UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Visión Electrónica
Más que un estado sólido
https://doi.org/10.14483/issn.2248-4728

VISIÓN ELECTRONICA
A CONTEXT VISION

Estimation of stored carbon in a productive forest: upper watershed of the river Domingodó

Estimación del carbono almacenado en un bosque productivo: cuenca alta del río Domingodó

Jenniffer Preciado-Barragán[1], Cristian Hurtado-Vásquez[2], Max Triana-Gómez[3]

INFORMACIÓN DEL ARTICULO

Historia del articulo
Envíado: 02/05/2019
Reccibido: 03/05/2019
Aceptado: 02/06/2019

Palabras clave:
Carbono Almacenado,
Biomasa,
Modelos Alométricos,
Cambio Climático

RESUMEN

En el bosque de la cuenca alta del río Domingodó, ubicado en el municipio de Carmen de Darién en el Chocó - Colombia-, se estimó la cantidad de biomasa aérea y de carbono almacenado del ecosistema, y de diez especies con mayor valor de importancia -estas representan el 46.69% del total del ecosistema-. Para ello, se seleccionaron once ecuaciones alométricas basadas en los modelos de estimación recomendados del IPCC (2005), teniendo presente los factores biogeográficos para elegir los que más se ajustaban al ecosistema. Para la mayoría de especies el modelo que más se ajustó fue el de Álvarez-bh-PM. El cálculo del carbono almacenado se determinó con la fracción del 50% de la biomasa, metodología dada por el IPPC (2005). Como resultado, se obtuvo que el ecosistema en promedio contiene 35,80t/0,05ha de biomasa aérea y captura 17,9t/0,05ha de carbono, los cuales son de gran importancia para combatir el cambio climático.

Keywords:
Stocked Carbon,
Biomass,
Allometric Models,
Global warming.

ABSTRACT:

In the forest of the upper watershed of the Domingodo's river, located to town of Carmen de Darien in Choco -Colombia-, it was estimated the amount of aerial and carbon biomass stored in the ecosystem, and ten species with greater importance value - they represent 46.69% of the total ecosystem-. Selected eleven allometric equations based on the recommended models of IPCC (2005) bearing in mind the biogeographical factors to choose the ones that best fit the ecosystem. For most species, the model that was most adjusted was the Alvarez-bh-PM. The calculation of stored carbon is determined with the fraction of 50% of the biomass, his is determined by the IPPC (2005). As a result, it was obtained that the ecosystem on average contains 35,80t/0,05he of aerial biomass and 17,9t/0,05he carbon capture, which are of great importance to combat global warming.

1BSc. In Forest Engineering, Universidad Distrital Francisco José de Caldas, Colombia. Current Position: Research Group PROMAFOR, Faculty of Environment and Natural Resources, Colombia. E-mail: jcpreciadob@correo.udistrital.edu.co
2BSc. In Forest Engineering, Universidad Distrital Francisco José de Caldas, Colombia. Current Position: Research Group PROMAFOR, Faculty of Environment and Natural Resources, Colombia. E-mail: cchurtadov@correo.udistrital.edu.co
3BSc. In Forest Engineering, MSc. In Production, Management and Conservation of Natural Resources, Sp. In Alternatives of Sustainable Development for the Colombian Amazon, Universidad Distrital Francisco José de Caldas, Colombia. Current position: Professor and director of Research Group PROMAFOR, Faculty of Environment and Natural Resources, Colombia. E-mail: mtriana@udistrital.edu.co
Cite this article as: J. Preciado-Barragán, C. Hurtado-Vásquez and M. Triana-Gómez, "Estimation of stored carbon in a productive forest: upper watershed of the river Domingodó", Visión electrónica, vol. 2, no. 1, Special edition, January-june 2019 https://doi.org/10.14483/issn.2248-4728

1. Introduction

Global Warming is one of the main environmental planet problems, since in last years the earth has increased the mean temperature, the climate records show that the total temperature heartened between the periods from 1850-1899 to 2001-2005 was 0.76 ° C ± 0.19 ° C. The warming rate averaged over the past 50 years (0.13 ° C ± 0.03 ° C per decade) this is almost double the rate of the last 100 years. One of the main causes of increased the global temperature is due to the greenhouse effect produced by gases such as carbon dioxide (CO_2), methane (CH_4), Chlorofluorocarbons (CFCs) and nitrous oxide (N_2O) [1]. The CO_2 is released towards the atmosphere daily in high quantities, in 2014 was estimated the production of 36,138,285 Kilotonnes (kt) of CO_2 [2].

Trees and forests help to strengthen living environment, they provide clean air and clean water, protect the soils, they are the key for the biodiversity conservation, because they safeguard more than three-fourths of the world's terrestrial biodiversity, with this they respond to global warming by its function of accumulating greenhouse gases in the atmosphere (United Nations UNFCCC,2015) [3], provide products and services which contribute to socioeconomic development, they are the key for food security and among other services. Therefore, it's of great importance the search for environmental sustainable, making necessary an appropriate forest management that can foster resilience and the capacities to adapt the problems related to global warming, [4].

Forests are fundamental in the carbon cycle because they capture carbon from the atmosphere and store it in the biomass form [5], it is estimated that forests absorbed approximately 2 000 million tons of carbon dioxide per year, [4]. This storage in a context of global warming is of great importance, given that the carbon accumulation in the biomass and in the soil can mitigate 30% of the annual CO_2 emissions produced anthropically [6]. The Reducing Emissions from Deforestation and Forest Degradation strategy (REDD+), along with the sustainable forest management, they are essential for the implementation of measures to combat the global warming effects, [4].

Biomass is a factor that determinate the ecosystem's capacity to accumulate organic matter through time [7], this is constituted by the organic matter weight, such aerial as underground, which is found in a forest ecosystem [8], [9]. It's essential to estimate the forest biomass, since it allows to determine the amounts of carbon and other chemical elements present, this represents the potential amount of carbon that can be released into the atmosphere or fixed to a surface area, in this way it will be possible to calculate the contribution that the forest makes to the mitigation of greenhouse gases [10], [11].

There are direct and indirect methods to estimate forest biomass. The direct method is destructive because is based on cutting a tree, weigh the biomass and then determine the dry weight, [12]. Indirect methods aren't destructive, because you don't need to cut the tree for calculation, one of the methods is done by means of equations or models based on regression analysis, where include such variables as tree diameter at breast height (DBH), tree commercial height (CH) and tree total height (TH), the diametric growth, basal area and specific wood density, [7]. These types of equations help to make some decisions and allow the biomass estimation and carbon on a large scale, [9].

In Colombia, the total carbon stored for 2007 was above 7800 million tons, with higher average reserve values in very wet tropical forest, obtaining values of 135.29 Tons (Ton) of Carbon (C) per hectare (he), together with the tropical forest in which it was calculated 131.87 Ton C/he. The Pacific Region ranks second after the Amazon Region, having an average of 131 Ton C/he, [13]. the Chocó value was estimated above of them 135 Ton C/ha, giving it the third place at state level, [14].

The present study suggests to estimate aerial biomass and carbon stored in a wet tropical forest of the Domingodo's watershed, determining ten species with the highest Importance Value Index (IVI), evaluating whether or not there are significant differences between these in relation to the allometric models, finally establishing which is the one that the most adjusts to an average value between models.

2. Methodology

2.1. Study area and features

The study takes place in the upper watershed of the Domingodo's river, is located in Carmen de Darién town, in the department of Chocó and this is part of the subregion of the demographic Chocó. The Domingodo's river is between the coordinates 77°00'00¨

and 77°12'00" length W; and North latitude 7°12'00" and 7°12'00". The average temperature in the area is 80.96 °F, the average rainfall is 3589 mm/year.

The high side of the Domingodo's river is made up of Afro-Colombian rural communities, which are Domingodó and Chintadó. The population that live in this area belongs to the forester family program, [15].

In the area there are low hills forests, has a primary natural vegetable cover slightly tapped, with soft and moderate slopes ranging, the soils have a clay-loam texture and moderate depth, good fertility and high levels of aluminum, they are determined as exclusively forest-based soils. The vegetation is very varied, feature of tropical rainforests. These information was obtained through the satellite images perform, with Erdas software application and field checks supported by information provided for the community as regards the types of the forest attendants in the study area.

In this area there are wood species of high commercial value such as Lecythis tuyrana Pittier (olleto), Tabebuia rosea (Bertol.) Bertero ex A.DC (roble), Prioria copaifera Griseb (cativo), Anacardium excelsum (Bertero ex Kunth) Skeels (caracolí), Ceiba pentandra (L.) Gaertn (ceiba), Dipteryx spp (Choiba), Nectandra membranacea (Sw.) Griseb (caidita) y Copaifera canime Harms (canime). There are also non-wood important species as Apeiba glabra Aubl (corcho), Bursera simaruba (L.) Sarg (resbala mono) y Schizolobium parahyba (Vell.) S. F. Blake (tambolero).

2.2. Collection Data

The sampling is systematic by strips, which was done through cartography obtained from the state's EOT and satellite images (Landsat ETM +), where 12 plots of 500 m2 were established, in which aspects of the floristic and structural composition of the vegetation were evaluated following the methodology defined by Rangel & Velásquez in 1997 [16], the total individuals registered number in the inventory was 2079.

were selected for the data collection Individuals with more than 10 cm of DBH (diameter at breast height), which was measured at 1.3m height, the total height and the commercial height in meters were also measured. finally, is carried out identification of the species, when these were not identified in the field, the procedure to the collection of plant material for subsequent taxonomic identification in the UDBC forest herbarium.

2.3. Processing Data

The data registered in the field sheets were digitized and filter in the Excel 2013 program, to start with the calculation of the importance value index (IVI), taking into account the variables of plenty, commonness and pervasiveness, to determine which species contribute the most to the character and structure of the forest using the following formula, [17]:

IVI = Relative abundance + Relative dominance + Relative frequency

After each species is classified in a category of importance sampling, the 10 species with the highest IVI are selected to apply 11 allometric models of indirect biomass estimation specified in Table 1, later an average model was made for each species and the ecosystem, this allowed selecting the model that was closed to the average by means of the Spearman correlation coefficient.

Model	Author	Description
Model 1 (LM- rf)	[18]	$B = EXP (2.226 + (-1.552 * \ln (DBH)) + (1.237 * (\ln (DBH))^2) + (-0.126 * (\ln (DBH))^3) + (-0.237 * \ln (0.65)))$
Model 2 (PM-rf)	[18]	$B = EXP (2.421 + (-1.415 * \ln (DBH)) + (1.237 * (\ln (DBH))^2) + (-0.126 * (\ln (DBH))^3) + (1.068 * \ln (0.65)))$
Model 3 (LM- rf)	[18]	$B = EXP (-1.663 + (2.37 * \ln (DBH)))$
Model 4 (PM-rf)	[18]	$B = EXP (-1.866 + (2.37 * \ln (DBH)))$
Model 5 (T-rf)	[19]	$B = EXP (-2.19 + (2.54 * \ln (DBH)))$
Model 6	[20]	$B = EXP (-2.289 + 2.649 * \ln (DBH) - 0.021 * \ln (DBH^2))$
Model 7	[21]	$B = 0.65 * EXP (-1.499 + 2.148 * \ln (DBH) + 0.207 * \ln (DBH^2) - 0.0281 * \ln (DBH^3))$
Model 8	[21]	$B = 0.65 * EXP (-0.667 + 1.784 * \ln (DAP) + 0.207 * \ln (DBH^2) - 0.0281 * \ln (DBH^3))$
Model 9	[22]	$B = EXP (-2.904 + (0.993 * \ln (\pi * DBH^2 * Ht)))$
Model 10	[21]	$B= EXP (-2.977 + \ln (0.65 * DBH^2 * Ht))$
Model 11	[21]	$B= EXP (-2.187 + (0.916 * \ln (0.65 * (DBH)^2 * Ht)))$

Conventions: B (aerial biomass), DBH (cm), Ht (Total height in meters), rf-LM (lower montane rainforest), rf-PM (premontane rainforest), T-rf (Tropical rainforest)

Table 1. Allometric models used to estimate the forest aerial biomass of the Domingodo's river upper watershed. Source: own.

After processing, the data was entered into the R Project 3.1.1 softwares, for descriptive statistical analysis; as the mean, the standard deviation, the confidence intervals, the normal distribution of the variables and the graphic outputs; and inferential statistics such as tests of variance and contrast. The calculation of stored carbon was based on the IPCC [23] where the carbon is 50% of the estimated biomass of each selected model.

3. Analysis and Discussion

3.1. Species selection

Table 2 summarizes the ten species with the highest IVI of the upper watershed of the Domingodo's river, which represent 46.69% of the total ecosystem, therefore, these species allow to givemore accurate approximation to conclude the amount of forest aerial biomass. The family Leguminosae is the one that has the most representation with four species in the list with a representation of 23.05% (P. copaifera, P. dulce, C. canime, P. officinalis), the species with greatest importance is P. copaifera with a value of 10.46% and the tenth species selected is C. canime with a value of 2.90%.

Species	Relative abundance	Relative frequency	Relative Dominance	IVI to 100%
Prioria copaifera	12,409	3,478	15,491	10,459
Pouteria caimito	6,926	3,18	6,131	5,415
Pithecellobium dulce	7,503	2,60	4,836	4,982
Pterocarpus officinalis	5,387	3,188	5,538	4,704
Anacardium excelsum	1,491	3,188	8,112	4,264
Ficus insipida	1,491	2,898	6,844	3,744
Cecropia garciae	5,339	2,898	2,666	3,634
Brosimum utile	4,377	2,028	4,083	3,496
Pouteria eugeniifolia	3,848	2,028	3,380	3,085
Copaifera canime	4,761	2,028	1,907	2,899

Table 2. Species with the highest Importance Value IVI Index in the forest of the upper watershed of the Domingodo's river. Source: own.

3.2. Biomass estimation

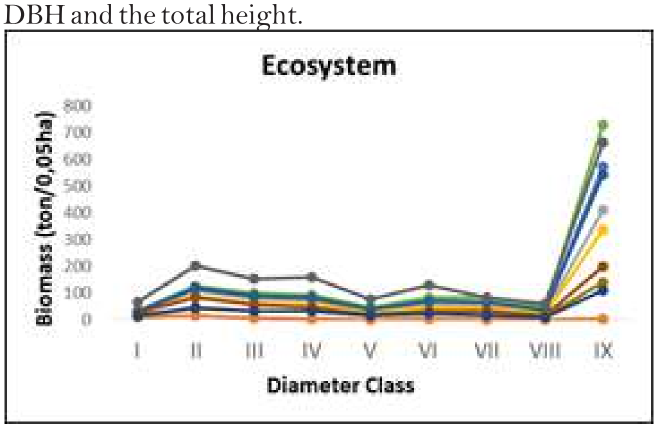
Table 3 shows the Spearman correlation coefficient calculated for eleven models, the models with values closer than 1 were the ones selected, in the cases of the species P. copaifera, P. dulce, P. officinalis, F. insípida, B. utile and P. eugeniifolia, it considered that the climatic conditions were similar to the study area, also keep in mind the proximity to the study area where the author of the model recommends that used it. The model with the best match at the area is 4, this model just contemplates the DBH of dasometric variable.

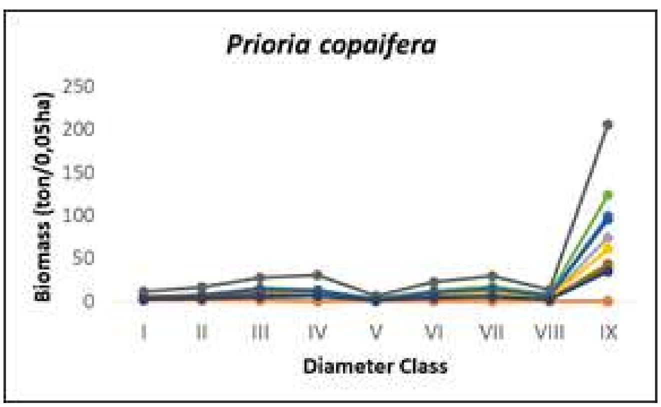
Model	*Prioria. copaifera*	*Pouteria caimito*	*Pithecellobium dulce*	*Pterocarpus officinalis*	*Anacardium excelsum*	*Ficus insipida*	*Cecropia garciae*	*Brosimum utile*	*Pouteria eugeniifolia*	*Copaifera canime*	Ecosystem
1	0,834	0,863	0,752	0,869	0,933	0,887	0,871	0,890	0,916	0,858	0,792
2	0,859	0,880	0,792	0,887	0,947	0,909	0,882	0,911	0,926	0,883	0,826
3	0,997	0,991	0,998	0,986	0,986	1,000	0,955	0,997	0,978	0,994	0,986
4	0,997	0,991	0,998	0,986	0,986	1,000	0,955	0,997	0,978	0,994	0,986
5	0,996	0,994	0,997	0,985	0,983	0,999	0,957	0,996	0,978	0,990	0,982
6	0,996	0,995	0,996	0,984	0,981	0,999	0,958	0,995	0,978	0,988	0,979
7	0,996	0,993	0,998	0,986	0,984	1,000	0,957	0,997	0,978	0,991	0,984
8	0,994	0,984	0,997	0,985	0,990	0,998	0,951	0,997	0,977	0,997	0,989
9	0,990	0,976	0,981	0,932	0,825	0,934	0,861	0,984	0,903	0,863	0,856
10	0,990	0,975	0,982	0,932	0,824	0,934	0,860	0,984	0,903	0,864	0,855
11	0,989	0,982	0,976	0,932	0,832	0,928	0,867	0,981	0,903	0,858	0,860

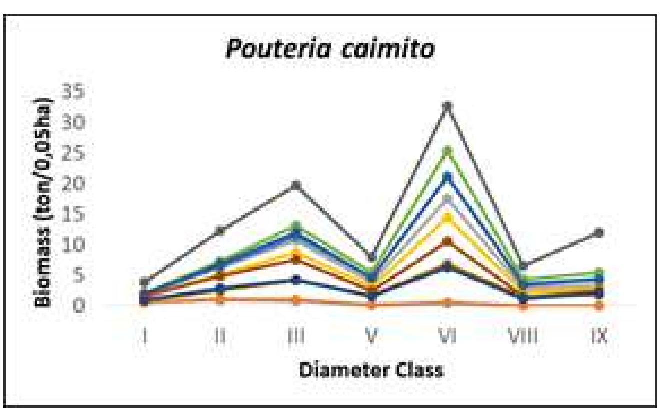
The highlighted values are the sellected models for each species and ecosystem.

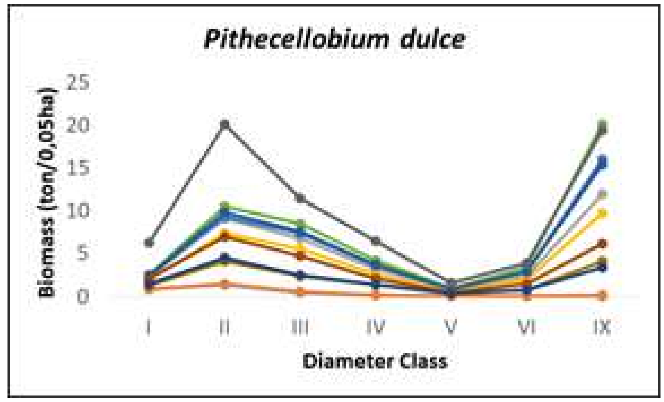
Table 3. Spearman's correlation quotient of the eleven allometric models. Source: own.

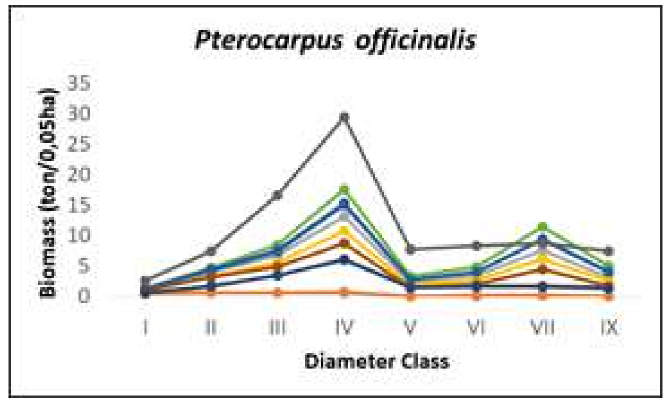
In terms of the distribution of aerial biomass in tons per each 0.05 hectares for the diametrical class, which were grouped every 10 cm of DBH I=10cm-20cm, II=20cm-30cm, III=30cm-40cm, IV=40cm-50cm, V=50cm-60cm, VI=60cm-70cm, VII=70cm-80cm, VIII=80cm-90cm, IX=90cm-100cm), for selected species and the ecosystem, described in Figure 1. The highest estimates correspond to model 9 and model 6, the model 6 estimates the biomass according to the DBH and the total height, while that the model 9 estimates the biomass only according to the DBH function. The lowest biomass estimate match to model 2, which only take notes to the DBH variable, followed by model 11 and model 10, both are a function of the DBH and the total height.

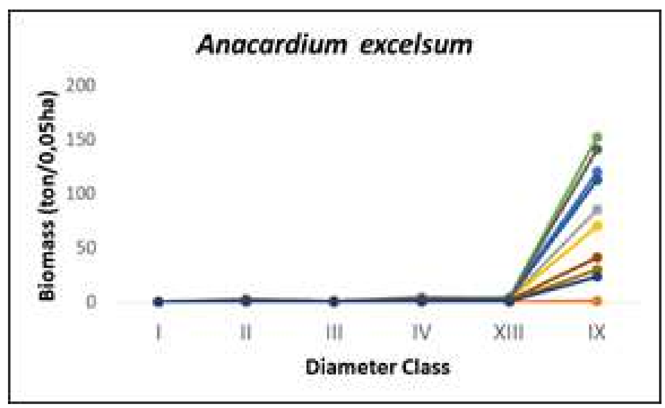


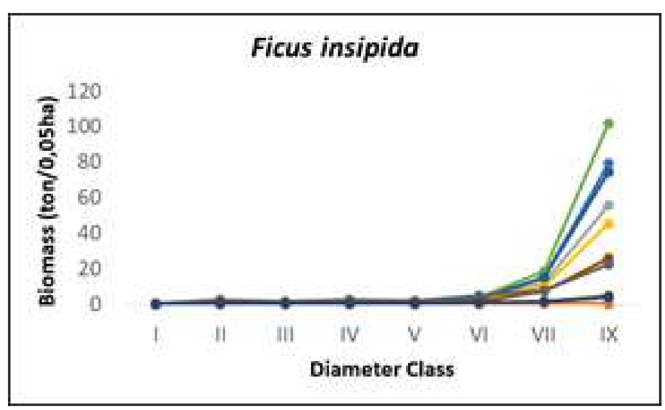












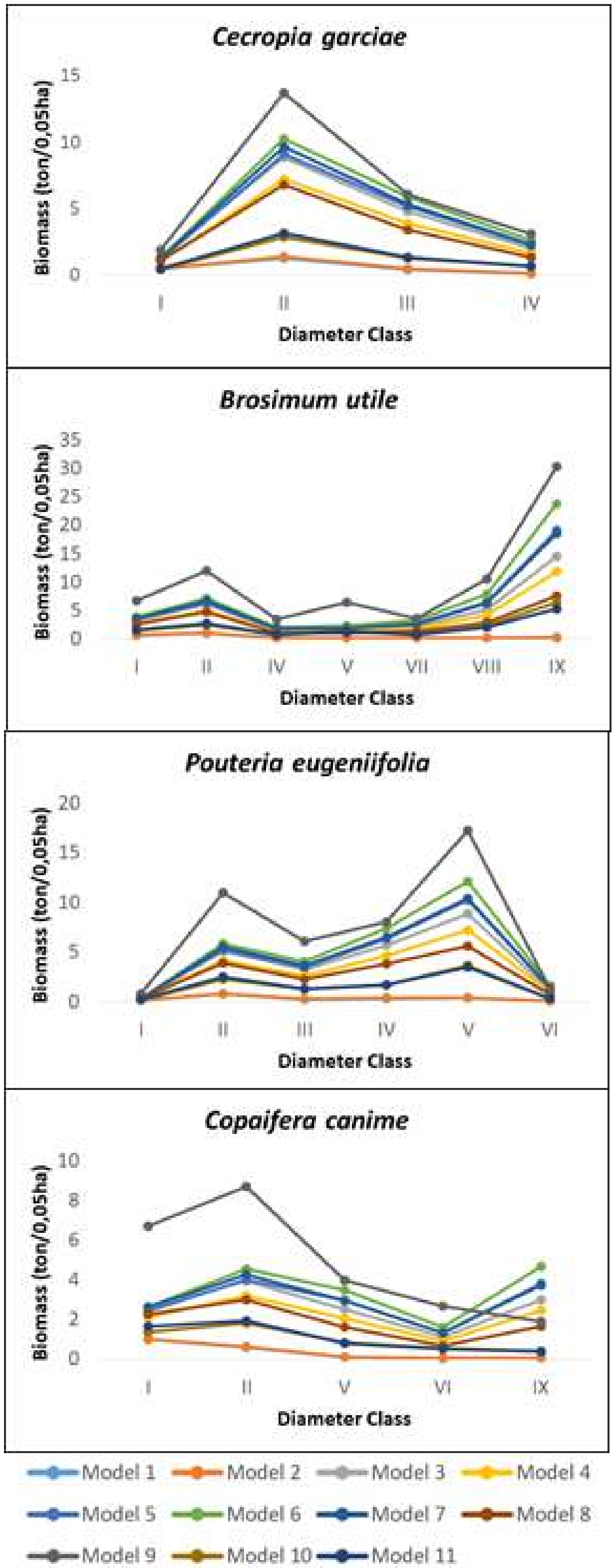


Figure 1. Aerial biomass distribution per diameter class (cm) using the eleven allometric models of Table 1. Source: own.

3.3. Structural variables and biomass

In the Box-Plot type drawings, of Figure 2, it can be seen that the species with the highest median in basal area is F. insipida with a value of 0,482m2, having a data distribution between 0,009m2 to 0,497m2, while the lowest median species is C. canime with a value of 0,042m2, having a distribution of data between 0,008m2 to 0,068 m2. In terms of the number of individuals in 0.05 hectares, the species with the highest median is P.copaifera with 22 individuals, having a distribution of 48 individuals to 3 species, the species with the lowest median are F.insipida and A.excelsum with 3 individuals.

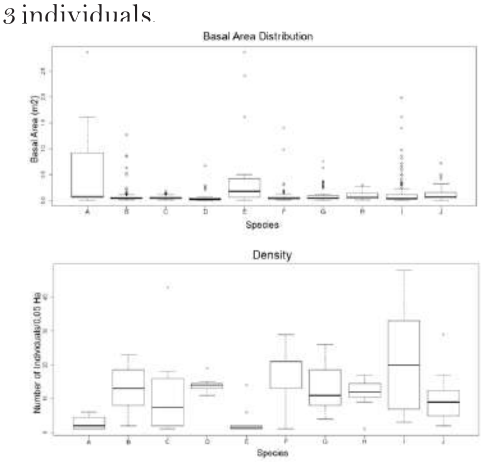


Figure 2. Structure settings (Density, Basal Area) for the species: (A) A. excelsum, (B) B. utile, (C) C. garciae, (D) C. canime, (E) F. insípida, (F) P. dulce, (G) P. caimito, (H) P. eugeniifolia, (I) P. copaifera, (J) P. officinalis. Source: own.

Table 4 shows the average value of structural variables, biomass and carbon, where the highest biomass values occur in the species A. excelsum with 43,05 +/- 10,37 tons in 0.05 hectares, storing 21.53 tons of carbon in 0.05 hectares; the lowest biomass value match to the P.dulce species with 3.62 +/- 0.20 tons in 0.05 hectares, storing 1.81 tons of carbon in 0.05 hectares; on average the ecosystem has a biomass of 35.80 +/- 3.03 tons in 0.05 hectares, storing on average 17.09 tons of carbon in 0.05 hectares. To set the meaningful differences between the structural variables at the ecosystem level and the species, applies the non-parametric test for the variance test of Kruskal-Wallis, all the structure variables, biomass and carbon, present important differences (with a probability of 0.05%), this shown that the characteristics of structure, floristic composition and degree of disturbance, have to do with the quantity of stored biomass in the vegetation.

Species	Density (ind/0,05 ha)	Total height (m)	Basal area (m2/0,05 ha)	Biomass (ton/0,05 ha)	Carbon (ton/0,05 ha)
Prioria copaifera	21,50	9,66	0,13	26,17 + /- 6,41	13,09
Pouteria caimito	13,09	8,08	0,09	18,34 + /- 1,22	9,17
Pithecellobium dulce	17,33	8,60	0,07	3,62 + /- 0,20	1,81
Pterocarpus officinalis	10,18	9,04	0,11	7,22 + /- 0,29	3,61
Anacardium excelsum	2,82	9,81	0,57	43,05 + /- 10,37	21,53
Ficus insipida	3,10	6,52	0,48	18,29 + /- 0,68	9,14
Cecropia garciae	11,10	5,48	0,05	23,38 + /- 0,96	11,69
Brosimum utile	13,00	8,07	0,10	6,74 + /- 0,53	3,37
Pouteria eugeniifolia	11,43	8,24	0,09	32,20 + /- 1,00	16,10
Copaifera canime	14,14	8,37	0,04	9,98 + /- 0,55	4,99
Ecosystem	173,25	11,45	3,70	35,80 +/ -3,03	17,90
Statistical H (10, N=367)	36,14	72,42	126,57	118.76	
Significance level (p)	0.00003752	0,00	< 2.2e-16	< 2.2e-16	

Conventions: ind = number of individuals.

Table 4. Average structure values, biomass and carbon variables in the forest of the upper watershed of the Domingodo´s river, compared by variance test based on (Kruskal-Wallis) categories. Source: own.

In terms of structural and biomass variability per diametric class, which is observed in table 5, in general, there are heights between 3 meters and 28 meters, the species P.dulce, P.caimito, P.officinalis, A.excelsum, F.insipida, C.garciae, B.utile, P.eugeniifolia and C.canime present absence of species in diametrical classes, this shows that these forests subject to low and medium intensity disturbances.

Table 5 shows that the highest biomass values are of the species P. copaifera with 112.48 tons, storing 56.24 tons of carbon; the species with the lowest biomass value is C. canime with 9.17 tons, storing 4.59 tons of carbon. It's observed a high variation in biomass, which is linked to the presence of trees with higher heights.

	Variable	I (10-20)	II (20-30)	III (30-40)	IV (40-50)	V (50-60)	VI (60- 70)	VII (70- 80)	VIII (80-90)	IX (90-100)	Total
Prioria copaifera	**Height (m)**	3.0-20.0	3.0-25.0	4.0-20.0	13.0-22.0	12.0-17.0	18.0-23.0	15.0-25.0	23.0-18.0	21.0-26.0	**3.0 - 26.0**
	Density (Ind/0.05ha)	14	6	4	3	1	1	2	2	4	**4**
	Basal area (m2/0.05ha)	2,17	2,54	4,01	3,06	0,68	2,19	2,79	1,20	15,21	**33,85**
	Biomass (ton/0,05ha)	4,19	5,65	10,31	8,58	2,02	6,93	9,54	4,31	60,95	**112,48**
	Relative biomass (%)	3,73	5,02	9,17	7,63	1,80	6,16	8,48	3,83	54,19	**100,00**
	Carbon (ton/0,05ha)	2,10	2,83	5,16	4,29	1,01	3,47	4,77	2,16	30,48	**56,24**
Pouteria caimito	**Height (m)**	3.0-15.0	6.0-15.0	8.0-15.0	0,00	9.0-15.0	15.0-23.0	0,00	15,00	23,00	**3.0 - 23.0**
	Density (Ind/0.05ha)	4	6	29	0	1	4	0	1	1	**5**
	Basal area (m2/0.05ha)	0,80	2,31	3,42	0,00	1,03	4,45	0,00	0,63	0,75	**13,40**
	Biomass (ton/0,05ha)	2,02	7,20	13,16	0,00	5,41	25,37	0,00	4,31	5,47	**62,94**

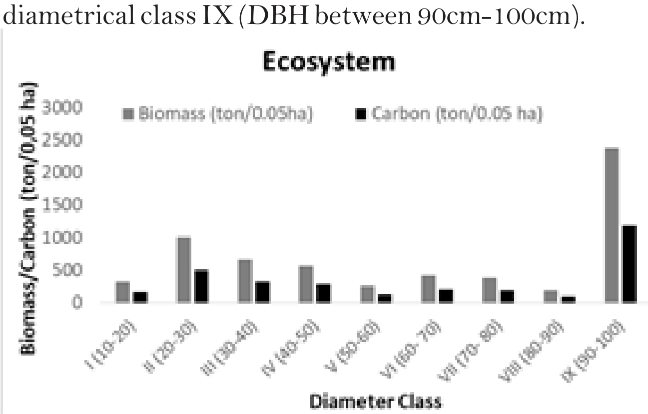
Pouteria caimito	**Relative biomass (%)**	3,21	11,44	20,91	0,00	8,60	40,31	0,00	6,85	8,69	**100,00**
	Carbon (ton/0,05ha)	0,40	1,16	1,71	0,00	0,52	2,22	0,00	0,31	0,38	**6,70**
Pithecellobium dulce	**Height (m)**	3.0-15.0	6.0-15.0	10.0-15.0	7.0-12.0	12.0-24.0	11,00	0,00	0,00	19.0 - 21.0	**3.0 - 24.0**
	Density (Ind/0.05ha)	8	9	4	2	20	1	0	0	1	**5**
	Basal area (m2/0.05ha)	1,04	3,26	2,12	0,93	0,20	6,23	0,00	0,00	2,40	**16,18**
	Biomass (ton/0,05ha)	1,97	7,42	5,51	2,61	0,58	1,95	0,00	0,00	9,78	**29,82**
	Relative biomass (%)	6,61	24,88	18,48	8,75	1,95	6,54	0,00	0,00	32,80	**100,00**
	Carbon (ton/0,05ha)	0,99	3,71	2,76	1,31	0,29	0,98	0,00	0,00	4,89	**14,91**
Pterocarpus officinalis	**Height (m)**	3.0 - 18.0	3.0 - 15.0	4.0 - 24	5.0 - 15.0	15.0 - 19.0	10.0 - 15.0	14.0 - 17.0	0,00	19,00	**3.0 - 24.0**
	Density (Ind/0.05ha)	3	3	3	5	1	2	1	0	1	**2**
	Basal area (m2/0.05ha)	0,52	1,46	2,19	3,82	0,66	0,89	1,84	0,00	0,72	**12,10**
	Biomass (ton/0,05ha)	1,01	3,34	5,56	10,79	1,96	2,81	6,25	0,00	2,65	**34,37**
	Relative biomass (%)	2,94	9,72	16,18	31,39	5,70	8,18	18,18	0,00	7,71	**100,00**
	Carbon (ton/0,05ha)	0,51	1,67	2,78	5,40	0,98	1,41	3,13	0,00	1,33	**17,19**
Anacardium excelsum	**Height (m)**	4.0-12.0	8.0-12.0	7,00	8.0-15.0	0,00	0,00	0,00	25,00	23.0-28.0	**4.0 - 28.0**
	Density (Ind/0.05ha)	1	2	1	1	0	0	0	1	1	**1**
	Basal area (m2/0.05ha)	0,08	0,57	0,20	0,58	0,00	0,00	0,00	0,62	15,68	**17,73**
	Biomass (ton/0,05ha)	0,16	1,21	0,45	1,30	0,00	0,00	0,00	1,53	41,11	**45,76**
	Relative biomass (%)	0,35	2,64	0,98	2,84	0,00	0,00	0,00	3,34	89,84	**100,00**
	Carbon (ton/0,05ha)	0,04	0,28	0,10	0,29	0,00	0,00	0,00	0,31	7,84	**8,86**
Ficus insipida	**Height (m)**	3.0-22.0	3.0-17.0	4.0-10.0	6.0-12.0	12,00	13.0-18.0	14.0-20.0	0,00	23.0-24.0	**3.0 - 24.0**
	Density (Ind/0.05ha)	2	1	1	2	1	1	4	0	2	**1**
	Basal area (m2/0.05ha)	0,05	0,38	0,35	0,49	0,26	0,67	3,01	0,00	9,75	**14,95**
	Biomass (ton/0,05ha)	0,09	0,88	0,88	1,37	0,79	2,14	10,15	0,00	45,42	**61,72**
	Relative biomass (%)	0,15	1,43	1,43	2,22	1,28	3,47	16,45	0,00	73,59	**100,00**
	Carbon (ton/0,05ha)	0,05	0,44	0,44	0,69	0,40	1,07	5,08	0,00	22,71	**30,86**
Cecropia garciae	**Height (m)**	3.0-16.0	12.0-17.0	10.0-20.0	10.0-23.0	0,00	0,00	0,00	0,00	0,00	**3.0 - 23.0**

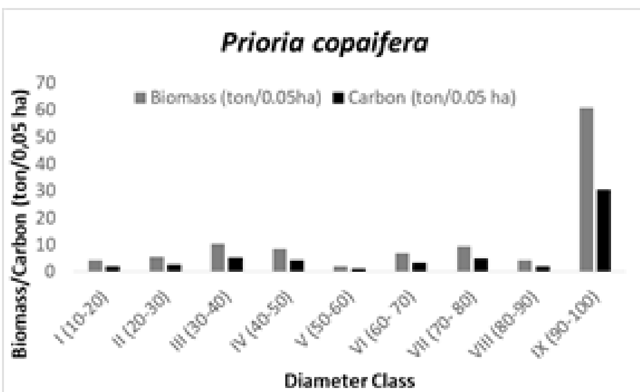
Cecropia garciae	**Density (Ind/0.05ha)**	5	8	3	1	0	0	0	0	0	**2**
	Basal area (m2/0.05ha)	0,53	3,17	1,54	0,59	0,00	0,00	0,00	0,00	0,00	**5,83**
	Biomass (ton/0,05ha)	1,27	10,28	5,90	2,59	0,00	0,00	0,00	0,00	0,00	**20,04**
	Relative biomass (%)	6,34	51,30	29,44	12,92	0,00	0,00	0,00	0,00	0,00	**100,00**
	Carbon (ton/0,05ha)	0,64	5,14	2,95	1,30	0,00	0,00	0,00	0,00	0,00	**10,02**
Brosimum utile	**Height (m)**	3.0-21.0	3.0-20.0	4.0-15.0	4.0-19.0	12.0-17.0	0,00	16,00	14.0-19.0	19.0-23.0	**3.0 - 23.0**
	Density (Ind/0.05ha)	5,40	6,57	1,75	1,50	1,00	0,00	1,00	2,00	1,00	**2,25**
	Basal area (m2/0.05ha)	0,50	2,22	0,67	0,45	0,44	0,00	0,50	1,16	2,99	**8,92**
	Biomass (ton/0,05ha)	0,95	5,00	1,71	1,23	1,30	0,00	1,72	4,13	11,80	**27,84**
	Relative biomass (%)	3,41	17,96	6,14	4,42	4,67	0,00	6,18	14,83	42,39	**100,00**
	Carbon (ton/0,05ha)	0,48	2,50	0,86	0,62	0,65	0,00	0,86	2,07	5,90	**13,92**
Pouteria eugeniifolia	**Height (m)**	3.0-15.0	5.0-15.0	7.0-15.0	4.0-15.0	10.0-15.0	16,00	0,00	0,00	0,00	**3.0 - 16.0**
	Density (Ind/0.05ha)	5	7	2	4	4	1	0	0	0	**3**
Pouteria eugenifolia	**Basal area (m2/0.05ha)**	0,14	1,83	0,99	1,69	2,43	0,30	0,00	0,00	0,00	**7,38**
	Biomass (ton/0,05ha)	0,29	5,20	3,48	6,34	10,26	1,35	0,00	0,00	0,00	**26,92**
	Relative biomass (%)	1,08	19,32	12,93	23,55	38,11	5,01	0,00	0,00	0,00	**100,00**
	Carbon (ton/0,05ha)	0,15	2,60	1,74	3,17	5,13	0,68	0,00	0,00	0,00	**13,46**
Copaifera canime	**Height (m)**	4.0-18.0	4.0-18.0	0,00	0,00	-12.010.0	13,00	0,00	0,00	24,00	**4.0 - 24.0**
	Density (Ind/0.05ha)	9	4	0	0	2	1	0	0	1	**2**
	Basal area (m2/0.05ha)	1,11	1,41	0,00	0,00	0,69	0,29	0,00	0,00	0,67	**4,17**
	Biomass (ton/0,05ha)	2,24	3,00	0,00	0,00	1,59	0,69	0,00	0,00	1,66	**9,18**
	Relative biomass (%)	24,39	32,66	0,00	0,00	17,31	7,51	0,00	0,00	18,12	**100,00**
	Carbon (ton/0,05ha)	1,12	1,50	0,00	0,00	0,80	0,35	0,00	0,00	0,83	**4,59**

Table 5. Layout of vegetation structure variables, biomass and carbon per diametric class of the upper watershed of the Domingodo´s river. Source: own.

3.4. Biomass and carbon distribution per diametric class

Figure 3 it does the relationship between the biomass-carbon ratio for each species, which is expressed in tons per 0.05ha for each of the diametric classes. The first group corresponds to the ecosystem in general and to the species P.copaifera, A.excelsum, F.insipida and B.utile, the largest amount of biomass is reported in diametrical class IX (DBH between 90cm-100cm).





The second group corresponds to the species P.caimito, P.officinalis and P.eugeniifolia, which present a greater amount of biomass in intermediate diametrical classes, from IV to VI (DBH between 40cm-70cm); the third group is made up for species P.dulce and B.utile, where they've two tall peaks, the first one is in the diametrical class II (DBH between 20cm-30cm), meanwhile the second one is presented in the diametrical class IX (DBH between 90cm-100cm); and the fourth group with the species C.canime, with 3 peaks distributed in the diametrical I and II class (DBH between 10cm-30cm), in the diameter V and VI class (DBH between 50cm-70cm) and in the diameter IX class (DBH between 90cm-100cm).

4. Conclusions

The diametrical class that concentrates the largest amount of biomass, and that therefore store more carbon, it´s IX (DBH 90-100). Species like P. caimito, P. officinalis y P. eugeniifolia, P. dulce y B. utile and C. canime, they reflect that the forest have any grade of transformation and intervention. It becomes apparent a high variation regarding the forest structure, between the biomass and carbon supplies in the upper watershed of the Domingodo's river, this is due to the natural succession process, environmental factors of the area and by processes that generate anthropic pressure, [24].

The average carbon stored by the forest of the upper watershed of the Domingodo's river (17.9 ton/0.05ha) it is considerable in comparison with other nearby areas, since in forests of the municipality of Quibdó-Choco, recorded stored carbon of 81.9 ton/ha, in the forest of the Botanical Garden of the Pacific-Bahía Solano-Chocó, recorded stored carbon of 68.1 ton/ha, and in the Botanical Garden of the Pacific 48.2 ton/ha is recorded, [25].

The model that most suited of the area was 4, being of great importance the life area for the model selection, this model demonstrated through statistical tests to be the best architecture, successional state, distribution of ecological guilds, functional relationships and grade of forest intervention evaluated, [26], [25].

It is of great importance to continue exploring models that estimate biomass and carbon, because it has been seen that exponential functions don't represent the whole part of the growth cycle of trees, so it's of great importance to continue generating and evaluating allometric equations that take into account the behavior of the forest to arrive at more accurate calculations of forest behavior, this includes trees of large dimensions, since it was appreciated that this factor was the one with the highest estimation error, [14].

In front of the multiple services offered by the forest, among those Global Warming, it is very important to manage this forest in a sustainable way, because this is one of the most effective forms of mitigation to combat Global Warming due to silvicultural costs [1], since on average, if 500 m2 of forest are cleared, approximately 17.9 tons of carbon are being emitted into the atmosphere, being a negative consequence in the long term due to the long terms that a forest recovery requires, [4]. Therefore, forest management is crucial in a context of territorial approach, understanding the dynamics between the biophysical, social, economic and institutional elements to elaborate strategies where the inclusion of the forest in the sustainable development of the territory is highlighted.

Acknowledgments

They going to expressed special thanksfully to Wilson Alzate Cortés for the provided support during the preparation of the article. The habitants of Domingodó are also thanked for their collaboration in obtaining data.

References

[1] IPCC. (2014). Cambio climático 2014: Informe de síntesis. Contribución de los Grupos de trabajo I, II y III al Quinto Informe de Evaluación del Grupo Intergubernamental de Expertos sobre el Cambio Climático. Ginebra (Suiza).

[2] Banco Mundial. (2018). Emisiones de CO2 (kt). Data. https://datos.bancomundial.org/indicador/en.atm.co2e.kt

[3] Naciones Unidas UNFCC (2015). Aprobación del Acuerdo de Paris. Disponible en http://unfccc.int/resource/docs/2015/cop21/spa/l09s.pdf

[4] FAO. (2018). El estado de los bosques del mundo. Las vías forestales hacia el desarrollo sostenible. Roma. X- 59p.

[5] R. Ruíz, P. Gertrudix, "Modelos para la estimación del carbono en la biomasa de los sistemas forestales & Influencia de la silvicultura en los stocks de carbon". Tesis doctoral. Universidad de Valladolid. Palencia. 58-87, 2013.

[6] J. Canadell, M. Raupach, "Managing forests for climate change mitigation". Science. 320, 1456-1457, 2008. https://doi.org/10.1126/science.1155458

[7] S. Brown, "Estimating biomass and biomass change of tropical forests. A primer". Roma, Italia. FAO. (Informe Montes N°134), 1997

[8] B. J. Schlegel, J. Gayoso, J Guerra. "Medición de la capacidad de captura de carbono en bosques de Chile y promoción en el mercado mundial: Manual de procedimientos: Muestreos de biomasa forestall". Valdivia, Chile. Universidad Austral de Chile. 24, 2000.

[9] G. Fonseca, G. William, G. Alice, Y. Federico, B. Rey, "Modelos para estimar la biomasa de especies nativas en plantaciones y bosques secundarios en la zona Caribe de Costa Rica". Bosque (Valdivia). 30(1): 36-47, 2009. https://doi.org/10.4067/S0717-92002009000100006

[10] S. Brown, J. Sathaye, M. Cannell, P. Kauppi, "Mitigation of carbon emission to the atmosphere by forest management". Commonwealth Forestry Review. 75(1): 80-91, 1996

[11] B. Budowski, "Secuestro de carbono y gestión forestal en América Tropical". Bosques y Desarrollo. Abril 20-21: 17-20p, 1999.

[12] B. Schlegel, "Estimación de la Biomasa y Carbono en Bosques del Tipo Forestal Siempre Verde. Simposio Internacional Medición y Monitoreo de la Captura de Carbono en Ecosistemas Forestales". Valdivia, Chile. 18 al 20 de Octubre. 13p. 2001

[13] E. Galindo García, D. M. Cabrera Montenegro, H. R. Vargas Galvis, K. R. Pabón Méndez, A. P. Cabrera Torres, J. F. Yepes Quintero, D. A. Phillips Bernal, A. J. Navarrete Encinales, M. C. Duque Montoya, M. F. García Dávila, M. F. Ordóñez Castro. "Estimación de la biomasa aérea usando datos de campo e información de sensores remotos". Instituto de Hidrología, Meteorología, y Estudios Ambientales (IDEAM), Bogotá, Colombia, 2011.

[14] N. Paipa, M. Triana, (2018). "Estimación del Carbono Almacenado en la Biomasa Aérea de un bosque húmedo tropical en Paimadó, Chocó". Ingenierías USBMed. 9(1): 18-29p. https://doi.org/10.21500/20275846.3180

[15] Oficina De Las Naciones Unidas Contra La Droga Y El Delito (UNODC) & Agencia Presidencial Para La Acción Social Y La Cooperación Internacional (Acción Social). "Fortalecimiento a Proyectos Productivos del Desarrollo Alternativo, en el Marco de los

Programas Regionales Integrales Sostenibles en Colombia". Monte Bravo. Riosucio-Choco. Pp. 7-16, 2007

[16] J. O. Rangel, A. Velásquez. "Métodos de estudio de la vegetación", Colombia Diversidad Biótica II. Tipos de vegetación en Colombia, Instituto de Ciencias Naturales, Universidad Nacional de Colombia, Ideam, Bogotá, pp. 59-87, 1997

[17] A. M. Campo, V. S. Duval, "Diversidad y valor de importancia para la conservación de la vegetación natural". Anales de Geografía. 34(2), pp.25-41p, 2014. https://doi.org/10.5209/rev_AGUC.2014.v34.n2.47071

[18] J. Álvarez. "Estimación de las reservas actuales (2010) de carbono almacenadas en la biomasa aérea en bosques naturales de Colombia. Estratificación, agometría y métodos analíticos". Bogotá - Colombia: IDEAM, 2011.

[19] J. B. Chave, M.A. Dubois. "Estimation of biomass in a neotropical forest of French Guiana: spatial and temporal variability". Journal of Tropical Ecology. 17: pp. 79-96, 2001. https://doi.org/10.1017/S0266467401001055

[20] IPCC. "Orientación del IPCC sobre las buenas prácticas para UTCUTS". Publicado por la Organización Metereológica Mundial (OMM) para el IPCC. Ginebra. pp.124-129, 2005.

[21] J. Chave, C. Andalo, S. Brown, M. A. Cairns, J. Q. Chambers, .et. al, "Tree allometry and improved estimation of carbon stocks and balance in tropical forests". Oecologia 145: 87–99, 2005. https://doi.org/10.1007/s00442-005-0100-x

[22] J. P. Overman, H.J.L. Witte, & J.G. Saldarriaga, "Evaluation of regression models for above-ground biomass determination in Amazon rainforest". Journal of Tropical Ecology 10 (2): pp. 207-218, 1994. https://doi.org/10.1017/S0266467400007859

[23] IPCC. "The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation". New York, 2011.

[24] A. Vásquez, H. Arellano, "Estructura, Biomasa Aérea y Carbono Almacenado en los Bosques del Sur y Noroccidente de Córdoba". Colomb. Divers. Biótica XII. La Región Caribe Colomb. pp.963-1009, 2012.

[25] J. J. Torres Torres, V. E. Mena Mosquera, E. Álvarez Dávila, « Carbono Aéreo Almacenado en Tres Bosques del Jardín Botánico del Pacífico, Chocó, Colombia ». Entramado. 13(1): pp.200-209, 2017. https://doi.org/10.18041/entramado.2017v13n1.25110

[26] C. Hurtado, C. Cortez, M. Triana, "Estimación del Carbono Almacenado en el Bosque Natural en la Cuenca Media-Baja. Municipio de Río Quito Chocó, Colombia. Ingeniería" e innovación. 5(1), pp.36-50, 2017.