature influences biomass distribution, with colder climates showing a higher proportion of total forest biomass in roots and a lower proportion in foliage (Reich *et al*., 2014). This shift in biomass distribution can affect key forest processes such as nutrient cycling, decomposition, and seed dispersal, which are vital for maintaining ecosystem functions. These findings underline the importance of considering both species diversity and biomass distribution when assessing the impact of climate change on forest ecosystems.

Primary forests, especially tropical humid forests, showed the highest rates of biodiversity. This biodiversity decreases the more these environments are altered (McDermott, 2024). In regions such as western Ecuador, these forests are considered biodiversity hotspots, harboring a rich diversity of species (Pesantes and Bonifaz, 2022; Cruz-García *et al*., 2024; Prieto-Benavides *et al*., 2024). These ecosystems provide crucial services for human well-being, such as food, weather regulation, and biodiversity preservation (Songliang and Sean, 2021; Barral *et al*., 2024).

Biodiversity plays a key role in the efficiency and resiliency of ecosystems, directly influencing their ability to provide these essential services (Manzanilla *et al*., 2020; Neto *et al*., 2023). Nonetheless, ongoing human activities and climate change are significantly impacting the availability and quality of natural resources, threatening the stability of ecosystems and the services they provide (Leal *et al*., 2020). An integrated approach to ecosystem management is essential for balancing human needs with biodiversity conservation, as it enhances efficiency, resilience, and long-term sustainability (Díaz *et al*., 2020).

Ecosystems offer a wide range of ecological services to society, both directly and indirectly. Additionally, they serve as sources of natural resources, regulate vital processes, and support essential life-sustaining functions (Manzanilla *et al*., 2020). Sometimes, they have also been influenced and modeled by ancestral cultures; thus, it is crucial to avoid any alterations to the life cycles they regulate (Machín and Casas, 2006; González, 2015).

Continental Ecuador is home to 91 ecosystems (MAE, 2018), as identified by the Ecosystem Classification System. Of these 27 ecosystems are located in the coastal region, comprising 35% of the region's land area (Cuesta *et al*., 2015). One of these ecosystems is the Bosque Siempreverde Estacional de Tierras Bajas del Chocó Ecuatoriano (Evergreen Stational Forest of the lowlands of the Ecuadorian Choco), found along the northwestern province of Esmeraldas. Furthermore, historically, its extension reached south to the Guayas and Los Rios provinces (MAE, 2013; Cuesta *et al*., 2015; Rodríguez-Echeverry and Leiton, 2020). However, there are decrease in extension due to anthropic activities such as agriculture, livestock, and urban population growth (Aguirre *et al*., 2021a; b). This type of forest possesses a remarkable diversity of amphibian, reptile, bird, and mammal species inhabiting various ecological niches (Morrone, 2019).

The diversity of ecosystems and species makes Ecuador one of the world's biodiversity hotspots. It hosts 6% of the world's biodiversity with only 2% of the surface (Pitman *et al*., 2002; Aguirre and Endara, 2016; Barros-Diaz *et al*., 2023). In Ecuador, the presence of some 25,560 plants has been reported, 5,348 of which are endemic, and comprehensive policies and strategies for biodiversity conservation have been established; however, significant challenges remain, particularly in addressing the environmental impacts of mining activities and the need to incorporate social-ecological interactions into biodiversity management. Further progress is essential to mitigate these threats and strengthen conservation efforts (Roy *et al*., 2018; Mestanza-Ramón *et al*., 2020).

In the Coastal region, agricultural activities dominate the landscape, covering 62% of the territory, according to Cuesta *et al.* (2015). This high rate of land conversion has led to the remaining ecosystems being distributed as small islands within an anthropogenic landscape characterized by high levels of fragmentation. The province of Los Ríos, located in the central part of the Coastal region, is one of the most altered areas in western Ecuador (Aguirre *et al*., 2018). The primary drivers of this transformation include poorly directed colonization policies supported by laws that promoted deforestation, such as the Agrarian Reform Law in effect until the 2000s; the economic advantages of crops such as bananas, African palm, and cacao over forest use; and the weak governmental control over deforestation. These actions have significantly contributed to the loss of forest resources and the degradation of other biodiversity components. This underscores the profound impact human activities have on the quality of ecosystems.

To reduce this vulnerability and improve the representativeness and protection of local ecosystems, this study assessed the floristic composition, structure, and diversity of the vegetation units in 'La Montaña enclave', a remnant of the tropical rainforest in the Ecuadorian Chocó, located in Los Ríos, Ecuador.

Materials and Methods

Location of the study area

'La Montaña enclave' serves as a research site within the Estación Experimental Tropical Pichilingue (EETP), part of the Instituto Nacional de Investigaciones Agropecuarias (INIAP). It is situated at kilometer 5 along the Quevedo-El Empalme highway in Mocache canton, Los Ríos province, Ecuador. The forest spans 210 hectares and is located at 79°28'06" W and 01°05'24" S, with an altitude ranging between 60 to 90 masl (Figure 1). The EET-Pichilingue has a humid tropical climate, with an annual precipitation of 2,178 mm, distributed throughout the year, an average temperature of 24 °C, 84% relative humidity, irregular topography, and a monthly average of 76 hours of sunlight (INAMHI, 2018). The predominant soil type is loam, derived from young volcanic ash, characterized by high fertility and excellent moisture retention properties.

'La Montaña enclave' (INIAP-EETP) is located within a fragmented landscape of the Ecuadorian Chocó but maintains a degree of connectivity with other important forest remnants. In Los Ríos province, it is approximately 39 km from Reserva Jauneche (Bosque Protector "Estación Científica Pedro Franco Dávila") and 73 km from Reserva Río Palenque, both of which serve as critical refuges for biodiversity with 138 and 100 ha, respectivility. Additionally, to the north, the Reserva Ecológica Mache Chindul (119,172 ha) in Esmeraldas is located 230 km away, representing a more distant but ecologically significant forested area.

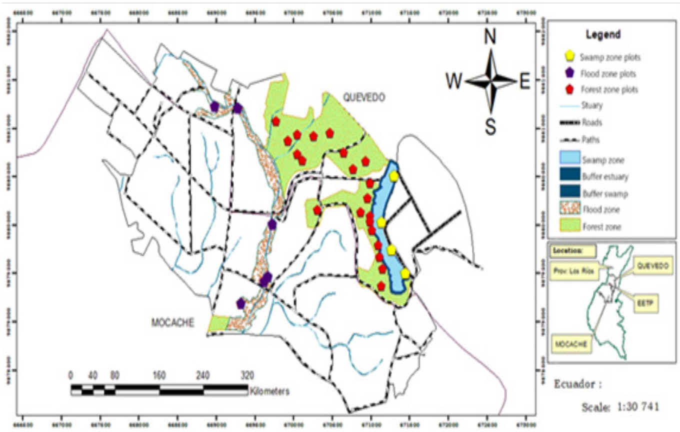

Figure 1: *Planimetric survey in 'La Montaña enclave', EET-Pichilingue Los Ríos province, Ecuador.*

Numerous scientific studies have examined 'La Montaña enclave', particularly its floristic diversity, structural composition, and natural regeneration dynamics. However, similar to many of Ecuador's forests, it faces serious threats from human activities. Among the primary concerns are deforestation, agricultural expansion, and infrastructure development, all of which endanger this small yet ecologically significant forest remnant (Mora, 2020; Arce-Cortez, 2021).

Floristic inventory

We randomly distributed 31 temporary sampling plots, each measuring 20 m × 20 m (400 m^2), to adequately represent the site's floristic variability (Magurran, 2004). In this regard, Sousa *et al.* (2023) suggest a standard sampling unit of one hectare for forest inventories, while smaller units (20m x 20m) effectively monitor growth variables. Morellato *et al.* (2010) recommend a minimum sample size of 15 trees to obtain accurate observations, especially when using less frequent sampling methods. In each plot, we measured key dasometric variables, including plant height (h), diameter at 1.30 m above ground (DBH) for individuals with DBH ≥10 cm, and basal area (BA).

Were analyzed the morphological characteristics of leaves, flowers, and fruits found in the study area to identify species. Herbarium vouchers of species were collected and stored in the department of plant genetic resources INIAP-EETP. We then compared these characteristics with those described in Ecuador's Catalogue of Vascular Plants (Jørgensen *et al*., 1999) and GBIF backbone taxonomy (GBIF Secretariat, 2023) was used for botanical identification and taxonomic classification. Additionally, we verified accepted scientific names and synonyms using The World Flora Online database (https://www.worldfloraonline.org/). As an ecological reference, was considered the characteristic flora of the Seasonal Evergreen Forest (MAE, 2013), providing a specific ecological framework to contextualize our findings.

Delimitation and mapping of vegetation units

We defined vegetation units as homogeneous groups of plant communities sharing similar composition, structure, and ecological function within a specific geographic area. To identify and classify these units, we applied ecological and botanical criteria, considering species composition, dominance, physiognomy, and structural attributes such as canopy cover and vegetation strata.

To map the vegetation, we conducted systematic transects across the enclave and its internal plant units. Each transect followed a predefined path to ensure comprehensive coverage of the study area. We used QGIS 3.14.15 for spatial analysis, integrating topographic maps provided by Instituto Geográfico Militar of Ecuador (IGM) at a 1:25,000 scale. We also incorporated contour lines to refine the delineation of vegetation units. The mapping process employed the WGS 84 UTM coordinate system. To define ecosystem-based vegetation areas, we used vector maps of Ecuador's ecosystems provided by the Ministerio de Ambiente, Agua y Transición Ecológica of Ecuador (MAATE). These maps served as a reference framework, allowing the classification of vegetation units within a broader ecological context.

Analysis of vegetation structure and diversity

To classified plant families and species were using frequency distribution tables, and to analyze vegetation structure, were conducted a Principal Component Analysis (PCA) using dasometric variables, including plant height, diameter at breast height (DBH), and basal area. Data standardization prior to PCA was applied to normalize variable scales, to ensure the analysis was based on the correlation matrix, preventing biases due to differences in measurement units.

Additionally, were applied a Hierarchical Cluster Analysis (HCA) to evaluate species similarity within each vegetation unit, using Bray-Curtis similarity index, because it accounts for differences in relative species abundance and is suitable for ecological data containing zero values and performed clustering using the average linkage method (UPGMA) due to its balanced sensitivity and robustness in cluster formation. All statistical analyses were conducted in R (R Core Team, 2024).

For each vegetation unit, we estimated structural parameters, including relative abundance (RA), frequency (FR), dominance (DR), and the Importance Value Index (IVI), following the methodologies of Manzanilla *et al*. (2020) and Torres *et al*. (2024). We calculated abundance as the number of individuals per hectare, frequency as the percentage of plots where each species was present, and dominance based on relative basal cover.

To calculated diversity indicators, including species richness (S), Simpson's diversity index (1-D), Shannon-Wiener index (H'), Margalef index (Dmg), and Pielou's evenness index (J), to evaluate species heterogeneity and community composition (Daly *et al*., 2018; Mulya *et al*., 2021). After determining the structure and diversity of the vegetation units, we identified indicator species by performing an Indicator Value (IndVal%) analysis. This method evaluates species associations based on their fidelity and specificity to particular habitats, helping to identify species that characterize distinct ecological zones. We conducted the IndVal% for the *a priori* defined ecological zones. These analyses were also performed using PAST software, version 4.12 (Hammer and Harper, 2001).

We calculated IndVal% values along with their statistical significance (p-values), determining the indicator value for each species based on its relative frequency and abundance within each zone, following the methodology of Dufrêne and Legendre (1997). To assess the statistical significance of species-habitat associations, we performed a randomization test with 999 permutations, comparing observed values to a null distribution. We considered a species a significant indicator of a given ecosystem when $p < 0.05$, indicating a non-random and strong association with that specific habitat.

Results and Discussion

Floristic classification and identification

A total of 23 botanical families, 55 species and 366 individuals were registered in the floristic inventory (Figure 2). The families with the highest number of species were: Moraceae (nine species), Malvaceae (eight species), Fabaceae (seven species), and Areceacea (five species), which represent 17.4% of all families. There were families with lower representation: Cordiaceae and Lauraceae, with three species each; and Meliaceae, Mimosaceae, and Ulmaceae with two species each. On the other hand, there were 14 families (60.9%) with only one species at the 'La Montaña enclave'. The families Moraceae, Malvaceae, Fabaceae, and Arecaceae had the highest number of species which shows how ecologically important 'La Montaña enclave' is, due to their adaptability and success in this forest. The area harbors relatively high diversity, which suggests that this is a complex ecosystem with a potential for diversity of microhabitats and ecological niches.

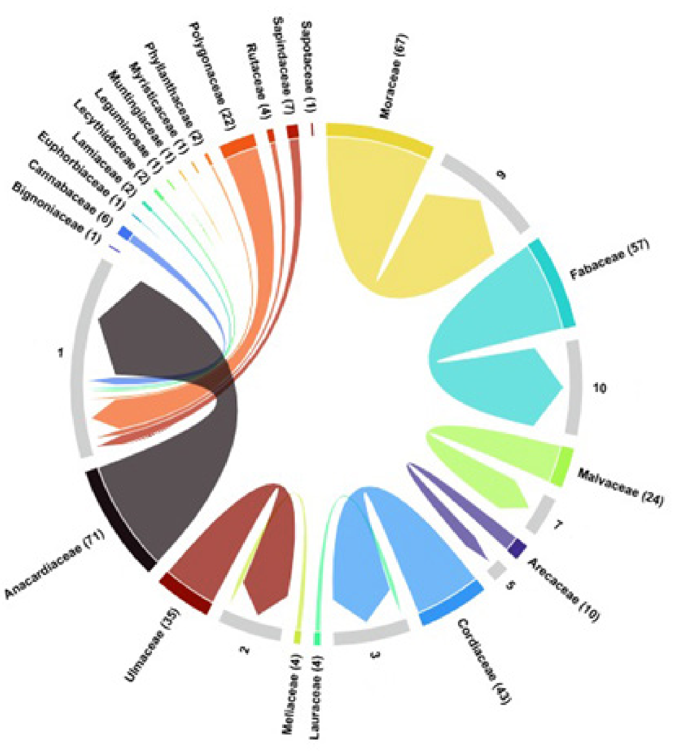

Figure 2: *Number of botanical families registered in 'La Montaña enclave'. The arrows indicate the number of species per family; the value in parentheses corresponds to the total number of individuals recorded for each family.*

This floristic composition was similar at found in the lower montane evergreen forest, Zamora Chinchipe Province, Ecuador; that were registered 46 species of 35 genera and 20 families; 33 arboreal and 13 shrubby, being the most diverse families in the arboreal stratum were: Lauraceae, Melastomataceae, Rubiaceae and Euphorbiaceae; and, in the shrub layer, Lauraceae, Primulaceae, Chlorantaceae and Rubiaceae (Aguirre *et al*., 2018). This result was similar at found for Jadán *et al*. (2022), who found that the five most diverse families were Fabaceae (35 species), Moraceae (17 species), Lauraceae (12 species), Rubiaceae (11 species), and Meliaceae (10 species) in the Bosque Protector Chongón Colonche, a lowland mountain range in coastal Ecuadorian. According to Mosquera (2017), in the municipality of Manungará, Tadó, Chocó, Colombia, the Rubiaceae, Arecaceae, Moraceae, Melastomataceae, Annonaceae, Clusiaceae, botanical families, among others, were found. This would classify the forest as a tropical rainforest life zone (bp-T).

Vegetation units

Three vegetation units were identified: forest zone, flood zone and swamp zone. During the rainy season (Figure 1), each type of plant was essential to the conservation of the ecosystem, while the diversity of species varied according to the conditions of the weather and the soil. Other studies have shown that this pattern is also present in other forest regions, such as the Chocó Forest in Colombia. Álvarez-Dávila *et al*. (2016) showed three physiographics in the forests: well-drained (hill), permanently flooded (terrace), and swamp zones. In the Bosque Protector Chongón Colonche (protected forest), a lowland mountain range in coastal Ecuadorian, six forest communities were found, each of these six forests has a distinct floristic composition, structure, and environmental optimal (Jadán *et al*., 2022).

The PCA of the 55 species (366 individuals) from several vegetation units showed that the self-values of PC1 and PC2 explain 98.2% of the data variation (Table 1; Figure 3). The first major component explained 74.0% of the variability, through DBH (0.967) and BA (0.931); while the second component explained 24.2% of the variability, explained with PH (0.762). It is possible to observe the distribution of individuals in all quarters, and this showed high variability on trees' sizes found at 'La Montaña enclave'.

Table 1: *Contribution of three axes created by principal component analysis (PCA), correlation of variables with the axis, percentage of explained and accumulated variance, based on three characteristics evaluated in several vegetation units in 'La Montaña enclave'.*

Variables	Loadings		
	PC1	PC2	PC3
Diameter at breast height (DBH)	0.967	-0.192	-0.166
Plant height (PH)	0.647	0.762	0.025
Basal area (BA)	0.931	-0.330	0.155
Standard deviation	1.490	0.853	0.229
Proportion of Variance	0.740	0.242	0.017
Cumulative Proportion	0.740	0.983	1.000

The individuals *Anacardium excelsum* (AEX-F), *Pithecellobium micradenium* (PMIC-F), *Ficus* sp. (FIC-F) y *Samanea saman* (SSA-S), showed higher DBH (129 to 180 cm) and BA (1.3 to 2.5 m) values. As for the individuals found in the woodland areas, *A. excelsum* (AEX-F), *Bactris gasipaes* (BGA-F), *Attalea colenda* (ACO-F), *Aspidosperma excelsum* (AEXC-F), *P. micradenium* (PMIC-F), *Clarisia racemosa* (CRA-F), *Gustavia superba* (GSU-F) y *Erythrina poeppigiana* (EPO-F), showed the highest height for plants (35 to 40 m).

Anacardiaceae is an ecologically and economically important plant family of about 200 species in 32 genera in the Neotropics (Mitchell *et al*., 2022). *Anacardium excelsum*, commonly known as 'caracolí' in Ecuador, Colombia, and Venezuela, is a forest species found at the dry and humid American tropics, as well as in gallery forests, from Costa Rica to the north of South America. This species is associated with other species, and sometimes in pure forests, it is dominant or co-dominant (Santander and Albertin, 1980). In Colombia, the restoration of forests through the translocation of native species has regained importance and *A. excelsum* represents a good candidate for local and national restoration programs of the seasonally dry tropical forests (Bocanegra-González and Guillemin, 2018). According to Mitchell *et al*. (2022), in some Neotropical cities this specie is planted as a street tree.

In the forest zone, there were three important groups based on the Importance Value Index (IVI). The first group had 39 species (86.7%), with IVI between 0.36-3.3%; the second group (11.1%) comprised of the species *C. alliadora, E. poeppigiana, Ficus* sp, *Pseudolmedia rigida* and *T. cumingiana* showed IVI between 4.71-7.57%; the third group, comprised of the species *A. excelsum*, obtained the highest IVI (28.32%), making it the most dominant species in the forest zone (Table 2). In a similar study in Sumaco Biosphere Reserve (Ecuador), which aimed to know the tree diversity and its ecological importance value in silvopastoral systems, the use of the IVI helped to identify the most important tree species in the pastures with trees dispersed along the altitudinal gradient studied represented approximately more than 70% of the IVI in the low and middle zones and up to 96% in the high zone (Torres *et al*., 2024).

The species in the forest zone with the highest IVI were generally timber. According to Quiroz (2010), the timber species of Palo Prieto (*E. poeppigiana* (Walp.) of Cook), Yuca de Ráton (*Gliricidia sepium* (Jacq.) Walp.), Laurel (*C. alliodora* (Ruiz and Pav.) Oken), adapted to the vast ecological zones and provided additional economic income to cacao producers, thus, it is recommended to grow these species with cacao. Likewise, Laurel (*C. alliodora*), Fernán Sánchez (*Triplaris guayaquilensis* Weed), Pachaco (*Schizolobium parahyba* (Vell.) S.F. Blake), Guachapelí (*Albizia guachapele* (Kunth) Dugand), Moral Fino (*Maclura tinctoria* (L.) D. Don ex Steud), are timber species associated with cacao production as well Prieto-Benavides *et al*. (2012).

In the flood zone, during the rainy season, the majority of species (90%) reported IVI levels lower than 7.49%. The species of *C. peltata* y *E. glauca* were the most dominant, as demonstrated by their IVI of 18.2 and 34.6%, respectively (Table 2). This might be due to their ability to tolerate flood conditions and compete with efficiency for resources with other species. These species also play an important role for the preservation of biodiversity and ecological stability of the area. Meanwhile, the species of *C. peltata* y *E. glauca*, belonging to the swamp zone stood out with IVI de 41.31 and 44.36%, respectively (Table 2). In the forest zone, there were species of economic and ecological importance. For example, cacao has important implications for the diversity of vascular epiphytes, shade cacao plantations preserve a portion of the diversity, suggesting some management practices that might improve vascular epiphytic conservation in cocoa agroforests (Haro-Carrión *et al*., 2009).

The timber species of *T. guayaquilensis* Weed (Fernán Sánchez), *Cybistax donnell-smithii* Rose (Guayacán Blanco), *Colubrina arborescens* (Mill.) Sarg (Caoba

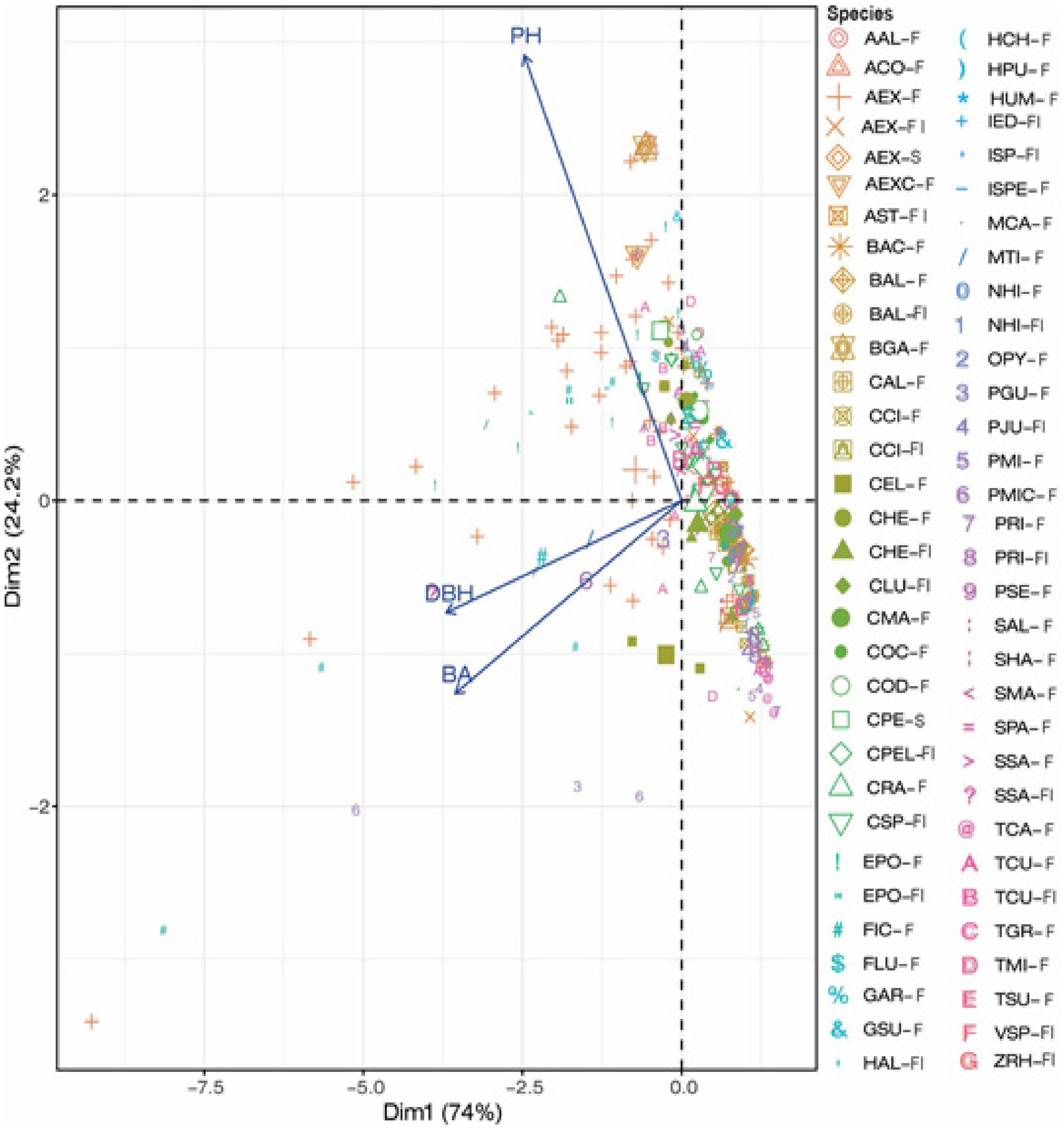

Figure 3: *Principal components analysis carried out with dasometric variables in the floristic inventory of the 'La Montaña enclave', 366 individuals of 55 species in the different vegetation units. Anacardium excelsum (AEX), Artocarpus altilis (AAL), Aspidosperma excelsum (AEXC), Astrocaryum standleyanum (AST), Attalea colenda (ACO), Bactris gasipaes (BGA), Bactris sp. (BAC), Brosimun alicastrum (BAL), Castilla elastica (CEL), C. tunu (CTU), Cecropia peltata (CPEL), Cecropia spp. (CSP), Cedrela odorata (COD), Ceiba pentandra (CPE), Centrolobium ochroxylum (COC), Chrysophyllum lucentifolium (CLU), Clarisia racemosa (CRA), Cordia alliadora (CAL), C. hebeclada (CHE), C. macrantha (CMA), Cupania cinerea (CCI), E. glauca (EGL), E. poeppigiana (EPO), Ficus luschnathiana (FLU), Ficus sp. (FIC), Gmelina arborea (GAR), Gustavia superba (GSU), Herrania purpurea (HPU), H. umbratica (HUM), Hieronyma alchorneoides (HAL), Inga edulis (IED), I. spectabilis (ISPE), Inga spp. (ISP), Maclura tinctoria (MTI), Muntingia calabura (MCA), Nectandra hihua (NHI), Ochroma pyramidale (OPY), Phyllantus juglandifolia (PJU), Phytelephas seemannii (PSE), Pithecellobium micradenium (PMIC), Pseudobombax millei (PMI), P. rigida (PRI), Pseudosamanea guachapele (PGU), Samanea saman (SSA), Sassafras albidum (SAL), Schizolobium parahyba (SPA), Swartzia haughtii (SHA), Swietenta macrophylla (SMA), Tabebuia chrysantha (TCH), Theobroma grandiflorum (TGR), T. cacao (TCA), T. subincanum (TSU), Trema micrantha (TMI), Triplaris cumingiana (TCU), Virola spp. (VSP) y Zanthoxylum rhoifolium (ZRH). F= forest zone, Fl= flood zone and S= Swamp zone.*

Table 2: *Floristic inventory in several areas found in 'La Montaña enclave', showing the values of abundance (RA), frequency (RF), dominance (RD), and IVI, for the species in forest zone, flood zone and swamps zone. INIAP, Ecuador.*

Species	Common name	Forest zone					Flood zone					Swamp zone				
		RA (%)	RF (%)	RD (%)	IVI	Group	RA (%)	RF (%)	RD (%)	IVI	Group	RA (%)	RF (%)	RD (%)	IVI	Group
Anacardium excelsum (Bertero ex Kunth) Skeels.	Marañón	24.90	11.33	48.74	28.32	3	6.41	6.00	1.61	4.67	1	4.17	5.26	0.38	3.27	1
Artocarpus altilis Parkinson ex F.A.Zorn) Fosberg.	Fruta de pan	0.77	1.33	0.29	0.80	1	-	-	-	-	-	-	-	-	-	-
Aspidosperma excel-sum Benth	Naranjo de monte	0.38	0.67	0.23	0.43	1	-	-	-	-	-	-	-	-	-	-
Astrocaryum standleyanum L.H.Bailey	Mocora	-	-	-	-	-	1.28	2.00	0.37	1.22	1	-	-	-	-	-
Attalea colenda (O.F.Cook) Balslev and A.J.Hend.	Palma	0.77	1.33	0.16	0.75	1	-	-	-	-	-	-	-	-	-	-
Bactris gasipaes Kunth	Palma	0.77	1.33	0.17	0.76	1	-	-	-	-	-	-	-	-	-	-
Bactris sp.	Chonta	1.53	1.33	0.10	0.99	1	-	-	-	-	-	-	-	-	-	-
Brosimun alicastrum Sw.	Tillo dulce	0.38	0.67	0.11	0.39	1	1.28	2.00	0.14	1.14	1	-	-	-	-	-
Castilla elastica Cerv.	Caucho	0.77	0.67	1.24	0.89	1	-	-	-	-	-	-	-	-	-	-
C. tunu Hemsl.	Cauchillo	1.15	2.00	0.10	1.08	1	10.26	10.00	2.22	7.49	1	8.33	10.53	2.97	7.28	1
Cecropia peltata (L.) *Gaertn.*	Guarumo						26.92	20.00	7.60	18.18	2	50.00	52.63	21.31	41.31	2
Cedrela odorata L.	Cedro	1.15	2.00	0.25	1.13	1	-	-	-	-	-	-	-	-	-	-
Ceiba pentandra (L.) Gaertn.	Ceibo	-	-	-	-	-	-	-	-	-	-	4.17	5.26	1.92	3.78	1
Centrolobium ochroxylum Rose ex Rudd.	Amarillo lagarto	0.77	1.33	0.15	0.75	1	-	-	-	-	-	-	-	-	-	-
Chrysophyllum lucentifoli-um Cronquist	Cauje	-	-	-	-	-	1.28	2.00	0.08	1.12	1					
Clarisia racemosa Ruiz and Pav.	Moral bobo	2.68	3.33	1.61	2.54	1	-	-	-	-	-	-	-	-	-	-
Cordia alliadora (Ruiz and Pav.) Oken	Laurel	8.81	8.00	1.57	6.13	2	-	-	-	-	-	-	-	-	-	-
C. hebeclada I.M.Johnst.	Tutumbe	3.45	2.67	1.24	2.45	1	3.85	6.00	1.63	3.83	1	-	-	-	-	-
C. macrantha Chodat.	Laurel negro	3.07	2.67	0.56	2.10	1						-	-	-	-	-
Cupania cinerea Poepp	Come pava	1.92	2.00	0.34	1.42	1	2.56	4.00	0.31	2.29	1	-	-	-	-	-
Erythrina glauca L. Willd	Palo prieto	0.77	1.33	2.81	1.64	1	17.95	20.00	65.82	34.59	3	33,33	26.32	73.42	44.36	2
E. poeppigiana (Walp.) O.F.Cook	Bombón	4.98	4.67	6.37	5.34	2	2.56	4.00	5.49	4.02	1					
Ficus luschnathiana (Miq.) Miq.	Higuerón	1.15	2.00	0.42	1.19	1	-	-	-	-	-	-	-	-	-	-
Ficus sp.	Mata palo	3.07	4.67	14.97	7.57	2	-	-	-	-	-	-	-	-	-	-
Gmelina arborea Roxb.	Melina	0.77	0.67	0.09	0.51	1	-	-	-	-	-	-	-	-	-	-
Gustavia superba (Kunth) O. Berg	Menbrillo	0.77	1.33	0.05	0.72	1	-	-	-	-	-	-	-	-	-	-
Handroanthus chrysanthus (Jacq.) S.O.Grose	Guayacán	0.38	1.33	0.23	0.65	1	-	-	-	-	-	-	-	-	-	-
Herrania purpurea (Pittier) R.E.Schult.	Cacao de mano	0.38	0.67	0.03	0.36	1	-	-	-	-	-	-	-	-	-	-
H. umbratica R.E.Schult.	Cacao de monte	0.38	0.67	0.04	0.36	1	-	-	-	-	-	-	-	-	-	-
Hieronyma alchorneoides Allemão	Palo curtidor	-	-	-	-	-	1.28	2.00	0.34	1.21	1	-	-	-	-	-

Table continues on next page..........

Species	Common name	Forest zone				Group	Flood zone				Group	Swamp zone				Group
		RA (%)	RF (%)	RD (%)	IVI		RA (%)	RF (%)	RD (%)	IVI		RA (%)	RF (%)	RD (%)	IVI	
Inga edulis Mart.	Guaba de bejuco	-	-	-	-	-	1.28	2.00	0.16	1.,15	1	-	-	-	-	-
I. spectabilis (Vahl) Willd.	Guaba de machete	0.38	0.67	0.04	0.36	1	1.28	2.00	0.23	1.17	1	-	-	-	-	-
Maclura tinctoria (L.) D.Don ex Steud.	Moral fino	1.15	2.00	3.59	2.25	1	-	-	-	-	-	-	-	-	-	-
Muntingia calabura L.	Niguito	0.38	0.67	0.16	0.40	1	-	-	-	-	-	-	-	-	-	-
Nectandra reticulata (Ruiz and Pav.) Mez	Jigua	0.38	0.67	0.06	0.37	1	-	-	-	-	-	-	-	-	-	-
Ochroma pyramidale (Cav. ex Lam.) Urb.	Balsa	4.21	4.00	0.55	2.92	1	-	-	-	-	-	-	-	-	-	-
Ocotea cernua (Nees) Mez	Palo largo	-	-	-	-	-	1.28	2.00	0.16	1.15	1	-	-	-	-	-
Phyllantus juglandifolia Willd	Camo de Costa	-	-	-	-	-	2.56	2.00	0.47	1.68	1	-	-	-	-	-
Phytelephas seemannii O.F.Cook	Mococha	0.38	0.67	0.06	0.37	1	-	-	-	-	-	-	-	-	-	-
Pithecellobium micradenium Benth.	Bantano	1.53	2.67	5.69	3.30	1	-	-	-	-	-	-	-	-	-	-
Pseudobombax millei (Standl.) A. Robyns	Beldaco	0.77	1.33	0.14	0.75	1	-	-	-	-	-	-	-	-	-	-
Pseudolmedia rigida (Klotzsch and H.Karst.) Cuatrec	Guión	9.20	7.33	1.45	5.99	2	1.28	2.00	0.14	1.14	1	-	-	-	-	-
Pseudosamanea guachapele (Kunth) Harms	Guachapeli	1.15	2.00	1.80	1.65	1	-	-	-	-	-	-	-	-	-	-
Samanea saman (Jacq.) Merr	Saman	0.77	1.33	0.45	0.85	1	1.28	2.00	7.66	3.65	1	-	-	-	-	-
Sassafras albidum (Nutt.) Nees.	Sasáfras	0.38	0.67	0.24	0.43	1	-	-	-	-	-	-	-	-	-	-
Schizolobium parahyba (Vell.) S.F.Blake	Pachaco	0.77	0.67	0.26	0.57	1	-	-	-	-	-	-	-	-	-	-
Swartzia haughtii R, S. Cowan.	Mea sangre	0.38	0.67	0.16	0.40	1	-	-	-	-	-	-	-	-	-	-
Swietenta macrophylla G. King.	Caoba	0.38	0.67	0.23	0.43	1	-	-	-	-	-	-	-	-	-	-
Theobroma grandiflorum (Willd. ex Spreng.) Schum.	Copoazú	0.77	0.67	0.04	0.49	1	-	-	-	-	-	-	-	-	-	-
T. cacao L.	Cacao nacional	2.68	4.00	0.22	2.30	1	-	-	-	-	-	-	-	-	-	-
T. subincanum March.	Cacao de monte	0.38	0.67	0.08	0.38	1	-	-	-	-	-	-	-	-	-	-
Trema micrantha (L.) Blume	Sapan de paloma	2.30	2.67	0.53	1.83	1	-	-	-	-	-	-	-	-	-	-
Triplaris cumingiana Fisch. and C.A.Mey.	Fernan Sanchez	5.75	6.00	2.37	4.71	2	8.97	4.00	4.60	5.86	1	-	-	-	-	-
Virola spp.	Carachaco-co, Llora sangre	-	-	-	-	-	1.28	2.00	0.34	1.21	1	-	-	-	-	-
Zanthoxylum rhoifolium Lam.	Tachuelo	-	-	-	-	-	5.13	4.00	0.65	3.26	1	-	-	-	-	-

de Montaña) and *Cordia macrantha* Chodat (Laurel Prieto) have been employed in studies on *T. cacao* association, where *T. guayaquilensis* and *C. donnell-smithii* obtained the highest accumulated volume of wood. The association of *T. guayaquilensis* with cacao showed the highest yield relative to dry cacao during the dry season, which makes it an excellent alternative for agroforest systems (Tapia-Vera *et al.*, 2021).

In the forest zone, there are species native to the region. The species *C. macranta* Chodat (Laurel Prieto) belongs to the Cordiaceae familiy, and is a symbolic species of the Guayas province and the country. It is an endemic species of the dry deciduous forest of the Ecuadorian Pacific coast, which have been used for a long time as an agroforest ecosystem species (Cornejo, 2015). This species is used for house building by the local population in rural zones (Macará and Zapotillo, Provincia de Loja) with dry forests (Sánchez *et al.*, 2006). It is also a timber species of the Seasonal Dry Forests of Ecuador and Perú, found mainly in the provinces of Guayas and Loja, and of great ecological importance (Aguirre *et al.*, 2006; Aguirre and Kvist, 2009). The species *T. guayaquilensis* (Fernan Sánchez), from the Polygonaceae family, native to Ecuador wherein there is genetic diversity for this species. The species is well distributed throughout the coastal regions and near the Andes mountains, and it shows rapid vegetative growth (Nieto-Rodríguez *et al.*, 2013). It is one of the species that forms the floristic composition and structure of dry forests in Ecuador. It is in high demand for construction, agroforestry and the furniture industries (Aguirre and Kvist, 2009; Nieto-Rodríguez *et al.*, 2013).

The composition of the vegetation was dramatically different in the three areas; the forest, flood and swamp zone registered 81.8, 36.4 and 9.0%, respectively, of the reported species on 'La Montaña enclave' (Table 3). The biodiversity indicators showed that the forest zone had the highest diversity of species (H_{SD}= 0.906, H'= 3.015 and D_{mg}= 7.913), followed by the flood zone (H_{SD}= 0.861, H'= 2.392 and D_{mg}= 4.348) and the swam zone (H_{SD}= 0.666, H'= 1.258 and D_{mg}= 1.228). These results showed that, in 'La Montaña enclave', the diversity of species is high in the forest zone, and it decreased in the flood and swamp zones. The Pielou's evenness index (J) obtained values 0.792, 0.798 and 0.782, for forest, flood and swamp zone, respectively. These results indicate that the tree species in the evaluated areas present a relatively balanced abundance distribution, suggesting a moderate equity in the distribution of individuals among the tree species in the studied community, which could be associated with greater ecological stability and functional diversity in the ecosystem.

The dendrogram for each vegetation unit, analyzed using the Bray-Curtis similarity index (Figure 4), shows the effects of the vegetation unit on species composition. Thus, flood and swamp zone are similar in terms of species abundance and diversity, while the forest zone had different values. This indicates that this unit possesses distinct characteristics that make it different from other vegetation units in the study.

Table 3: *Diversity indexes per vegetation unit in 'La Montaña enclave'.*

Diversity Index	Vegetation unit		
	Forest zone	Flood zone	Swamp zone
Richness (S)	45	20	5
Individuals	261	79	26
Simpson_1-D Index (H_{SD})	0.906	0.861	0.666
Shannon_H Index (H')	3.015	2.392	1.258
Margalef Index (D_{mg})	7.913	4.348	1.228
Pielou's evenness index (J)	0.792	0.798	0.782

According to Ferreira-Júnior *et al.* (2016) the moisture gradient is a determining factor to explain floristic variations of plant communities. Hence, flood and soil water table oscillations are key environmental (abiotic) variables that define plant community patterns in the Pantanal landscape (Brazil). The coexistence of species with very contrasting environmental requirements in Pantanal is only possible because of the proximity of large adjacent phytogeographical spaces (Chaco, Cerrado and Amazonia).

A similar result was reported by Álvarez-Dávila *et al.* (2016) in three plant associations in the San Juan River Delta, Chocó, Colombia, which found a high diversity of species, and in the same way a high density of small and medium-sized trees in the terrace and the hill, in contrast to the low richness in the swamp zone with predominance of one species and a higher basal area. In Brazil's forest, the decrease of species richness and diversity in function of increasing flood duration and intensity were report (Ferreira, 2000; Ferreira-Júnior *et al.*, 2016). In swamp vegetation in Peruvian Amazonia, Kalliola *et al.* (1991), it was found that the number of species for the category of shrub swamps was low, while *C. latiloba* Miq. (Cecropiaceae) had the highest number of species.

According to Kurtz *et al*. (2013) swamp forests (Southeastern Brazil) are associated with soils that are saturated or flooded because of a high-water table; ecological conditions, and geographic proximity are key to determining floristic composition, in swamp forests in Southeast Brazil a stronger floristic resemblance to their closest neighbors (areas of dry, open resting within the same park) and to a few other swamp forests, than to the adjacent Atlantic Forest in the mountain chains and flooded riparian forests at the regional or national level.

Of the total registered species in 'La Montaña enclave' (55 species), 61.8% are found exclusively in forest areas; seven species (12.7%) are found exclusively in flood zone; and only one species is unique to swamp areas (*Ceiba pentandra* - CPE) (Figure 4). The species *A. excelsum* (AEX), *Castilla tunu* (CTU) and, *E. glauca* (EGL) are present in the three conservation units; meanwhile, the species *Brosimum alicastrum* (BAL), *C. hebeclada* (CHE), *Cupania cinerea* (CCI), *E. poeppigiana* (EPO), *Inga edulis* (IED), *Nectandra hihua* (NHI), *P. rigida* (PRI), *S. saman* (SSA) y *T. cumingiana* (TCU) are found in the forest and flood zone. Of the total species found at the enclave, 44% can be used for timber in Ecuador: *C. pentandra, A. excelsum, Castilla tunu, B. alicastrum E. poeppigiana, N. hihua, P. rigida, S. saman* y *T. cumingiana* (Palacios, 2011).

The timber species are characterized by their great size, which makes them adaptable to flood zone.

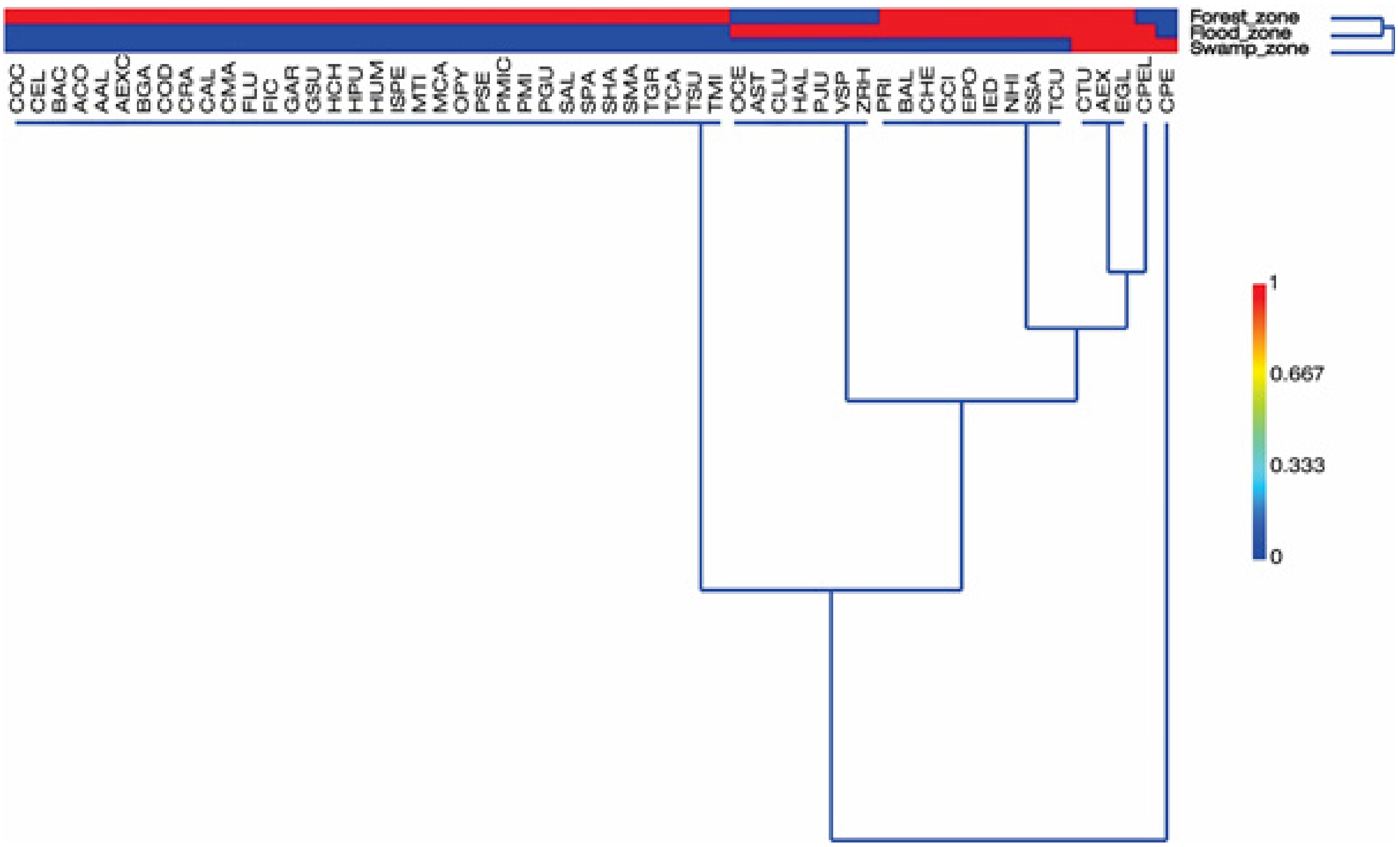

Figure 4: *Clusters analysis with several zones of vegetation at 'La Montaña enclave'. Anacardium excelsum (AEX), Artocarpus altilis (AAL), Aspidosperma excelsum (AEXC), Astrocaryum standleyanum (AST), Attalea colenda (ACO), Bactris gasipaes (BGA), Bactris sp. (BAC), Brosimun alicastrum (BAL), Castilla elastica (CEL), Castilla tunu (CTU), Cecropia peltata (CPEL), Cecropia spp. (CSP), Cedrela odorata (COD), Ceiba pentandra (CPE), Centrolobium ochroxylum (COC), Chrysophyllum lucentifolium (CLU), Clarisia racemosa (CRA), Cordia alliadora (CAL), C. hebeclada (CHE), C. macrantha (CMA), Cupania cinerea (CCI), Erythrina glauca (EGL), E. poeppigiana (EPO), Ficus luschnathiana (FLU), Ficus sp. (FIC), Gmelina arborea (GAR), Gustavia superba (GSU), Herrania purpurea (HPU), H. umbratica (HUM), Hieronyma alchorneoides (HAL), Inga edulis (IED), Inga spectabilis (ISPE), Inga spp. (ISP), Maclura tinctoria (MTI), Muntingia calabura (MCA), Nectandra hihua (NHI), Ochroma pyramidale (OPY), Phyllantus juglandifolia (PJU), Phytelephas seemannii (PSE), Pithecellobium micradenium (PMIC), Pseudobombax millei (PMI), P. rigida (PRI), Pseudosamanea guachapele (PGU), Samanea saman (SSA), Sassafras albidum (SAL), Schizolobium parahyba (SPA), Swartzia haughtii (SHA), Swietenta macrophylla (SMA), Tabebuia chrysantha (TCH), Theobroma grandiflorum (TGR), T. cacao (TCA), T. subincanum (TSU), Trema micrantha (TMI), T. cumingiana (TCU), Virola spp. (VSP) y Zanthoxylum rhoifolium (ZRH).*

In the Ucayali River (Peru), forest species such as *Adenaria floribunda* H.B.K. (Lytharaceae), *Alchornea catanaefolia* A. Juss (Euphrobiaceae), and *Salix martiana* Leyb. (Salicaceae) were observed in the outermost shrub swamps (Kalliola *et al*., 1991). The differences in the distribution of dominant species in flooded forests in the Jaú and Tarumã-Mirim floodplains (Brazil), are probably related to their ability to tolerate seasonal floods (Ferreira-Júnior *et al*., 2016).

The flood and swamp zones at 'La Montaña enclave' both have the species *C. peltata*, CPEL (Figure 4). *Cecropia* species have been reported in other studies as tolerant to flood zones (Kalliola *et al*., 1991; Kurtz *et al*., 2013). For example, in Manaus, Brazil, *C. latiloba* Miq. (Cecropiaceae) is considered to be one of the most efficient colonizers of open areas in the Amazonian floodplain; its main strategy to be successful is the high tolerance towards waterlogging and submergence, and the fast vertical growth and reiteration capacity (Parolin, 2002). Species of the genus *Cecropia* represent an important ecological relationship, with biological interactions reported, for example, predation of ants by birds (Mangini and Thomas, 2020) and are efficient floodplain colonizers in open areas of Amazonian várzea (Parolin, 2003).

In addition to these observations, the species turnover, or beta diversity, plays a key role in understanding the differentiation of vegetation between these zones (Figure 4). Beta diversity can help explain why certain species, like *Cecropia*, are more dominant in flood-prone areas while others are better adapted to less disturbed environments. The flood and swamp zones at 'La Montaña enclave', with their distinct environmental conditions, likely support different species assemblages. This species turnover can be linked to ecological processes such as habitat disturbance, competition, and environmental filtering. Thus, understanding beta diversity in these areas can provide deeper insights into the dynamics of species distribution and the role of environmental factors in shaping community composition (Baselga, 2010; Lomolino *et al*., 2010).

In other the hand, the IndVal% analysis (Figure 5) revealed that AEX is significantly associated with the forest zone, with an IndVal% of 59.96% and a *p*-value= 0.001. This result indicates that AEX is a good indicator of this ecosystem, as its presence is strongly linked. In contrast, its values in the flood (3.32%) and swamp (1.49%) zones are low and statistically non-significant ($p > 0.05$), suggesting that its presence in these areas is sporadic or the result of chance.

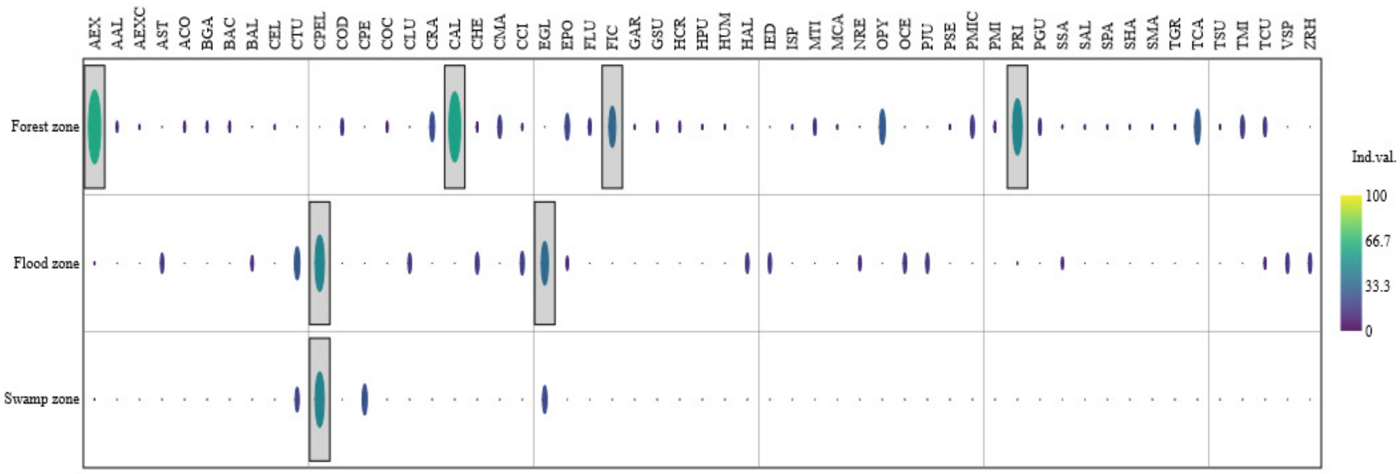

Figure 5: *Indicator species across ecological zones based on Indicator Value Analysis (IndVal%). Anacardium excelsum (AEX), Artocarpus altilis (AAL), Aspidosperma excelsum (AEXC), Astrocaryum standleyanum (AST), Attalea colenda (ACO), Bactris gasipaes (BGA), Bactris sp. (BAC), Brosimun alicastrum (BAL), Castilla elastica (CEL), C. tunu (CTU), Cecropia peltata (CPEL), Cecropia spp. (CSP), Cedrela odorata (COD), Ceiba pentandra (CPE), Centrolobium ochroxylum (COC), Chrysophyllum lucentifolium (CLU), Clarisia racemosa (CRA), Cordia alliadora (CAL), C. hebeclada (CHE), C. macrantha (CMA), Cupania cinerea (CCI), E. glauca (EGL), E. poeppigiana (EPO), Ficus luschnathiana (FLU), Ficus sp. (FIC), Gmelina arborea (GAR), Gustavia superba (GSU), Herrania purpurea (HPU), H. umbratica (HUM), Hieronyma alchorneoides (HAL), Inga edulis (IED), I. spectabilis (ISPE), Inga spp. (ISP), Maclura tinctoria (MTI), Muntingia calabura (MCA), Nectandra hihua (NHI), Ochroma pyramidale (OPY), Phyllantus juglandifolia (PJU), Phytelephas seemannii (PSE), Pithecellobium micradenium (PMIC), Pseudobombax millei (PMI), P. rigida (PRI), Pseudosamanea guachapele (PGU), Samanea saman (SSA), Sassafras albidum (SAL), Schizolobium parahyba (SPA), Swartzia haughtii (SHA), Swietenta macrophylla (SMA), Tabebuia chrysantha (TCH), Theobroma grandiflorum (TGR), T. cacao (TCA), T. subincanum (TSU), Trema micrantha (TMI), Triplaris cumingiana (TCU), Virola spp. (VSP) y Zanthoxylum rhoifolium (ZRH).*

The species AST showed an IndVal% of 16.67% in the flood zone, but its p-value= 0.1911 indicates that this relationship is not statistically significant. Although the species may be present in the flood zone, its distribution is not sufficiently representative to be considered a reliable bioindicator. Other species, such as AAL and AEXC, showed low IndVal% values in all zones and $p>0.05$, suggesting they are not explicitly associated with any ecosystem. Their wide or random distribution may indicate that these species are not dependent on particular environmental conditions but have a higher tolerance to habitat variation.

These results reflect the absence of multiple indicator species with significant associations in the ecosystems assessed. The strong relationship of AEX with the forest zone suggests that this species might be adapted to particular conditions, such as more stable soils and lower water variability, consistent with previous studies that have identified the specialization of certain species in forested habitats (Dirk-Jan *et al*., 2013; Letcher *et al*., 2015; Salas, 2020).

On the other hand, the lack of indicator species in the floodplain and marsh could be related to the high environmental variability of these ecosystems. Fluctuating water levels and other environmental factors may favor generalist species with a broad ecological tolerance rather than highly specialized species. Previous research has shown that species often exhibit phenotypic plasticity strategies in ecosystems with marked water fluctuations, reducing the possibility of finding strict indicators of these environments (Nolan *et al*., 2017; Wei *et al*., 2019; Li *et al*., 2022).

The findings of this study underscore the urgency of implementing public policies aimed at conserving 'La Montaña enclave', a stronghold of biodiversity in the Ecuadorian Chocó. The broad diversity of species, including endemic and ecologically significant ones, highlights the need to establish protected areas and promote the restoration of ecological connectivity with other forest fragments. Moreover, it is crucial to integrate local communities into sustainable management strategies, ensuring that the conservation of the enclave aligns with regional socioeconomic development.

Conclusions and Recommendations

'La Montaña enclave' represents an ecosystem with high ecological relevance. The observed differentiation between vegetation units suggests that the stability and functionality of these ecosystems depend on specific environmental conditions.

The presence of species ecological and economic interest in specific vegetation units presents an opportunity to develop sustainable management approaches that balance ecosystem protection with local production needs. For example, *A. excelsum*, *C. tunu*, *E. glauca*, are adapted to all three environments (forest, flood and swamp zone) and are timber species that can be used to manufacture pallets and shuttering. Also *A. excelsum* could be wildlife refuge and food to mammals, *C. tunu* to latex vegetal extraction and *E. glauca* as living fence, bird nesting, so they are of interest for restoration programs in these areas.

Species such as *C. hebeclada*, *E. poeppigiana* and *T. cumingiana* are well adapted forest and flood zone and commonly could be integrated into a agroforestry system, some species providing regulated shade, fixing nitrogen, enriching the soil, or serving as barriers against pests and diseases, thereby promoting environmental and ecological sustainability without compromising crop productivity. The species *B. alicastrum*, *C. cinerea*, *N. hihua*, *P. rigida* and *S. saman* are forest species with significant ecosystem value, as they provide shade and shelter for wildlife. *Cecropia peltata* is confirmed as an important species in flood and swamp zone.

Understanding the context of landscape transformation in the region, strengthening conservation efforts through long-term monitoring programs and implementing measures to mitigate the impacts of fragmentation and agricultural expansion is essential. to improve the management of these ecosystems, ensuring their functionality and resilience in the face of environmental and anthropogenic changes.

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Novelty Statement

'La Montaña enclave' (EETP-INIAP), with its three distinct vegetation units: forest, flood, and swamp zones, is a highly significant ecosystem. A total of 23 botanical families, 55 species, and 366 individuals were identified, highlighting the area's rich plant diversity and ecological complexity. The differentiation among these vegetation units underscores their dependence on specific environmental conditions. Identifying bioindicator species reinforces the necessity of biodiversity-based monitoring and management strategies.

Authors' Contribution

Raúl Valentín Mora Yela: Conceived the study idea, conducted the fieldwork, collected data and analysed and visualised the data.
Cesar Tapia Bastidas and Joaquin Giménez de Azcárate-Cornide: Provided guidance throughout the research process, helped in the writing and reviewing the manuscript.
Fernando David Sánchez-Mora, Carlos A. Salas-Macías and Adriana Beatriz Sánchez-Urdaneta: Contributed during data analysis, writing up and editing of the manuscript.

Availability of data
Data are available on request from the authors.

Conflict of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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