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Original article

Structure, floristic diversity and carbon storage in the aboveground biomass of a piemont evergreen forest in the Cordillera del Cóndor-Kutukú

Estructura, diversidad florística y almacenamiento de carbono en la biomasa aérea de un bosque siempreverde piemontano en la Cordillera del Cóndor-Kutukú

Estrutura, diversidade florística e armazenamento de carbono na biomassa acima do solo de uma floresta perene do Piemonte na cordilheira Cóndor-Kutukú

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ABSTRACT

The piemont forests of southern Ecuador harbor a unique composition of forest species, giving them exceptional value from the perspective of conservation and sustainable management. The objective of this study was to evaluate the composition, structure, diversity, and carbon storage potential of a Piemont Evergreen Forest in the Cordillera del Cóndor-Kutukú. Five 20 × 20 m sampling plots were established, in which all woody individuals, including palms, with a diameter at breast height ≥ 10 cm were recorded. The floristic inventory identified a total of 48 species belonging to 38 genera and 21 botanical families. The vertical structure of the forest presented a bell-shaped distribution, with a higher concentration of individuals in the intermediate stratum (10–19.99 m). The horizontal structure showed an inverted J distribution, typical of self-sustaining forest communities. The study area presented moderate diversity, with a Shannon-Wiener index of 3.36. Aboveground biomass reached 287.58 Mg ha⁻¹, equivalent to an estimated stored carbon stock of 135.16 Mg ha⁻¹. The species with the highest ecological importance were *Aniba muca* and *Wettinia maynensis*, notable for their abundance and biomass. This study highlights the need to implement management and conservation strategies that protect the functionality of these ecosystems and promote their sustainability in the face of increasing anthropogenic pressures.

Keywords: Ecuador, forestry, conservation, ecology, inventory.

RESUMEN

Los bosques piemontanos del sur de Ecuador albergan una composición única de especies forestales, lo que les otorga un valor excepcional desde el punto de vista de la conservación y el manejo sostenible. El objetivo de este estudio fue evaluar la composición, estructura, diversidad y el potencial de almacenamiento de carbono de un bosque siempreverde piemontano de la Cordillera del Cóndor-Kutukú. Se establecieron cinco parcelas de muestreo de 20 × 20 m, en las cuales se registraron todos los individuos leñosos, incluidas las palmas, con un diámetro a la altura del pecho ≥ 10 cm. El inventario florístico permitió identificar un total de 48 especies, pertenecientes a 38 géneros y 21 familias botánicas. La estructura vertical del bosque presentó una distribución en forma de campana, con una mayor concentración de individuos en el estrato intermedio (10–19,99 m). La estructura horizontal mostró una distribución de J invertida, típica de comunidades forestales autosustentables. El área de estudio presentó una diversidad moderada, con un índice de Shannon-Wiener de 3,36. La biomasa aérea alcanzó un valor de 287,58 Mg ha^{-1}, lo que equivale a un stock de carbono almacenado estimado en 135,16 Mg ha^{-1}. Las especies con mayores valores de importancia ecológica fueron *Aniba muca* y *Wettinia maynensis*, destacándose por su abundancia y biomasa. Este estudio subraya la necesidad de implementar estrategias de manejo y conservación que protejan la funcionalidad de estos ecosistemas y promuevan su sostenibilidad ante las crecientes presiones antrópicas.

Palabras clave: Ecuador, forestal, conservación, Ecología, inventario.

RESUMO

As florestas do Piemonte, no sul do Equador, abrigam uma composição única de espécies florestais, o que lhes confere um valor excepcional do ponto de vista da conservação e do manejo sustentável. O objetivo deste estudo foi avaliar a composição, estrutura, diversidade e potencial de armazenamento de carbono de uma floresta perene do Piemonte na cordilheira Cóndor-Kutukú. Foram estabelecidas cinco parcelas amostrais de 20 × 20 m, nas quais foram registrados todos os indivíduos lenhosos, incluindo palmeiras, com diâmetro à altura do peito (DAP) ≥ 10 cm. O inventário florístico identificou um total de 48 espécies, pertencentes a 38 gêneros e 21 famílias botânicas. A estrutura vertical da floresta apresentou distribuição em forma de sino, com maior concentração de indivíduos no estrato intermediário (10–19,99 m). A estrutura horizontal apresentou uma distribuição em J invertido, típica de comunidades florestais autossustentáveis. A área de estudo apresentou diversidade moderada, com índice de Shannon-Wiener de 3,36. A biomassa acima do solo atingiu um valor de 287,58 Mg ha^{-1}, o que equivale a um estoque estimado de carbono armazenado de 135,16 Mg ha^{-1}. As espécies com maior importância ecológica foram *Aniba muca* e *Wettinia maynensis*, destacando-se pela abundância e biomassa. Este estudo ressalta a necessidade de implementar estratégias de gestão e conservação que protejam a funcionalidade desses ecossistemas e promovam sua sustentabilidade diante das crescentes pressões humanas.

Palavras-chave: Equador, silvicultura, conservação, ecologia, inventário.

INTRODUCTION

Tropical forests are considered the most biodiverse ecosystems on the planet, hosting an exceptional wealth of flora and fauna. Furthermore, they play essential roles in global biogeochemical cycles, such as climate regulation, water conservation, and carbon storage (Wang *et al.*, 2024). However, within this category, piemont forests have received less attention despite their ecological relevance. In particular, the piemont forests of southern Ecuador, located in the transition zone between lowland and montane forests, stand out not only for their high biodiversity, but also for the key ecosystem services they provide (Jadán *et al.*, 2021). Its transitional location allows the coexistence of species from different altitudinal gradients, giving them unique value for conservation and sustainable management (Huera-Lucero *et al.*, 2024).

Ecuador, recognized as a megadiverse country in terms of ecosystems, species, and cultures (Palacios *et al.*, 2017), has concentrated scientific research on ecosystems with greater visibility, such as páramos and lowland tropical forests (Jadán *et al.*, 2021). In contrast, piemont forests have been less studied, despite their crucial function as biological corridors connecting different habitats and their role in water regulation and carbon capture, both essential for climate change mitigation (Ulloa *et al.*, 2018).

One of the most representative examples of these ecosystems is the Piemont Evergreen Forest of the Cordillera del Cóndor in southern Ecuador. However, its conservation faces significant threats due to deforestation and degradation, driven by agricultural expansion and mining in the region (Jadán *et al.*, 2017). In particular, the province of Zamora Chinchipe has recorded alarming rates of forest loss, it is estimated that approximately 94,353 hectares of forest have been lost in recent years, compromising not only biodiversity but also the provision of essential ecosystem services (González *et al.*, 2016; Vizuete *et al.*, 2023).

Despite their ecological importance, piemont forests remain poorly studied in terms of structure, floristic composition, and ecological dynamics. The lack of detailed information hampers the implementation of appropriate management and conservation strategies. Recent studies have shown that these forests have high potential for climate change mitigation due to their carbon capture and storage capacity, both in aboveground biomass and in soils (Jadán *et al.,* 2017; Palacios *et al.,* 2017; Santander-Malo and García-Quintana 2022). Therefore, it is essential to advance in its ecological characterization to support conservation and sustainable management policies (Rivas, Guerrero-Casado and Navarro-Cerrillo 2024).

In this context, this study aims to evaluate the composition, structure, diversity, and carbon storage potential of the Piemont Evergreen Forest of the Cordillera del Cóndor - Kutukú , in Timbara parish, Zamora Chinchipe province. The information generated will contribute to the design of conservation and sustainable management strategies, promoting a better understanding of the ecological role of these ecosystems and their relevance in mitigating climate change.

MATERIALS AND METHODS

Study area

The study was carried out in the Martin Ujukam sector, Timbara parish, canton and province of Zamora Chinchipe, geographically framed between 4°04'03.8"S and 78°55'23.4"W (Figure 1). The parish has an area of 128.71 km ^{2,} an altitude of 1,048 m a.s.l, average annual rainfall of 2,090 mm and average annual temperature of 23.7ºC (León Abarca *et al.,* 2022).

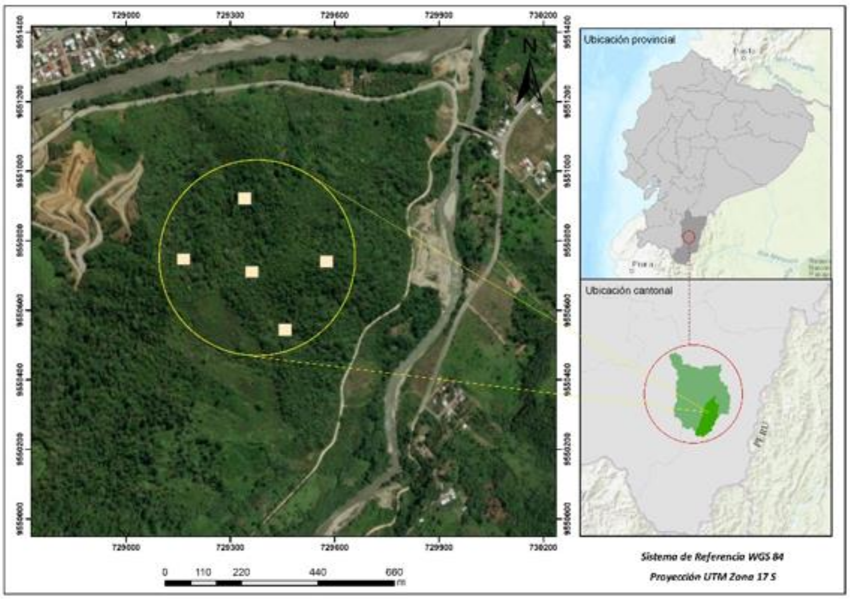

Figure 1. *- Spatial location of the study area*

Collection of floristic information

Systematic surveys were carried out in the Piemont Evergreen Forest to select representative sites, in which five sampling plots of 20 × 20 m (400 m²) were established. The plots were located at a minimum distance of 200 m from each other and at least 60 m from roads, trails or other vegetation cover, in order to minimize the edge effect. In addition, a maximum slope of 45° was considered, and areas with atypical topographic conditions such as watercourses or flooded areas were avoided. In each plot, all woody individuals were inventoried, including palms with a diameter at breast height (DBH) ≥ 10 cm. Each individual was assigned a unique code, its diameter was recorded using a diameter tape and its height with a Vertex hypsometer. Taxonomic identification was performed in the field whenever possible, and unidentified specimens were collected as botanical samples and sent to the "Reinaldo Espinosa" Herbarium for identification.

Structural parameters

The vertical structure of the study area was assessed by stratifying the tree component into three levels: lower stratum (≤ 9.99 m tall), intermediate stratum (10–19.99 m), and upper stratum (≥ 20 m), following the criteria established by García-Quintana *et al.* (2020). The horizontal structure was determined based on the diameter of the individuals recorded in the five plots. They were grouped into diameter classes with a width of 10 cm. In each class, the number of individuals was determined according to the limits established for each range, following the methodology described by García-Quintana *et al.* (2020). In parallel, the Importance Value Index (IVI) was calculated for each species by summing the absolute density (D), relative density (DR), relative frequency (FR), and relative dominance (DmR), using the formulas proposed by Aguirre *et al.* (2022). This approach allowed not only to analyze the distribution of diameters in the studied population, but also to characterize the structure and ecological importance of the species in the ecosystem.

Determination of specific diversity

As proposed by Aguirre *et al.* (2022), specific diversity was determined using the Shannon Index, which integrates both species richness and their relative abundance in the ecosystem. This index assesses the uncertainty in predicting the identity of a randomly selected species, providing a robust measure of community complexity and stability Equation 1

$$H' = -\sum_{i=1}^{s}(Pi)(LogN\ Pi) \qquad (1)$$

Donde:

H' = Shannon index

S = Number of species

Pi = Proportion of individuals that make up the species

LogN = Natural logarithm

Estimation of aboveground biomass

The biomass of the tree stratum was calculated using the indirect method relating the DBH and wood density of the trees in each plot through the allometric equation developed by (Chave *et al.*, 2014): Equation 2

$$\mathrm{AGBest} = \exp[-1{,}803 - 0{,}976\mathrm{E} + 0{,}976\mathrm{In}(p) + 2{,}673\mathrm{In}(\mathrm{D}) - 0{,}0299[\mathrm{In}(\mathrm{D})]^2] \ (2)$$

Where:

AGBest = Estimated biomass in (Mg ha^{-1})

D = Diameter at chest height (cm)

p = Basic density of wood (g/cm³)

E = measure of environmental stress

For the determination of palm biomass, the equation proposed by was used (Goodman *et al.*, 2013): Equation 3.

$$\text{AGBpalm} = \exp(-3{,}3488 + (2{,}7483 \times \ln\text{DBH}) \quad (3)$$

Where:

AGBpalm = Estimated biomass in (Mg ha^{-1}) for palms

DHB = Diameter at chest height (cm)

The wood density data (*p*), for the species of the five sampled plots was taken from the Global Wood Density Database (http://db.worldagroforestry.org/wd). If species identification was unavailable, the average wood density at the genus level was used. The E coefficient was obtained from a 2.5 arc sec global raster layer (http://chave.upstlse.fr/pantropicalallometry.htm).

Estimation of accumulated carbon in tree biomass

The estimated biomass values for each species in the five sample plots were multiplied by a constant, as proposed by (Jumbo Salazar, Arévalo Delgado y Ramirez-Cando 2018). This calculation yielded the value corresponding to the carbon fixed in the biomass of each species (Equation 4).

$$Cest = AGBest \times 0{,}47 \quad (4)$$

Where:

Basket = Accumulated carbon in biomass (Mg ha^{-1})

AGBest = Estimated biomass in (Mg ha^{-1})

0.47 = constant considering that 47% of the biomass of every living being is carbon.

RESULTS

Floristic composition of the study area

In the inventory carried out on an area of 2,000 m², 48 tree species with a DBH ≥ 10 cm were recorded, distributed in 38 genera and 21 botanical families, with a total of 156 individuals (Figure 2). The high taxonomic diversity evidences the structural complexity of the forest and its potential to host a significant variety of tree species. Among the 21 families identified, the most diverse in terms of number of species were Lauraceae and Melastomataceae, with six species each, followed by Moraceae with five species, and Rubiaceae and Meliaceae with four species each. This predominance of families such as Lauraceae and Melastomataceae suggests an adaptation of these species to local conditions, reflecting their potential ecological role in the dynamics of succession and ecosystem composition.

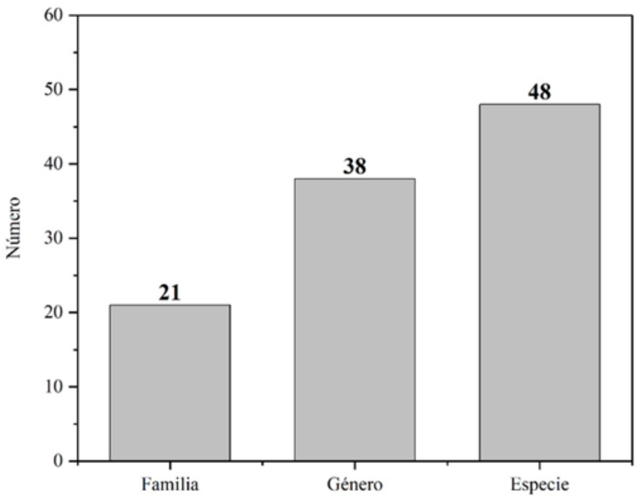

Figure 2. *- Floristic composition of the Piemont Evergreen Forest of the Cóndor – Kutukú Mountain Range*

Structural characteristics of the study area

The distribution of individuals into height classes allows describing the vertical structure of the forest, providing key information about its dynamics and composition. In the study area, the population presented a bell-shaped height distribution, with the largest number of individuals concentrated in the intermediate stratum (10–19.99 m), which includes 79 individuals and represents 50.64% of the total. This was followed by the upper stratum (≥20 m), which recorded 69 individuals, equivalent to 44.23% of the population, while the lower stratum (≤9.99 m) included only eight individuals, representing 5.13% (Figure 3a). The predominance of individuals in the intermediate stratum suggests a forest structure in a developmental stage, where vertical growth and competition for light are actively shaping the community. The presence of a canopy exceeding 20 m, along with some emergent trees, indicates a mature forest capable of supporting large species. The presence of emergent individuals such as *Aniba muca*, which reach heights exceeding 30 m, highlighting the structural heterogeneity and potential ecological function of these trees in carbon capture and habitat formation for arboreal fauna.

The distribution of diameter classes is a key descriptor of forest horizontal structure, revealing regeneration patterns and population dynamics. In the study area, the diameter class with the highest number of individuals was 10–19.99 cm DBH, with 98 records constituting 62.82% of the total population (Figure 3b). This abundance pattern in the smaller diameter classes suggests a high proportion of young individuals or individuals in early stages of growth, indicating high regeneration potential.

The inverted "J"-shaped diameter distribution observed is characteristic of self-sustaining forest communities that are relatively uniform in terms of population structure. This type of distribution implies a constant flow of individuals that reach larger sizes as density decreases in the upper diameter classes, a sign that the forest has a stable demographic structure and active successional dynamics. This is indicative of a forest in good condition, with adequate regeneration capacity to maintain diversity and structural stability over time.

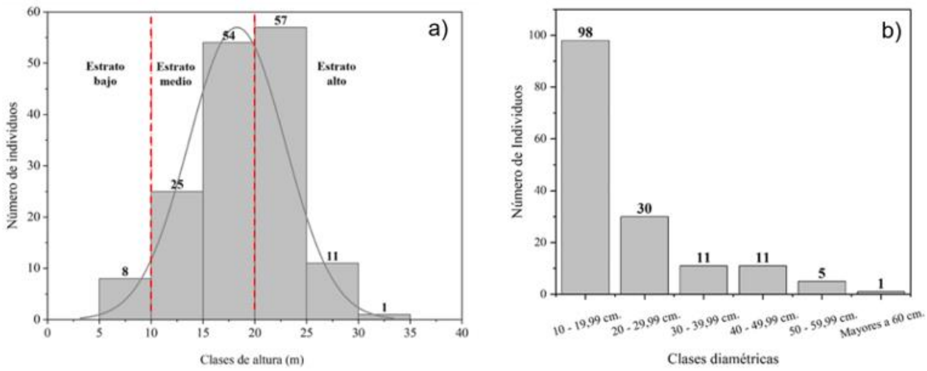

Figure 3. *- Structural characteristics of the Piemont Evergreen Forest of the Cóndor- Kutukú mountain range: a) Vertical structure; b) Horizontal structure.*

Legend: *Red dashed lines show the boundary of each vertical stratum.*

Ecological importance of the tree species in the study area

The ten species with the highest IVI recorded in the Piemont Evergreen Forest of the Cordillera del Cóndor – Kutukú represent an ecological value of 61.92 among the flora present, standing out for their high dominance and abundance. Among these, *Aniba muca* stand out with an IVI of 16.23, followed by *Wettinia maynensis* with 11.05, *Jacaranda copaia* with 6.74, *Vochysia sp.* with 6.16, and *Ladenbergia oblongifolia* with 5.03 (Figure 4). These species play a crucial role in forest structure and dynamics, influencing ecological processes such as resource competition, habitat formation, and carbon sequestration.

The remaining 38 identified species contribute an ecological value of 38.08% of the total, reflecting a diverse tree community where most species are underrepresented in terms of dominance and abundance. This uneven distribution suggests a forest with a hierarchical structure, typical of mature ecosystems, in which a few dominant species coexist with a wide variety of less common species. This pattern is indicative of a resilient ecosystem, capable of sustaining high biodiversity and responding to environmental changes or natural disturbances.

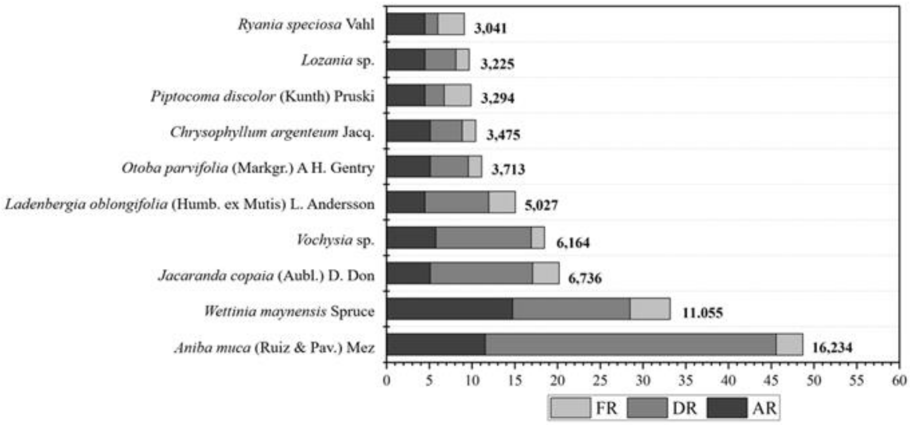

Figure 4. *- Structural parameters of the piemont evergreen forest of the Cordillera del Cóndor – Kutukú*

Legend: *Relative Dominance (RD); Relative Frequency (RF); Relative Abundance (RA).*

Diversity of the study area

By calculating the Shannon-Wiener Diversity Index, it was determined that the piemont evergreen forest of the Cordillera del Cóndor - Kutukú, in the Timbara parish, presented a moderate diversity with a value of 3.36. This result indicates a balanced composition between species richness and their relative abundance, reflecting an ecosystem with a stable biological structure and active ecological dynamics.

A medium diversity value suggests that the forest hosts a significant variety of species, although it does not necessarily reach the maximum levels observed in more complex ecosystems, such as lowland tropical rainforests. This diversity can be influenced by factors such as elevational gradient, resource availability, and local climatic conditions. The presence of a diverse range of species contributes to the ecosystem's resilience, allowing it to adapt to environmental changes and perform key functions such as carbon sequestration, maintaining the hydrological cycle, and providing habitats for associated fauna. This value also highlights the importance of conserving this ecosystem, which acts as a reservoir of biodiversity in the region.

Aboveground biomass and stored carbon

The floristic inventory carried out in the study area allowed determining a tree biomass of 281.71 Mg ha^{-1}, complemented by a biomass of 5.87 Mg ha^{-1} corresponding to palms, represented predominantly by *Wettinia maynensis*. Overall, the total aboveground biomass of trees and palms reached a value of 287.58 Mg ha^{-1}, which translates into an estimated stored carbon stock of 135.16 Mg ha^{-1}.

These results highlight the important role of forests as carbon sinks, directly contributing to climate change mitigation by capturing and storing atmospheric carbon dioxide (CO_2). The biomass associated with palm trees, although smaller in proportion, underscores their ecological relevance, given their role in ecosystem dynamics and in providing resources for local fauna.

Table 1. *- Above-ground biomass of the tree and palm component of the piemont evergreen forest of the Cóndor- Kutukú mountain range*

Aboveground biomass (trees)	281.71 Mg ha^{-1}	**Carbon storage (trees)**	132.40 Mg ha^{-1}
Areal biomass (palms)	5.87 Mg ha^{-1}	**Stored carbon (Palms)**	2.76 Mg ha^{-1}
Total, aboveground biomass	287.58 Mg ha^{-1}	**Total carbon stored**	135.16 Mg ha^{-1}

DISCUSSION

The floristic composition recorded in the piemont evergreen forest of the Cordillera del Cóndor– Kutukú , in the Timbara parish, generally agrees with other studies carried out in the province of Zamora Chinchipe. For example, in a lower montane evergreen forest of the San Andrés parish, 21 families, 38 genera and 48 species were reported, with Lauraceae and Melastomataceae being the families with the highest specific richness (Aguirre Mendoza *et al.*, 2018). However, our results differ from those observed in the El Suhi micro-basin, where 31 families, 51 genera and 59 species were identified, with a predominance of Rubiaceae and Lauraceae. (Maldonado Ojeda 2018). In addition, Aguirre *et al.* (2022) in an evergreen forest in the Palanda canton, at 1,200 m a.s.l., reported Myristicaceae, Lauraceae and Rubiaceae as representative families, evidencing floristic variations between attitudinally close localities. This phenomenon suggests a high turnover of species between ecosystems, probably influenced by local environmental factors and landscape heterogeneity, although common floristic elements persist in the region.

In contrast, studies in Piemont forests of the northeastern Amazon show important differences. For example, in Pastaza province, a Piemont Evergreen Forest in the Puyo River micro-basin recorded 65 species distributed in 30 families, with Fabaceae, Euphorbiaceae, and Lauraceae standing out (García-Quintana *et al.,* 2021). In Napo province, in the Piatúa River basin, 68 species from 32 families were identified, with Arecaceae, Fabaceae, and Moraceae predominating (Patiño *et al.,* 2015). These floristic differences reflect the influence of elements from the tropical rainforests of the Ecuadorian Amazon, where factors such as water regime and soil type play a determining role (Peñuela *et al.,* 2019).

The vertical structure of the forest showed the presence of trees with average heights greater than 20 m, consistent with the typical characteristics of this type of forest. In particular, the highest number of individuals was concentrated in the intermediate and upper strata, which represent 94.87% of the total, while the lower stratum showed a lower density. These results contrast with the findings of (García-Quintana *et al.,* 2021; Aguirre-Mendoza *et al.*, 2018), who documented dominant patterns in the lower and intermediate strata, which shows a decreasing distribution as the height increases. The observed variations could be associated with mountainous topography, which influences the dynamics of ecosystems and generates differences in the composition and structure of the vertical strata (García-Quintana *et al.*, 2020). Likewise, the presence of emergent trees, such as *Aniba muca*, indicates an important structural complexity that contributes to ecosystem functioning.

Regarding horizontal structure, the forest presented an inverted "J"-shaped diameter distribution. This pattern, characterized by the predominance of individuals in the first diameter classes (10–29.99 cm DBH), is typical of self-sustaining and actively regenerating tree communities (Santander-Malo and García-Quintana 2022). However, local variations can be attributed to dynamics such as interspecific competition, differences in growth rates, and anthropogenic activities, including selective logging (Freitas *et al*., 2019; Espejo *et al.*, 2018).

The IVI analysis indicated that five species represent 45.22% of the forest's ecological structure, with *Aniba muca* due to its greater dominance and *Wettinia maynensis* due to its high abundance. These results are consistent with those reported in a Piemont Evergreen Forest in Pastaza, where *Wettinia maynensis* showed a high IVI due to its abundance (García-Quintana *et al.,* 2020). However, research in other locations has documented different dominant species, such as *Alsophila cuspidata* in Zamora Chinchipe (Maldonado, 2018) and *Iriartea deltoidea* in Napo and Pastaza, with high IVI values associated with their colonization capacity in diverse ecological niches (Patiño *et al.,* 2015). This reinforces the idea that the structure and composition of the Piemont Amazonian forests are highly variable and influenced by geographic and environmental factors.

The aerial biomass recorded in the studied forest was 287.58 Mg ha^{-1}, a value that coincides with studies carried out in the western Amazon, where average biomasses of 290 to 340 Mg ha^{-1} have been reported. (Torres *et al*., 2020). On the other hand, studies in forests with greater anthropogenic intervention have reported lower values, such as 199.4 Mg ha^{-1} in Zamora Chinchipe (Jadán *et al.,* 2017) and 83 Mg ha^{-1} in Morona Santiago (Jumbo Salazar *et al*., 2018), which highlights the influence of the conservation status on biomass storage capacity.

The estimate of carbon stored in the analyzed ecosystem was 136.80 Mg ha^{-1}, a value that is within the range reported for other forests in the Ecuadorian Amazon, such as Sucumbíos (135.8 Mg ha^{-1}) and Zamora Chinchipe (153.57 Mg ha^{-1}) (Cabrera Quezada *et al.,* 2020). These results highlight the fundamental role of Amazon forests as carbon sinks on a global scale, contributing significantly to climate change mitigation and biodiversity conservation (Palacios et *al*., 2017).

CONCLUSIONS

The research determined that the evergreen piemont forest of the Cordillera del Cóndor - Kutukú has a rich flora, is structurally complex, and has a significant carbon storage capacity; species with high ecological importance, such as *Aniba, are notable. muca and Wettinia maynensis,* which dominate in both abundance and biomass. These results confirm that this ecosystem plays a crucial role in regulating atmospheric carbon and conserving biodiversity, reaffirming its ecological and climatic value.

The vertical and horizontal structure reveals a mature forest with a typical pattern of active regeneration; its carbon storage, estimated at 136.8 Mg ha^{-1}, is within the expected range for well-preserved Piemont forests. This study highlights the need to implement management and conservation strategies that protect the functionality of these ecosystems and promote their sustainability in the face of increasing anthropogenic pressures.

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***Conflicts of interest*:**

The authors declare not to have any interest conflicts.

***Contribution of the authors*:**

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