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Original article

Evaluation of aerial biomass accumulation and ecological sustainability in Amazonian forests: a case study of the Cotococha community

Evaluación de biomasa aérea acumulada y sostenibilidad ecológica en bosques amazónicos: estudio de caso comunidad Cotococha

Avaliação do acúmulo de biomassa acima do solo e da sustentabilidade ecológica nas florestas amazônicas: um estudo de caso da comunidade de Cotococha

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RESUMEN

Los boques tropicales amazónicos tienen una enorme variedad de especies y son reconocidos por su gran biodiversidad y captura de carbono, pero se ven amenazados por la presión antrópica que ejerce el cambio de uso de tierra. Por lo tanto, el objetivo de esta investigación fue evaluar la biomasa aérea acumulada y sostenibilidad ecológica de un bosque amazónico de la comunidad Cotococha. Se establecieron cinco transectos de 0,1 ha (10 x 100 m) separados en intervalos de 100 m y se registró todas las especies arbóreas con $d_{1.30}$ ≥10 cm. Se evaluaron indicadores ecológicos en base a vegetación, suelo, biodiversidad y productividad. Se estimó la biomasa aérea mediante ecuaciones alométricas y se determinó el índice de valor de importancia de biomasa (BIVF). Las familias Melastomataceae, Fabaceae, Euphorbiaceae y Salicaceae presentaron mayor número de especies. La distribución de clases diamétrica presentó una tendencia de J invertida. El diagnóstico de sostenibilidad ecológica evidenció que no todos los indicadores alcanzan el umbral de sostenibilidad. Se reportó una biomasa área de 78,67 ± 5,87 Mg/ha y un stock de carbono almacenado de 39,33 ± 2,34 Mg/ha. Las tres familias que mayor BIVF presentaron fueron Melastomataceae con 38,43, Annonaceae con 24,36 y Meliaceae con 22,69. Estas familias podrían ser recomendadas para programas de restauración dentro de la comunidad, por el alto potencial para acumular biomasa aérea y stock de carbono contribuyendo a un manejo que le permita mejorar y alcanzar el umbral de sostenibilidad en todos los indicadores ecológicos.

Palabras clave: Amazonía; Inventario florístico; Clases diamétricas; Captura de carbono.

ABSTRACT

Amazonian tropical forests have an enormous variety of species and are recognized for their great biodiversity and carbon sequestration, but they are threatened by anthropogenic pressure from land use change. Therefore, the objective of this research was to evaluate the accumulated aerial biomass and ecological sustainability of an Amazonian forest in the Cotococha community. Five 0.1 ha transects (10 x 100 m) separated at 100 m intervals were established and all tree species were recorded with $D_{1.30}$ ≥10 cm. Ecological indicators were evaluated based on vegetation, soil, biodiversity and productivity. Aerial biomass was estimated using allometric equations and the biomass importance value index (BIVF) was determined. The families Melastomataceae, Fabaceae, Euphorbiaceae and Salicaceae presented the highest number of species. The distribution of diameter classes showed an inverted J trend. The ecological su stainability diagnosis showed that not all indicators reach the sustainability threshold. An area biomass of 78.67 ± 5.87 Mg ha^{-1} and a carbon stock of 39.33 ± 2.34 Mg ha^{-1} were reported. The three families with the highest BIVF were Melastomataceae with 38.43, Annonaceae with 24.36 and Meliaceae with 22.69 These families could be recommended for restoration programs within the community, due to their high potential to accumulate aerial biomass and carbon stock, contributing to a management that allows them to improve and reach the threshold of sustainability in all ecological indicators.

Keywords: Amazon; Floristic inventory; Diameter classes; Carbon sequestration.

RESUMO

As florestas tropicais amazônicas têm uma enorme variedade de espécies e são conhecidas por sua alta biodiversidade e captura de carbono, mas estão ameaçadas pela pressão antropogênica da mudança do uso da terra. Portanto, o objetivo desta pesquisa era avaliar a biomassa acumulada acima do solo e a sustentabilidade ecológica de uma floresta amazônica na comunidade de Cotococha. Cinco transeptos de 0,1 ha (10 x 100 m) foram estabelecidos em intervalos de 100 m e todas as espécies de árvores foram registradas com $D_{1.30}$ ≥10cm. Os indicadores ecológicos foram avaliados com base na vegetação, solo, biodiversidade e produtividade. A biomassa acima do solo foi estimada usando equações alométricas e o índice de importância da biomassa (BIVF) foi determinado. As famílias Melastomataceae, Fabaceae, Euphorbiaceae e Salicaceae tinham o maior número de espécies. A distribuição das classes de diâmetro mostrou uma tendência J invertida. O diagnóstico de sustentabilidade ecológica mostrou que nem todos os indicadores atingem o limiar de sustentabilidade. Foi relatada uma área de biomassa de 78,67 ± 5,87 Mg/ha^{-1} e um estoque de carbono de 39,33 ± 2,34 Mg/ha^{-1}. As três famílias com a maior BIVF foram Melastomataceae com 38,43, Annonaceae com 24,36 e Meliaceae com 22,69. Essas famílias poderiam ser recomendadas para programas de restauração dentro da comunidade, devido ao seu alto potencial de acumulação de biomassa aérea e captura de carbono, contribuindo para uma gestão que lhes permita melhorar e alcançar o limiar de sustentabilidade em todos os indicadores ecológicos.

Palavras-chave: Amazônia; Inventário florístico; Classes diamétricas; Captura de carbono.

INTRODUCTION

Tropical forests have an enormous variety of species and are recognized for their great biodiversity, with the existence of unique species in the world. These in turn possess a high floristic richness and complex structures that, based on their functionality, allow the obtaining of several resources (Jadán *et al*., 2017).

At present the search for alternatives that promote a sustainable development model, environmentally balanced and respectful of cultural diversity that conserves biodiversity, ecosystem services and the self-regenerating capacity of the Amazon forests is becoming increasingly important (Torres *et al*., 2020).

Ecuador has a variety of flora that are among the richest and most diverse in the world, made up of various types of vegetation, forests harbor a high biomass productivity due to soil fertility and represent a certain percentage of carbon stocks; however, biomass accumulation is the key purpose for the balance between accumulated biomass gain and losses in the conservation of ecosystems (García Quintana *et al*., 2021).

Estimates of biomass and carbon accumulated in tropical forests provide important information that allows predicting the response to changing environmental conditions, in a way that makes possible the selection of taxa for greater effectiveness in reforestation programs (Rodríguez-Larramendi *et al*., 2017).

Given the imminent loss of biodiversity, biomass and the accelerated destruction of these ecosystems that safeguard an enormous carbon reserve, the scientific community needs to orient studies that provide basic information to achieve adequate sustainable development in vulnerable communities (García-Quintana *et al*., 2021; Torres *et al.*, 2020).

In this way, it is seeking to take appropriate measures to mitigate the affected sectors, find alternatives and propose measures for the conservation of these resources; generate a conscious and effective consumption, as well as promote the immediate restoration of the affected areas, with a view to protect the Amazon forests and in particular the Cotococha Community, which has extensive areas of tropical rainforest adjacent to the micro-watershed of the Puyo River, presenting serious socio-environmental problems, one of the greatest concerns is the accelerated deforestation that has increased progressively in recent years, causing changes in land use towards agroforestry systems, in order to seek other resources for their economic livelihood. This situation has led to susceptibility to landslides, directly affecting biodiversity, conservation status and livelihoods, as well as affecting carbon sequestration, one of the causes of climate change of greatest concern. Therefore, the objective of the research was to evaluate the accumulated aerial biomass and ecological sustainability of an Amazonian forest of the Cotococha community, as a socio-environmental contribution to the Ecuadorian Amazon.

MATERIALS AND METHODS

Study area

This research was carried out in an evergreen foothill forest sector of the Kiwchua de Cotococha community, located in the Pastaza province, Pastaza canton, Tarqui Parroquia, approximately half an hour from the city of Puyo, on the left side of the Puyo river bank (Figure 1). Its coordinates are S 1°36'30.6113" W 77°54'46.3421". The climate is characteristic of a tropical rainforest with an average altitude of 600 m asl. The study area corresponds to a humid tropical megathermal climate, with an average annual temperature of 21.3ºC and an annual precipitation of 4 119 mm (INAMHI, 2020).

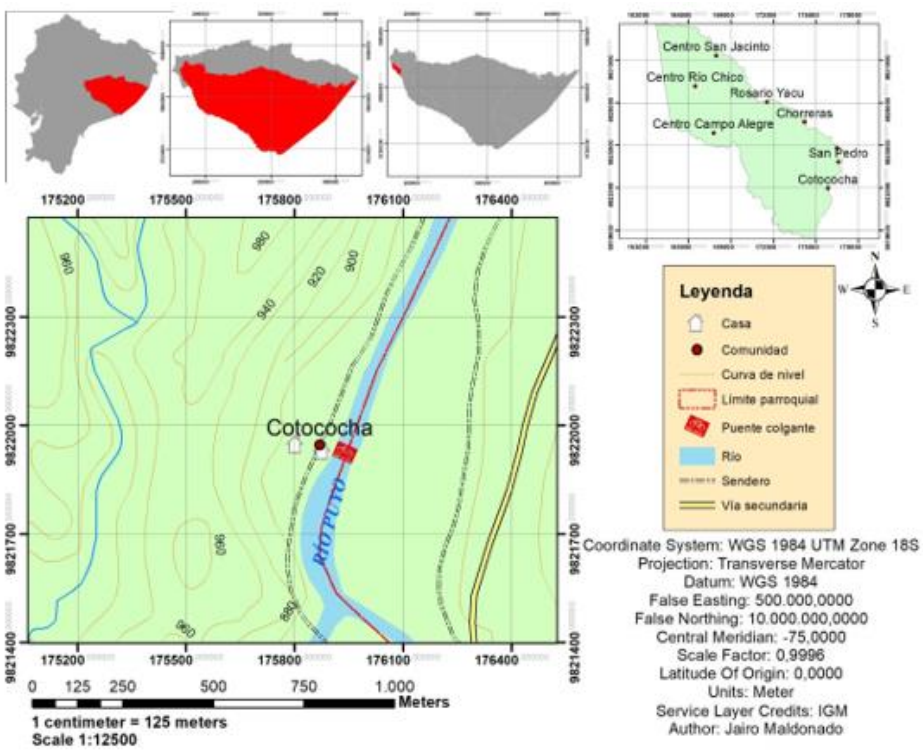

Figure 1. - Geographical location of the study area

Sampling unit

The field work was based on information obtained from the research project "Forest restoration through nucleation as a contribution to the ecosystem services of the Puyo River micro-basin", in which we participated as part of the joint work team with the Universidad Estatal Amazónica.

Five transects of 0.1 ha (10 x 100 m) were established in the lower zone of the Puyo River micro-watershed, separated at 100 m intervals (Figure 2). Each transect started from a central axis, from which five meters were taken on each side, stakes were placed and georeferenced with Garmin 760MT-D GPS and delimited with a stake. All species with $d \geq 10_{1.30}$ cm, measured from the ground, were recorded in a field matrix. The matrix consisted of the following data: common name, scientific name, family, species, $d_{1.30}$, and total height.

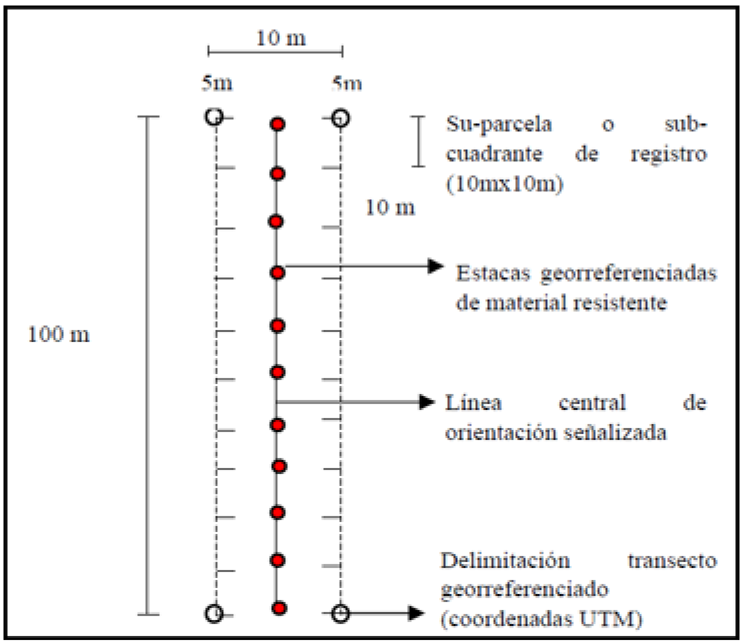

Figure 2. - Model of transect establishment for field sampling

Diagnosis of the current state of ecological sustainability based on soil, vegetation, biodiversity and productivity indicators

In order to diagnose the current state of ecological sustainability, the rapid ecological valuation technique was used, based on the methodology proposed by RIFA (2008) which consisted of field observations of a set of ecological indicators structured in four criteria: soil, structure, biodiversity and ecosystem productivity. This tool made it possible to identify the sensitive elements of the ecosystem by means of the ecological sustainability threshold, considering that values lower than 8 resulted 5, in a low sustainability threshold and therefore require more attention; however, while values approaching 8 indicated more sustainability in the system (Hechavarría and Toirac 2011; RIFA 2008).

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Determination of aboveground biomass potential and carbon stocks

The accumulated aerial biomass of tree species with $D_{1.30}$ ≥10cm was estimated. Diameter data taken from the floristic inventory and wood specific density (ñ) were considered using standard allometric equation for biomass estimation proposed by Chave *et al*., (2005) specific methodology for tropical forests (Equation 1).

$$BA= \rho \times \exp(-1{,}499 + 2{,}148\ln(d_{1.30}) + 0{,}207(\ln(d_{1.30}))^2 - 0{,}0281(\ln(d_{1.30}))^3) \quad (1)$$

Wood specific density data of the species from studies developed in the local area were used and in cases where specific density was not available, the global mean (p) for tropical South America (0.632 g cm^{-1}) was used (0.632 g cm^{-3}) (Chave *et al*., 2005).

The carbon content per hectare was estimated through the indirect estimation method of the aerial biomass obtained. Where approximately 50% of the plant biomass corresponds to carbon, so to estimate the total stored carbon, the total biomass (BT) was multiplied by the correction factor 0.5 in the absence of specific information (Quiceno-Urbina *et al*., 2016) (Equation 2).

$$CBT = BT * FC\ (0{,}5) \quad (2)$$

A biomass importance value index (BIV) was calculated, proposed by (Torres *et al*., 2020) which reported the biomass potential accumulated by each species and the structure of the species that make up each land use (Equation 3).

$$BIV = AR + DR + BR \quad (3)$$

Where:
RA: relative abundance;
DR: Relative dominance;
BR: Relative biomass;

Relative abundance was determined (Equation 4).

$$AR= (n/N)*100 \quad (4)$$

Where:
n: Number of individuals of each species;
N: Total number of individuals

Relative dominance was determined (Equation 5).

$$DR=(Ga/GT)*100 \quad (5)$$

Where:
Ga: Basal area of each species;
GT: total basal area;

The basal area was determined (Equation 6).

$$Ga=(\Pi/4)*(d_{1.30})^2 \quad (6)$$

The relative biomass was determined (Equation 7).

$$BR=(Ba/BT)*100 \ (7)$$

Where:
Ba: absolute biomass of each species;
BT: total accumulated aerial biomass.

RESULTS

Floristic composition and structure

The results of the floristic composition, from the forest inventory, recorded a total of 83 species distributed in 31 botanical families and 284 individuals (Figure 3a), being the families Melastomataceae (10), Fabaceae (7), Euphorbiaceae (7) and Salicaceae (6) are the ones with the highest number of species with 36.14% of the species recorded in the inventory, in addition three of these families also represented the highest number of individuals Melastomataceae (71), Salicaceae (22), Fabaceae (20). In terms of vertical structure, the vegetation was in constant growth, with one individual in the high stratum (> 20.1 m), 134 in the middle stratum (10.1 - 20 m) and 149 individuals in the low stratum (< 10 m) (Figure 3b). The distribution of diameter classes showed a trend in the form of an inverted J, indicating that the vegetation is self-sustaining, with a greater concentration of individuals in the lower diameter class 10-cm19,9 and with representation of individuals in all diameter classes (Figure 3c).

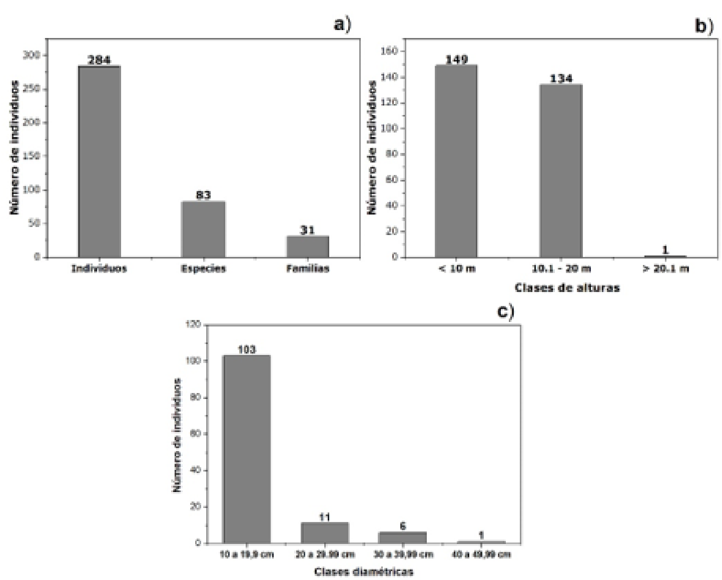

Figure 3. - Floristic composition and structure of a forest in the Cotococha community
Legend: a: Floristic composition; b: Distribution of height classes; c: Distribution of diameter classes.

Current state of ecological sustainability based on indicators of vegetation, soil, biodiversity and productivity

The Figure showed 4 the set of indicators that describe the current state of ecological sustainability present in the Cotococha community forest area. The soil profile is an ecological indicator that helps to establish soil quality. In the study area a value of (3) was obtained, which indicated the presence of a thin surface soil (Figure 4).

Bulk density is an indicator of the mass to volume ratio of the soil. The study area presented a value of (6), reporting the presence of non-compacted soils, which is evidence of adequate plant root growth.

The number of earthworms and arthropods, together with the presence of decomposing vegetation are indicators of soil biological activity. The study area showed an ecological value of (6), which indicated the presence of earthworms and arthropods in large numbers. The presence of decomposing vegetation showed an ecological value of 6, characteristic of vegetation in various stages of decomposition and well decomposed residues. Both indicators showed a high biological activity of the soil.

Biodiversity of flora and fauna is an ecological indicator of the conservation status of the forest. The study area presented a value of (5), which described for the flora component the presence of little variability of plant species (5-10 tree species and few understory species), while the fauna component presented an ecological value of (4) being a descriptor of little presence and visibility of fauna species in the study area.

The structure as a function of height is an ecological indicator of the degree of complexity of the ecosystem. The study area presented an ecological value of (4) which indicated the presence of a moderately complex ecosystem and also a moderate diversity of species and interactions between elements.

Ecological and economic productivity is an ecological indicator that determines the degree of sustainability of the ecosystem. The forest area presented a value of (3) for the ecological productivity indicator, which indicated the existence of some ecological functions associated with water quality, soil conservation, habitat and food available for animals, in addition to considering that there are systems under development for scientific studies related to carbon sequestration or tourism. The economic productivity indicator also presented a value (3), which indicated the existence of a productive system for self-consumption or for commercialization, but which does not meet the objectives of the owners.

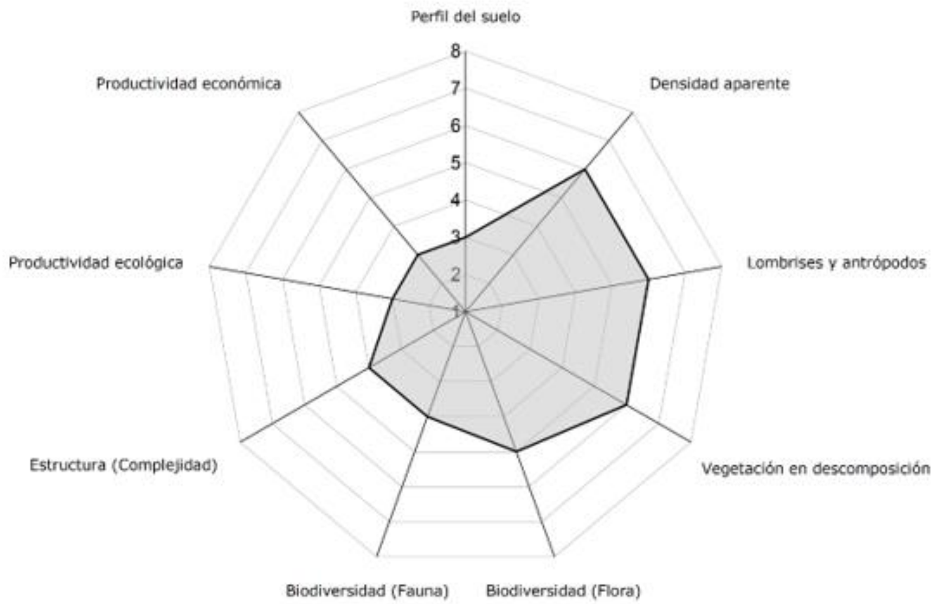

Figure 4. - Spider diagram of ecological indicators related to vegetation, soil, biodiversity and productivity

Potential accumulated aerial biomass and carbon stock in the lower zone of the Puyo River microbasin

Based on the results obtained from the floristic inventory, it was possible to estimate the potential of aerial biomass and carbon stock, which showed that the forest area of the Cotococha community had an area biomass of 78.67 ± 5.87 Mg ha^{-1} and a carbon stock of 39.33 ± 2.34 Mg ha^{-1} (Figure 5a).

Of the ten families with the highest biomass importance value index (BIVF) recorded in the forest sector of the Cotococha community, the three with the highest BIVF were Melastomataceae with a value of 38,43 and were represented by 10 species of the genus *Miconia*, with the species *M. multispicata, M. grandiflora, M. spicata, M. pilgeriana* being the most representative. *M. pilgeriana* were the most representative; followed by Annonaceae with a BIVF of 24,36 and represented by the species *Duguetia veneficiorum, Rollinia crysocarpa, Xylopia cuspidata and Rollinia pittieri*, the latter being the most representative; and the Meliaceae family with a BIVF of 22,69 represented by the species *Cabralea canjerana, Cedrela odorata, Guarea grandifolia, Guarea kunthiana, Trichillia septentrionalis, the* latter being the most representative (Figure 5b).

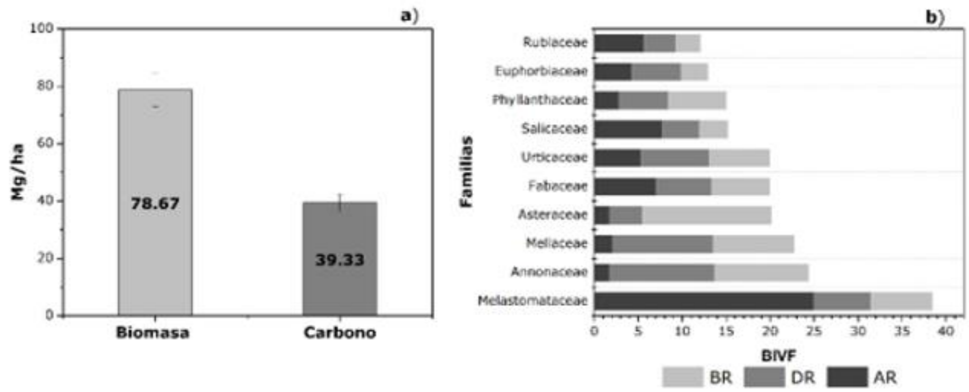

Figure 5. - Cumulative aboveground biomass potential in the Cotococha community forest

Legend: a: Mean cumulative aboveground biomass and carbon stock; b: Biomass importance value index at family level (BIVF); BR: Relative biomass; RD: Relative dominance; AR: Relative abundance.

DISCUSSION

The floristic composition in the forest area of the Cotococha community in the lower zone of the Puyo River micro-watershed, agrees with several studies that describe similar floristic patterns that have been reported for the Amazon (Cabrera-Amaya and Rivera-Díaz, 2016; García-Quintana *et al*., 2021; Jadán *et al*., 2017). The families Melastomataceae, Fabaceae, Euphorbiaceae and Salicaceae were the most representative in terms of the largest number of species recorded, which is consistent with previously reported studies in areas that present topographic and hydrographic characteristics similar to the present investigation (Caranqui 2013; García-Quintana *et al*., 2021). However, only the Melastomataceae and Fabaceae families are the ones with the highest number of individuals, being potential for use in restoration programs due to their high capacity to survive the anthropic alterations present in this study area, and they have also been catalogued among the families with the highest richness in lowland forests (Gentry 1988). On the other hand, the Arecaceae family also reported a high number of individuals (15), being the species *Wettinia maynensis* the most representative in this family, besides the presence of this species is characteristic of a tropical rainforest (Peñuela *et al*., 2019). The high presence of species of the Melastomataceae family, characteristic of secondary forest, with natural regeneration, especially in clearings, is typical of ecological succession that indicates environmental changes in the ecosystem (Ducuara 2013).

The results of the ecological sustainability analysis based on the criteria of vegetation, soil, biodiversity and productivity indicate that in order to achieve ecological balance, values below five should be prioritized because they do not reach the sustainability threshold, while indicators with values above five have reached the sustainability threshold. Therefore, as a result of the ecological sustainability analysis, it became evident that the Cotococha community forest area requires management that will allow it to reach the sustainability threshold (RIFA, 2008).

The results of aerial biomass obtained in the present investigation, resulted relatively low compared to a study conducted in the upper zone of the Puyo river microbasin, where an area biomass content of 339.70 Mg ha^{-1} has been recorded (García Quintana *et al*., 2021). In an evergreen forest in the province of Napo, up to 340 Mg ha^{-1} have been recorded. (Torres *et al*., 2020) in an evergreen forest in the Colombian Amazon up to 297.6 Mg ha^{-1} has been reported (Parky *et al.*, 2017). Studies have also been reported in other forest areas, as is the case of western Amazonia registering up to 239.8 Mg ha^{-1} and in eastern central Amazonia with 316.8 Mg ha^{-1} (Mitchard *et al*., 2014). The low biomass content in the forest area of the Cotococha community located in the lower zone of the Puyo River micro-watershed can be attributed to the disturbances generated by the community's inhabitants, who over the years have made strong alterations through agricultural and livestock expansion, timber harvesting and the commercialization of various non-timber forest products.

At present, it is said that Amazon forests function as a large carbon sink, due to the aerial biomass accumulated by forest species and are also one of the largest stores of biodiversity (Oca-cano, 2012; Ureta Adrianzén, 2015). An analysis carried out by Keeling and Phillips (2007) mentions that the world's tropical forests generally do not have biomass values above 350 Mg/ha^{-1}. This highlights the great importance of the conservation of Amazonian forests worldwide, but the data from the analysis conducted in this study are worrying because of the low aerial biomass content of the Cotococha community forest, which requires immediate action.

With the results obtained from BIVF, it was possible to identify the botanical families that contribute most to the accumulation of aerial biomass, providing information of vital importance when establishing plans to help recover areas fragmented by poor management and use of forest resources. Several studies have been reported in which BIVF is used as a tool for a good forest restoration program, because it presents scientifically based information on the families with the greatest ecological value and with the capacity to maintain carbon stocks (García-Quintana *et al*., 2021; Torres *et al*., 2020).

The BIVF, based on the phytosociological parameters of abundance, frequency and dominance, allows the ecological analysis of plant communities oriented to interpretations of the relative importance of botanical families (Torres *et al*., 2020). This provides relevant information regarding biomass accumulation, production and quality of the site or environmental condition of each specific habitat occupied by groups of botanical families.

The capacity of forests to store carbon in the form of biomass varies with floristic composition, stock density, and stock age (Rojas-Vargas *et al*., 2019). This corroborates the results of the present investigation in which a low accumulated carbon content was evidenced, which is very worrying and requires immediate measures to mitigate the socio-environmental impact generated, in order to conserve and recover this important forest reservoir of the Amazon basin, which is threatened by poor harvesting practices. This points to the fact that logging practices and changes in land use generate a high risk in the trees with the greatest carbon storage potential and can lead to the impoverishment of carbon stocks in the Montaño evergreen forest (García-Quintana *et al*., 2021).

CONCLUSIONS

The floristic composition recorded a total of 83 species, distributed in 31 botanical families and 284 individuals, resulting in the Melastomataceae and Fabaceae families with the highest floristic richness, which can be considered as a reference for Amazonian conditions.

The structure of the forest indicated that the vegetation is growing with a greater number of individuals in the lower stratum (h < 10 m) and a distribution of diameter classes in the form of an inverted jack, reflecting the predominance of a young forest.

Ecological sustainability based on the indicators vegetation, soil, biodiversity and productivity reported that the forest sector of the Cotococha community is vulnerable.

For the Cotococha community, a low potential of aerial biomass was reported with values of 78,67±5.87 Mg ha^{-1} and a carbon stock of 39.33±2.34 Mg ha^{-1}. The biomass importance value index helped identify the Melastomataceae, Annonaceae and Meliaceae families with the greatest potential to accumulate biomass, which could be recommended for restoration programs.

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