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Translated from the original in spanish

Original article

Carbon potential in a forest's tree layer lowland evergreen, Sucumbíos-Ecuador

Potencial de carbono en el estrato arbóreo de un bosque siempreverde de tierras bajas, Sucumbíos-Ecuador

Potencial de carbono no estrato arbóreo de uma floresta de planície sempreverde, Sucumbíos-Ecuador

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ABSTRACT

The present study aimed to determine the accumulated carbon potential in the arboreal stratum of a Lowland Evergreen Forest in the Cuyabeno Fauna Production Reserve. A conglomerate of one hectare was established, subdivided into 25 sampling units of 20 x 20 m. The floristic composition, the index of ecological importance at family and species level, and the aerial biomass were determined through allometric equations, biomass importance value and carbon stored potential in the arboreal stratum. It was determined that the forest in the study area stores 392.1 ± 2.35 Mg ha-1 of biomass and 196.05 ± 1.17 Mg C ha-1 in 685 ind ha-1 with $D_{1,30}$ ≥ 10 cm distributed in 13 orders, 19 families, 35 genera 43 species. The families with the largest number of species were Fabacea, Moraceae, Lauraceae, among families that store the largest amount of carbon stood out: Lauraceae (35.6± 0.7 Mg ha-1), Chrysobalanaceae (34.5 ± 5.3 Mg ha-1), Fabaceae (23.6 ± 0.52 Mg ha-1), Sapotaceae (22.6 ± 0.6 Mg ha-1), Arecaceae (21.99 ± 0.25 Mg ha-1) which accumulate 70.4 % of carbon retained in the forest aerial biomass. The accumulation of biomass is determined by the age of each biotype present in the forest, the density of its wood and the abundance of individuals. According to its structure, it is evident that the biomass is self-replenishing in the process of development with a tendency towards growth, biomass productivity and carbon sequestration.

Keywords: Carbon accumulation; Biomass; Evergreen forest; Cuyabeno.

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RESUMEN

El presente estudio tuvo como objetivo determinar el potencial de carbono acumulado en el estrato arbóreo de un Bosque Siempreverde de Tierras Bajas en la Reserva de Producción Faunística Cuyabeno. Se estableció un conglomerado de una hectárea subdividida en 25 unidades de muestreo de 20 x 20 m. Se determinó la composición florística, el índice de importancia ecológica a nivel de familia y especie, la biomasa aérea a través de ecuaciones alométricas, valor de importancia de biomasa y potencial de carbono almacenado en el estrato arbóreo. Se determinó que el bosque del área de estudio almacena 392,1 ± 2,35 Mg ha^{-1} de biomasa y 196,05 ± 1,17 Mg C ha^{-1} en 685 ind ha^{-1}. con $D_{1,30}$ ≥ 10 cm distribuidos en 13 órdenes, 19 familias, 35 géneros y 43 especies. Las familias con mayor número de especies fueron Fabacea, Moraceae, Lauraceae; entre las familias que almacenan la mayor cantidad de carbono destacaron: Lauraceae (35,6± 0,7 Mg ha^{-1}), Chrysobalanaceae (34,5 ± 5,3 Mg ha^{-1}), Fabaceae (23,6 ± 0,52 Mg ha^{-1}), Sapotaceae (22,6 ± 0,6 Mg ha^{-1}), Arecaceae (21,99 ± 0,25 Mg ha^{-1}) que acumulan el 70,4 % de carbono retenido en la biomasa aérea del bosque. La acumulación de la biomasa está determinada por la edad de cada biotipo presente en bosque, la densidad de su madera y la abundancia de individuos. De acuerdo a su estructura se evidencia que la misma es autoregenerativa en proceso de desarrollo con tendencia al crecimiento, productividad de biomasa y secuestro de carbono.

Palabras clave: Carbono acumulado; Biomasa; Bosque siempreverde; Cuyabeno.

RESUMO

O presente estudo visou determinar o potencial de carbono acumulado no estrato arbóreo de uma floresta Sempreverde de terras baixas na Reserva de Produção de Vida Selvagem de Cuyabeno. Foi estabelecido um conglomerado de um hectare, subdividido em 25 unidades de amostragem de 20 x 20 m. A composição florística, o índice de importância ecológica a nível da família e da espécie, a biomassa aérea foram determinados através de equações alométricas, o valor da importância da biomassa e o potencial de carbono armazenado no estrato arbóreo. Foi determinado que a floresta na área de estudo armazena 392,1 ± 2,35 Mg ha-1 de biomassa e 196,05 ± 1,17 Mg C ha-1 em 685 ind. ha-1. Com $D_{1,30}$ ≥ *10* cm distribuídos em 13 ordens, 19 famílias, 35 géneros 43 espécies. As famílias com o maior número de espécies foram Fabacea, Moraceae, Lauraceae, entre as famílias que armazenam a maior quantidade de carbono que se destacaram: Lauraceae (35,6 ± 0,7 Mg ha-1), Chrysobalanaceae (34,5 ± 5,3 Mg ha-1), Fabaceae (23,6 ± 0,52 Mg ha-1), Sapotaceae (22,6 ± 0,6 Mg ha-1), Arecaceae (21,99 ± 0,25 Mg ha-1) que acumulam 70,4 % de carbono retido na biomassa aérea florestal. A acumulação de biomassa é determinada pela idade de cada biótipo presente na floresta, pela densidade da sua madeira e pela abundância de indivíduos. De acordo com a sua estrutura, é evidente que a biomassa se auto reabastece no processo de desenvolvimento com tendência para o crescimento, produtividade da biomassa e sequestro de carbono.

Palavras-chave: Carbono acumulado; Biomassa; Floresta Sempreverde; Cuyabeno.

INTRODUCTION

The Amazon basin covers an area of 6,122,736 km², making it the largest in the world, and includes territories of eight countriesÐ Brazil, Peru, Colombia, Bolivia, Ecuador, Venezuela, Guyana and Suriname, which constitutes a reservoir of great ecological diversity. In addition, 50 % of existing tropical forests play a strategic role in carbon sequestration. Due to its quantitative and qualitative importance, any type of disturbance to the ecosystem generates environmental damage and affects the carbon cycle (Torres *et al.*, 2019).

Indeed, these ecosystems, in addition to other attributes, have high biomass productivity and represent a significant fraction of total carbon and nutrient stocks (Torres *et al*., 2019) Therefore, plant biomass is a sensitive indicator of environmental change and ecological functioning, and is a determining factor for ecosystem variability and resilience (Eisfelder *et al*., 2017).

Recent data suggest that the primary forest in the Amazon Basin is a carbon sink of 0.71 ± 0.34 t C ha^{-1} $year^{-1}$ (FAO, 2000). It is not known if these values can be applied to the whole basin in general. Therefore, there is an urgent need to verify these data and thus extend them to cover a wider geographical range. If the primary forest is a net sump, then it is important to protect it from destruction.

The carbon potential and dynamics of the forests of the northern Amazon of Ecuador are influenced by natural phenomena and anthropogenic activities that alter the structure of the forest and affect the fundamental processes of the carbon cycle. In this sense, the present study was conducted in a lowland evergreen forest of the Cuyabeno Wildlife Production Reserve (RPFC), which is part of the Amazon basin and belongs to the National System of Protected Areas (SNAP) administered by the Ministry of the Environment of Ecuador (MAE), whose purpose was to determine the carbon potential accumulated in the arboreal stratum, analyzing the floristic richness by family, structure and arboreal biomass on the ground which constitutes the starting point for future studies involving the valuation of the forest and the environmental services it provides in addition to serving as a management tool for its conservation

MATERIALS AND METHODS

Study area

The study area is politically located in the provinces of Sucumbíos and Orellana, bordering the Republic of Peru to the east and its northern boundary is very close to the Colombian border. Due to its large surface area and geographical location, it is a strategic protected area for the representation of the Amazon region in Ecuador. It is made up of the largest lake system in the country, covering 603,380 hectares. The average temperature is 24º C, with an average annual rainfall of 3,300 mm. The wettest months are from April to November and the driest months are December and January (MAE 2012). Geographically, it is located at the following coordinates WGS84 18S 9993335 N 359450 E; 9993434 N 359442 E; 9993319 N 359547 E; 9993435 N 359538 E.

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Installation of the plot

The selection of the field study area was made by analyzing the vegetation *in situ*, considering variables such as accessibility, topography and heterogeneity. A conglomerate was established with an extension of one hectare (10 000 m^2) subdivided into 25 subplots of 20 x 20 m (Lozano *et al*., 2018) on mainland sites, where trees and palm species with a diameter of 1.30 m from the ground ($D_{1.30}$) ≥ 10 cm were located and marked. The following data were recorded for each plant: family, genus, species and common name, $D_{1.30}$ and number of individuals.

The identification of botanical species was based on the Catalogue of the vascular plants of Ecuador (Jørgensen and León 1999), as well as work carried out in the northern Amazon (Villa *et al.*, 2015) and the Tropicos database (2019).

Value of ecological importance at species level

The structure of the forest was described by means of the importance value index (IVI) developed mainly to prioritize the dominance of each species. The value of this index was obtained by the sum of relative frequency, relative abundance and relative dominance (Cottam and Curtis, 1956), based on the following expressions (Equation 1); (Equation 2); (Equation 3); (Equation 4) and (Equation 5).

$$\textit{Abundance}\ (D)\#\ \textit{of ind/surface} = \frac{\textit{Number of Individuals by species}}{\textit{Total area sampled}} \quad (1)$$

$$\textit{Relative abundance}\ (AbR)\% = \frac{\textit{Number of Individuals by species}}{\textit{total of individuals}} x100 \quad (2)$$

$$\textit{Relative dominance}\ (DmR)\ \% = \frac{\textit{Basal area of species}}{\text{Basal area of all species}} x100 \quad (3)$$

$$\textit{Relative Frequency}\ (Fr)\% = \frac{\text{Absolute frequency of the species}}{\text{Total sum of absolute frequencies}} x100 \quad (4)$$

$$\textit{Importance Value Index}\ (IVI) = \frac{(DR + DmR + Fr)}{3} x100 \quad (5)$$

Methodology for estimating accumulated aerial biomass

The determination of biomass was done by indirect methods and required the measurement of variables such as $D_{1.30}$. Since this is a protected area, the biomass estimate was based on non-destructive methods, which is why the allometric model best suited to tropical forests proposed by Chave *et al*., (2005) was used to estimate aerial biomass in trees. The expression applied was (Equation 6)

$$\mathbf{AGB} = \rho \text{ x } \exp\left[1{,}499 + 2{,}148 \ln(D_{1{,}30}) + 0{,}207 (\ln(D_{1{,}30}))^2 - 0{,}0281(D_{1{,}30}))^3\right] \quad (6)$$

Where:
AGB **=** biomass in kg of dry mass.
ρ **=** specific gravity of the species in g cm^{-3}
$D_{1,30}$**=** trees with $D_{1.30} \geq$ 10cm

The specific gravity of the wood was obtained from the FAO list of wood densities, when the specific gravity (ρ) was not available the global average for tropical South America was used (0.632 g cm^{-3}) (Zanne *et al*., 2009).

To convert the biomass data to carbon (Mg ha^{-1}) it was multiplied by the 0.5 conversion factor proposed by the Intergovernmental Panel on Climate Change (Penman 2003). The values obtained were expressed in tons of carbon per hectare (Mg C ha^{-1}). The total carbon stored was calculated by adding the carbon in each of the storage compartments (aerial biomass of trees, palms and tree ferns).

Determination of biomass by family

The botanical families that store the most carbon in the study area were determined and graphically represented. A multivariate statistical analysis (ANOVA) was performed using the professional Infostat statistical program, in order to group the families that meet this condition.

Significant value of biomass at species level

The value of biomass importance index (BIV) proposed by Torres *et al.*, (2019) was used. This index relates the accumulated biomass of each botanical species to determine the species that have the greatest ecological weight from the sum of relative abundance (ARF), relative dominance (DRF) and relative biomass (BRF) whose expression is (Equation 7).

$$\mathbf{BIV} = \text{ARF} + \text{DRF} + \text{BRF}$$

$$\boldsymbol{ARF}\ (\%) = \frac{Number\ of\ individuals\ per\ species}{total\ individuals} x100$$

$$\boldsymbol{DRF}\ (\%) = \frac{Basal\ area\ of\ the\ species}{\text{Basal area of all species}} x100$$

$$\mathbf{BRF}\ (\%) = \frac{Biomass\ of\ the\ species}{Biomass\ of\ all\ species} x100 \qquad (7)$$

Where:

BIV= Biomass Importance Value Index.
ARF= Relative abundance.
DRF= Relative dominance.
BRF= Relative biomass.

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RESULTS AND DISCUSSION

Floristic composition

Considering the study area, a total of 685 ind ha^{-1} with $D_{1.30}$ ≥10 cm were recorded, distributed in 13 orders, 19 families, 35 genera and 43 species. The most representative families were Fabaceae (7 spp.), Moraceae (5 spp.) and Lauraceae (5 spp.), 2019), who found that Moraceae and Fabaceae are the most species-rich families in the Amazon evergreen forest in Napo Province and with the results of Ter Steege *et al*., (2000) who report that Leguminosae is a species-rich family in primary neotropical forests. Arecaceae, Myristicaceae and Sapotaceae recorded 3 spp. each; on the other hand, the genera with greater richness were *Brosimun* and *Ocotea* (3 spp.), *Chrysophyllum*, *Guarea* e *Inga* (2 *spp*.).

It was determined that of the total species recorded (46), some of these are represented by a small number of individuals. The most abundant species, however, are few and far between, with more than 60 % of individuals, which has been a widely reported distribution pattern in tropical rainforests around the world (Ter Steege *et al.,* 2013).

Structure of the forest

The trend curve of the diameter distribution is in inverted "J" (Figure 1), where the diameter class (10.2-27.1 cm) concentrates 79 % of the individuals (542), evidencing that the forest is formed by young and thin individuals, there are few individuals with $D_{1.30}$ ≥ 60 cm (10) that are dispersed; showing that the tree community by having greater abundance of individuals in low diameter classes has a higher rate of growth and greater potential for catching C by increasing its biomass. However, this increase is not constant since the growth rates during the cycle of each species are different.

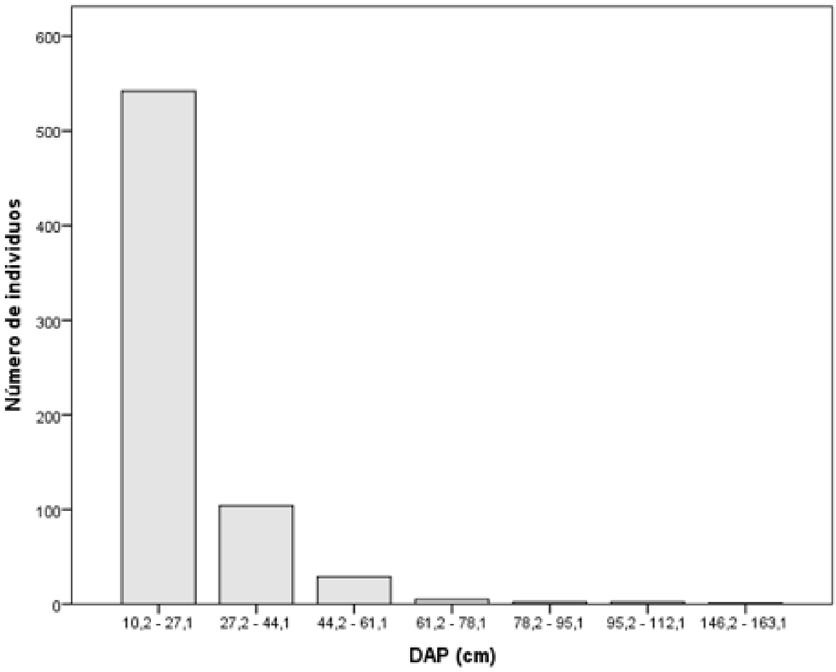

Figure 1. - Structure of the arboreal community according to the number of individuals by diameter classes in the Cuyabeno Fauna Production Reserve, Sucumbíos-Ecuador

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Value of ecological importance at family level (IVIF)

The basal area was 33.05 m^2 ha^{-1}. The five families with the highest IVIF were Lauraceae (17.53 %); Fabaceae (13.17 %); Arecacea (12.93%); Sapotaceae (9.75 %); Myristicaceae (9.24 %). The most diverse families were Fabaceae (7 species and 108 individuals), followed by Lauraceae (5 species and 141 individuals), Moraceae (5 species and 36 individuals) and Arecaceae (3 species and 106 individuals). The IVIF is mainly given by the number of individuals and the dominance in the ecosystem of these families (Arecaceae, Lauraceae, Fabaceae, Myristicaceae, Moraceae) coincides as the species with the highest IVIF with the study of floristic composition and structure of a Piemontano evergreen forest carried out in the province of Napo by Patiño *et al.*, (2015). The families with the lowest IVIF were Phyllanthaceae (0.25 %) and Araliaceae (0.21 %) due to the lower number of individuals and smaller basal area per family (Table 1).

Table 1. - Forest structure, abundance, frequency, dominance and importance value index at family level (IVIF) of the Cuyabeno Fauna Production Reserve, Sucumbíos Ecuador

FAMILIES	No. ind	AbR (%)	DmR (%)	Fr (%)	IVIF
Lauraceae	141	20.58	20.60	11.42	17.53
Fabaceae	108	15.77	13.69	10.05	13.17
Arecaceae	106	15.47	13.26	10.05	12.93
Sapotaceae	69	10.07	9.58	9.59	9.75
Myristicaceae	71	10.36	8.21	9.13	9.24
Moraceae	36	5.26	5.87	9.59	6.90
Chrysobalanaceae	26	3.80	9.46	6.39	6.55
Burseraceae	41	5.99	5.69	6.85	6.17
Vochysiaceae	22	3.21	3.12	6.85	4.39
Urticaceae	18	2.63	2.32	4.11	3.02
Melastomataceae	11	1.61	1.66	4.11	2.46
Meliaceae	10	1.46	1.60	3.65	2.24
Elaeocarpaceae	7	1.02	2.93	2.28	2.08
Malvaceae	8	1.17	1.01	1.83	1.33
Clusiaceae	4	0.58	0.42	1.37	0.79
Lecythidaceae	3	0.44	0.23	0.91	0.53
Rubiaceae	2	0.29	0.17	0.91	0.46
Phyllanthaceae	1	0.15	0.14	0.46	0.25
Araliaceae	1	0.15	0.04	0.46	0.21

AbR = Relative Abundance; **DmR** = Relative Dominance; **Fr**= Relative Frequency; **IVIF**= Family Importance Value Index

Value of ecological importance at species level (IVIE)

Table 2 shows the species with the highest IVIE: *Oenocarpus bataua* Mart. (11.10 %), *Inga spp*. (8.46 %), *Ocotea spp*. (8.41 %) *Nectandra membranacea* (Sw.) Griseb. (7.73 %) and *Osteophloeum platyspermum* Spruce (6.29 %); due to abundance, dominance and relative frequency. The species with the lowest IVIE were *Ocotea javitensis* (Kunth) Pittier; *Hieronyma oblonga* (Tul.) Müll. Arg.; *Simira cordifolia* (Hook. f.) Steyerm; *Faramea sp*. and *Schefflera morototoni* Aubl. with percentages below 0.33 %.

Table 2. - Structure of the forest, it shows the 5 species with the highest and lowest abundance, frequency, dominance and Importance Value Index (IVIE) of the Cuyabeno Fauna Production Reserve, Sucumbíos-Ecuador

SPECIES	No. ind	AbR (%)	DmR (%)	Fr (%)	IVIE
Oenocarpus bataua Mart.	93	13.58	12.20	7.53	11.10
Inga spp.	77	11.24	8.31	5.82	8.46
Ocotea spp.	66	9.64	8.75	6.85	8.41
Nectandra membranacea (Sw.) Griseb.	60	8.76	7.59	6.85	7.73
Osteophloeum platyspermum Spruce.	48	7.01	5.71	6.16	6.29
Ocotea javitensis (Kunth) Pittier	3	0.44	0.17	0.34	0.32
Hieronyma oblonga (Tul.) Müll. Arg.	1	0.15	0.14	0.34	0.21
Simira cordifolia (Hook. f.) Steyerm.	1	0.15	0.10	0.34	0.20
Faramea sp.	1	0.15	0.07	0.34	0.19
Schefflera morototoni	1	0.15	0.04	0.34	0.18

AbR = Relative Abundance; **DmR** = Relative Dominance; **Fr=** Relative Frequency; **IVIE=** Species Importance Value Index

Accumulated aerial biomass

With regard to total dry aerial biomass, the forest registers 392.0 ± 2.35 Mg ha^{-1}; according to the analysis of Keeling and Phillips (2007) the tropical forests of the world generally do not have biomass values higher than 350 Mg ha^{-1}. However, Nascimento and Laurance (2002) report biomass values of almost 400 Mg ha^{-1} in undisturbed Amazon tropical forests. This suggests a high potential for carbon storage by these ecosystems.

Carbon ptential

The accumulated carbon in the tree stratum was 196.05 ± 1.17 Mg C ha^{-1}; similar values were found in studies conducted in the Amazon forest (206.2 Mg C ha^{-1}) (Jadan *et al.,* 2012). In relation to the accumulated carbon by family, there is a statistical difference ($P < 0.05$) between two groups of families; the structural characteristics of the tree stratum and individuals explain this grouping mainly in relation to the density of the wood (Kg m^{-3}), number of individuals by species (ind ha^{-1}) and $D_{1.30}$ (cm), which is corroborated by Fonseca *et al.,* (2009).

In Figure 2, the taxonomic groups differentiated according to carbon accumulation are indicated; group 1 accumulates 29.6 % (57.95 Mg C ha^{-1}) and group 2; 70.4 % (138.1 Mg C ha^{-1}).

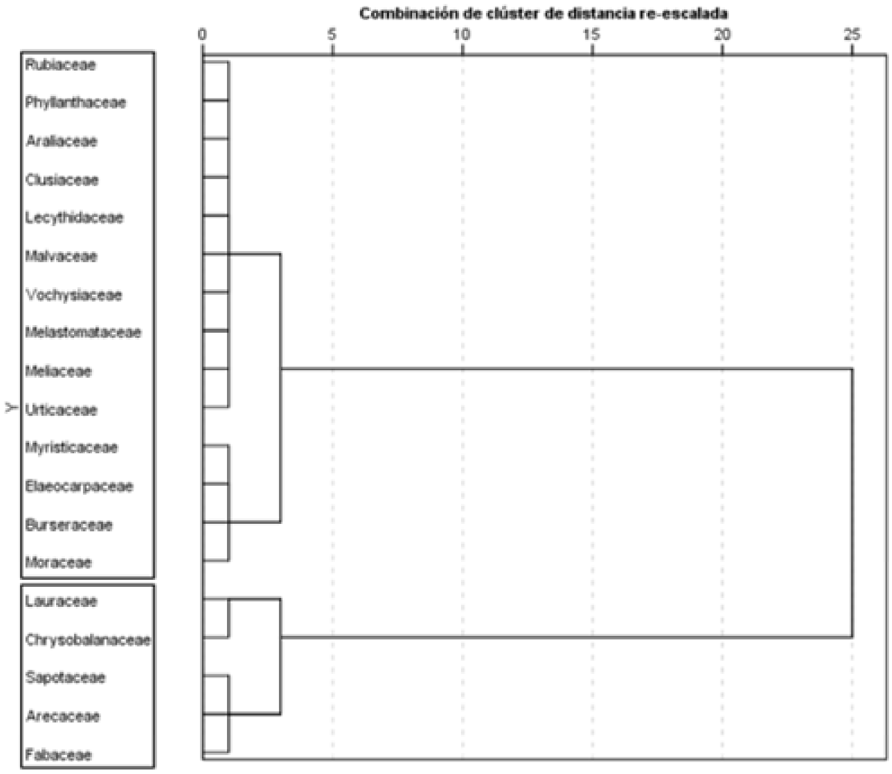

Figure 2. - Dendrogram of biomass accumulation by family applying the Ward method and Bray Curtis distance

Figure 3 shows the families that store the most carbon: Lauraceae (35,6 ± 0,7 Mg C ha^{-1}), Chrysobalanaceae (34,5 ± 5,3 Mg ha^{-1}), Fabaceae (23,6 ± 0,52 Mg C ha^{-1}), Sapotaceae (22,6 ± 0,6 Mg C ha^{-1}), Arecaceae (21,99 ± 0,25 Mg ha^{-1}) accumulate 70, 4 % of the carbon in the aerial biomass of the forest, followed by Moraceae (12.02± 1.02 Mg C ha^{-1}) Myristicaceae (10.3±0.19 Mg C ha^{-1}), Burseraceae (8.07 ± 0.42 Mg C ha^{-1}), Elaeocarpaceae (9.84 ± 2.04 MgC ha^{-1}) which accumulate 10.26 %. The nine families together accumulate 80.7 % (178.25 Mg C ha^{-1}) of the carbon fixed in the aerial biomass tree stratum. The families Lauraceae and Fabaceae constitute in these ecosystems one of the taxonomic groups that have great ecological importance mainly due to their distribution and structural development of their species, corroborated by similar studies carried out in the Peruvian Amazon where Lauraceae Fabaceae, Sapotaceae Myristicaceae, are within the 10 most important families according to their biomass contribution (Ureta, 2015).

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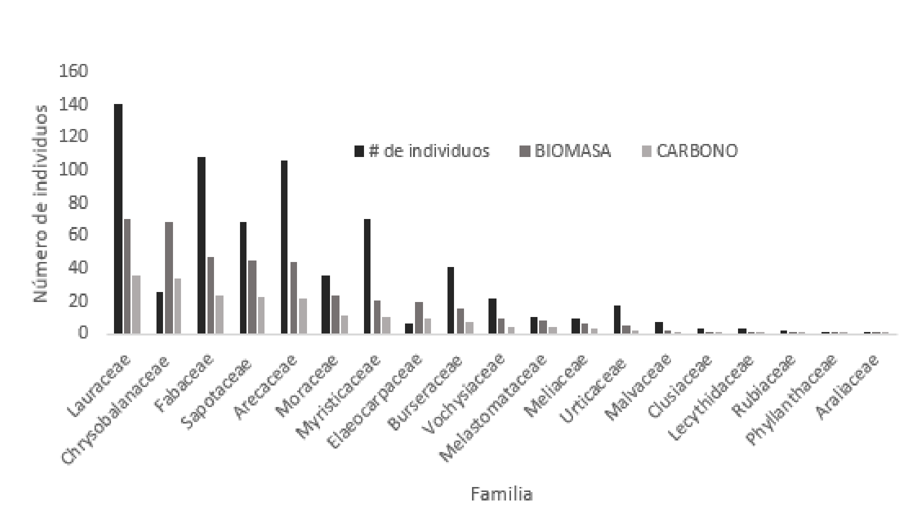

Figure 3. - Biomass and accumulated carbon by family of the Cuyabeno Fauna Production Reserve, Sucumbíos-Ecuador

Significance value of biomass at species level (VIB)

According to the value of biomass importance *Oenocarpus bataua Mart*. had the highest values mainly due to the number of individuals (93) and relative dominance (12.2 %) this species is included in the list of the 20 most abundant tree species in the Amazon (Ter Steege *et al*., 2013), the abundance and dominance of this species is an indicator of the potential of these ecosystems to retain carbon. *Licania glauca* Cuatrec, despite having fewer individuals, its relative biomass is the most influential factor, mainly due to the $D_{1.30}$ of the individuals found and the density of its wood (0.81 g cm^{-3}). These species, together with *Ocotea spp*., *Inga spp*. and *Nectandra membranacea* (Sw.) Griseb. constitute the group of species that retain the most carbon in the ecosystem (Table 3).

Table 3. - Species with higher and lower abundance, Relative Dominance, Relative Biomass and Biomass Value Index at species level (BIV) of the Cuyabeno Fauna Production Reserve, Sucumbíos-Ecuador

SPECIES	No. ind	AbR (%)	DmR (%)	Biomass R (%)	BIV (%)
Oenocarpus bataua Mart.	93	13.58	12.20	10.86	12.21
Licania glauca Cuatrec.	26	3.80	9.46	17.57	10.28
Ocotea spp.	66	9.64	8.75	7.92	8.77
Inga spp.	77	11.24	8.31	6.49	8.68
Nectandra membranacea (Sw.) Griseb.	60	8.76	7.59	6.43	7.59
Acacia glomerosa Benth.	2	0.29	0.09	0.05	0.14
Hieronyma oblonga (Tul.) Müll. Arg.	1	0.15	0.14	0.11	0.13
Simira cordifolia (Hook. f.) Steyerm.	1	0.15	0.10	0.08	0.11
Faramea sp.	1	0.15	0.07	0.04	0.09
Schefflera morototoni Aubl.	1	0.15	0.04	0.02	0.07

AbR = Relative Abundance; **DmR** = Relative Dominance; **BVI =** Biomass Value Index

The forest ecosystem of the Cuyabeno Wildlife Production Reserve retains 392.1 ± 2.35 Mg ha^{-1} of aerial biomass and 196.05 ± 1.17 Mg C ha^{-1} with 685 ind ha^{-1} with $D_{1.30}$ ≥ 10 cm distributed in 13 orders, 19 families, 35 genera and 43 species.

The structural characteristics of the forest such as the IVI, IVIF, VIB are an indicator of the potential of these ecosystems to sequester carbon.

Lauraceae, Chrysobalanaceae, Fabaceae, Sapotaceae and *Arecaceae* accumulate 70.4 % of the forest biomass, constituting the group of species indicative of the carbon sequestration potential in these ecosystems.

The rate of biomass accumulation is determined by the age of each biotype present in the forest, given the diameter distribution of the tree community that concentrates 79 % of the individuals in the class (10.2-27.1 cm) could be determined that it is self-regenerative and in the process of development with a tendency to growth and productivity of biomass, the thin shafts will gradually be recruited in the larger diameter classes and ensure the future capture and fixation of carbon.

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