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ALLOMETRIC EQUATIONS TO ESTIMATE ABOVEGROUND BIOMASS AND CARBON IN POLYLEPIS RACEMOSA IN A RELICT FOREST LOCATED IN THE COMMUNITY OF BELLA ANDINA, CHOTA, CAJAMARCA

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ABSTRACT

Global warming is caused by the increase in CO2 concentration and the decrease in areas with forest cover, mainly natural forests and Andean relicts, which are the main sources of carbon sinks to counteract climate change. The objective of the study was to determine allometric equations to estimate the aboveground biomass and carbon in Polylepis racemosa of the relict forest in the community of Bella Andina, Chalamarca, Chota-Cajamarca, for this, a forest census of the individuals of Polylepis racemosa was carried out, by recording the diameter at 50 centimeters above the ground, number of branches, shaft height and crown diameter. 1232 trees were inventoried distributed in 11 diameter classes, then the biomass and carbon were estimated by the destructive method of 11 trees. The specimens were dried in an oven at 105± 2°C for five days to determine the dry biomass, the choice of the best allometric equation was using the statistical indicators R2, adjusted R2, RECM. Sxy, E and AIC, the allometric equation that best estimated the aboveground biomass in Polylepis racemosa in the relict forest of Bella Andina was LnBA = 2.394988 + 0.082807 ∗ D50; with R2 = 0.932; Adjusted R2 0.925; RECM = 16.826; E = 0.363; Sxy = 50,477; AIC = 32.013 and the best model for estimating carbon is LnBA = 1.8177 + 0.08644 ∗ D50; it reaches an R2: 0.833; Adjusted R2 = 0.815; RECM 16,673; E = 0.259; Sxy = 50.0182 and AIC = 1.926; concluding that at least one adjusted allometric equation is statistically superior and adequate to estimate aboveground biomass and carbon in P. racemosa trees in the study area.

KEYWORDS: Quinatal, Ecosystem Service, Carbon Sequestration, Allometric Equations, Relict Forest.

1. INTRODUCTION

According to Estrada et al. (2003), it is necessary to establish conservation strategies as sources of carbon sinks to counteract climate change. Gómez (2015) mentions that, in páramo areas, natural forests buffer 51% of all greenhouse gas emissions. Cordella (2017) mentions that in order to address climate change, the value of ecosystem goods and services and their importance in mitigation must be known in order to make the best decisions regarding their conservation, sustainable management and increase forest carbon stocks.

Various studies carried out by Caluña (2017), Navarro et al. (2013) and Alvis, (2018) describe that climate change is a very serious environmental problem, since it is directly related to deforestation; Millions of people live from the harvesting and extraction of wood that has a negative impact on the environment. Estrada et al. (2003); Pumasupa (2018), Gómez (2015) and Cordella (2017) agree that deforestation allows for an increase in CO2 and influences global warming.

Díaz and Gálvez (2019) state that the inappropriate management and use of forests causes changes in the planet such as the increase in the temperature of the atmosphere. Forests and shrubs of the genus Polylepis form small patches commonly present on mountain slopes and rocky ravines along the Andes mountain range (Cuyckens and Renison, 2018). In this sense, the conservation of the genus Polylepis contributes to minimizing the effects of climate change because it stores CO2 in its three components: stem, branches, and foliage (Mollocondo & Aguilar, 2019).

This genus represents the natural vegetation of a large part of the central Andes at altitudes ranging from 3,500 to 5,200 m.a.s.l. (Kessler, 2006) and is distributed in the Andes of Peru (Caluña, 2017). There are 28 species of Polylepis that are distributed from the upper limit of cloud forests to areas of the Altiplano (Navarro et al., 2013). The conservation and restoration of Polylepis relict forests provides environmental services such as CO2 capture, as well as contributing to mitigating climate change and generating greater well-being for rural communities (Sarcca Huisa, 2017).

Trinidad and Cano (2016) mention that Polylepis forests are currently one of the most threatened ecosystems in the world and are distributed in patches as a result of the process of degradation and alteration to which they were subjected for centuries by human intervention, economic, social and cultural factors that directly affect the protection and management of relict forests. However, these ecosystems play a central role in the high Andean ecology as a CO2 sink (Castro and Flores, 2015; Alvis, 2018)

Estimating and monitoring carbon stocks is a first step in understanding the value of forests and forest plantations (Delgado, 2020). Polylepis forest conservation projects contribute to carbon sequestration and diversify their income through land productivity (Choque, 2019). For this reason, Pumasupa (2018) agrees in establishing the protection and management of relict forests to increase environmental service with carbon fixation, regulation of water resources and biodiversity.

According to Chalco and Gen (2015), relict forests of P. racemosa are complex systems that contribute to mitigating climate change by storing CO2 in their vegetation and in the soil, exchanging CO2 with the atmosphere through the photosynthetic process and respiration. Therefore, it is important to perform allometric modeling to obtain a reliable and direct estimate of the biomass in plant systems such as P. racemosa (Rivera, 2018).

Solano et al. (2014) consider that to estimate the forest biomass better, equations adjusted with data obtained through the destructive method using expansion and correction factors are used. Emanuelli et al. (2017) indicate that allometric models are tools for estimating the forest biomass of aboveground and underground components. These functions are based on variables such as normal diameter, total height, and volume (Pompa, 2009).

Bravo et al. (2007) consider that allometric modeling allows quantifying the potential for plant growth and fixation of greenhouse gases. Being an alternative valuation of forest areas for the payment of environmental services for CO2 capture and sequestration. (Vargas, 2019).

Similarly, Gómez et al. (2011) establish that allometric equations are methods that facilitate the estimation of biomass and carbon on a small and large scale. To estimate biomass and carbon sequestration, different types of regression models and combination of variables are used (Fonseca et al., 2009); various studies conclude that DAP is the variable that best correlates and adjusts to predict aboveground biomass (Aristizábal, 2011). In addition, it is easy to measure in the field and is recorded in forest inventories (Brown et al., 1989).

In order to provide scientific information on the biomass and carbon sequestration in relict forests of P. racemosa, the main objective was to determine an allometric equation to estimate the aboveground biomass and carbon in P. racemosa of a forest relict in the community of Bella Andina, Chalamarca, Chota Cajamarca, and as specific objectives, 1) to carry out a forest census to determine the number of individuals and the diametric distribution of P. racemosa in a relict forest in the Bella Andina community, 2) to adjust allometric equations to estimate the aboveground biomass of P. racemosa in a relict in the Bella Andina community, Chalamarca, Chota-Cajamarca, 3) to adjust allometric equations to estimate the aboveground carbon content of Polylepis racemosa in a relict forest in the community of Bella Andina, Chalamarca, Chota – Cajamarca. It was proposed as an alternating hypothesis that at least one adjusted allometric equation is statistically superior and adequate to estimate aboveground biomass and carbon in P. racemosa trees in the community of Bella Andina.

The objective of the research is to determine allometric equations to estimate the aboveground biomass and carbon in Polylepis racemosa of the relict forest in the community of Bella Andina, Chalamarca, Chota-Cajamarca

2. THEORETICAL FRAMEWORK

Tello and Vargas (2019) determined that the equations with the best fit for estimating biomass of four tree species were $Y = \exp[-2.289 + 2.649 * \ln(D) - 0.021 * (\ln(D))^2]$, $B = 0.1184 * D^{2.53}$, $B = EXP(-1.996+2.32 * LN(D))$, $B = -26.63+0.42*(D^2)$; while Cuenca et al., (2014) obtained coefficients of determination 0.910; 0.999; 0.936; 1 respectively, estimating 1998.04 t C/ha in Schinus latifolius, followed by Vachellia macracantha 1329.91 t C/ha, Eucalyptus globules 667.94 t C/ha and finally Pouteria lucuma 25.20 t C/ha. Andrade and Arias (2016) determined that the equation that best estimates the carbon content in 11 sinks of the Metropolitan District of Quito in Ecuador is $CC = 0.18254 x D^{2.3627}$ determining that the largest amount of carbon is found in the North Metropolitan area with a value of 2090.55 t C/ha, while in the lowest amount in the Itchimbía zone with 17.70 t C/ha. Antepara (2019) developed an allometric model for the estimation of the aboveground biomass of Tecoma castaneifolia, whose statistical tests and validation criteria indicated that the best model was $B = 0.065D^2 + 0.57D - 1.371$ with $R^2=0.84$, the selection criteria were AIC=153.13, BIC=56.54, RMSE=2.03 and RRMSE=38.34%, a weight of AIC=74.80 and a weight of BIC=77.6 demonstrating that it has a high level of biomass prognosis, in a range of 0.8 to 12cm stump diameter. Acosta et al. (2002) determined that the $\ln(Y) = b0 + b1 \ln(X)$ model was the best ($R^2 = 0.97$) to estimate the biomass of six species grouped into two subgroups, in the QLI subgroup the three largest species (Alnus, Querus and Rapanca), while in the ACR subgroup the three smallest species (Clethra, Liquidambar and Inga).

Návar (2013) determined the total aboveground biomass of Trichospermum mexicanun by means of allometric equation $M = \rho w * e(-0.67+1.78Ln(D)+ 0.207Ln(D)^2 - 0.028Ln(D)^3)$ with an R^2 of 0.83 and; suggests performing the adjustment by the destructive method and developing the allometry at the tree level in situ.

Soriano (2015) estimated the biomass by structural component for Pinus patula and 11 broadleaved species, using the biomass model B□ Exp (□□) ∗ (dn2 ∗ h) □1, his results indicated that the biomass of the studied species is distributed 68.2 % in the stem, followed by 14.3, 9.3 and 8.2 % in the branches, bark and foliage.

Benavides (2014) determined the aboveground biomass for Acacia pennatula using the model $y = 0.4357x - 8.3423$ where y: biomass; x: DAP, determining the relationship between the diameter of the base and the length of the regrowth reaching $R^2 = 0.635$.

Ramírez (2017) compared six allometric equations through the Akaike Information Criterion (AIC), adjusted R^2, and cross-validation. The model $B = -\exp(-1.996 + 2.32\ln(D))$ obtained an AIC value of 48.36 and an adjusted R^2 of 0.96; considered the best to estimate the epigeal biomass of medium-sized subdeciduous forests.

Spain (2016) determined the aboveground biomass and carbon in Alnus using the allometric models $B = -163.36+44.42 \ln(DAP \times DB)$ and $C = 37.157 + 1.75 \times 10^{-4} (DAP \times DB \times ht)$, which showed coefficients of determination of 0.93 and 0.90, respectively.

Guillen and Salome (2019) carried out a random sampling where 15 plots of 10m x 10m were randomly selected from a total of 10 stands taking the dasometric data (DBH, commercial and total height, volume of branches with diameters greater than 4 cm) and biomass, then laboratory work was carried out determining that Polylepis sp stores 132,834 tC.

Mírez (2021) studied the allometric models that best estimate the aboveground biomass of Pinus patula in Chota, Cajamarca, determining that the models that best estimate the biomass $Log(BA) = -1.26088 + 0.86431 * Log(d^2 + ht) + €$, and for CO_2 storage it is the Log model $(CC) = -1.56191 + 0.86431 (d^2 * ht) + €$, concluding that the best allometric models are those that use DAP and ht as variables.

3. METHODOLOGY

3.1. *Location of the Study Area.*

Location The study was carried out in the Bella Andina community of the district of Chalamarca, province of Chota, Cajamarca region, which has as centroid 6°33'17.72"S, 78°33'6.87"W with an altitude of 3607 m.a.s.l. The district of Chalamarca is located at an altitude of 3581 meters above sea level, the Bella Andina community is a high Andean area and is characterized by low and windy temperatures ranging between 4 and 16 °C.

3.2. *Research Methodology*

The research is quasi-experimental (Hernández-Sampieri & Mendoza, 2018), because there was no manipulation of variables, only the data was observed and taken as they occur in their natural context, being correlated and analyzed. Cross-sectional because the data collection of the dasometric variables D50, ht, number of branches and crown diameter being correlated to adjust the allometric equations to estimate biomass and carbon sequestration.

3.3. *Research Design.*

The present research is of the regression type because it seeks to describe the statistical relationship between dependent and independent variables (Hernández Sampieri & Mendoza, 2018) referring to the height of the diameter at 50 cm, above the ground, number of branches, stem height, crown diameter, biomass and carbon sequestration.

4. RESULTS AND DISCUSSION

Table 1 shows the frequency of P. racemosa individuals distributed in 11 diameter classes (distributed between the range 6.05 and 38.20), the largest number of individuals are in classes 10.4; 13.2; 16.0; 18.8 and 21; 6 cm with 217, 347, 202, 159 and 107 individuals, respectively and the least amount is at the 30.0 class mark; 32; 8 and 36; 2 cm with 10, 6 and 3 individuals. A maximum D50 of 38.19 centimeters and a minimum D50 of 6 centimeters have been recorded in 1232 individuals of P. racemosa.

Table 1: Distribution of Diameter Classes.

N° de clases	Li	Ls	X	fi	Fi	ni	Ni
1	6,05	9,05	7,5	66	66	0.05	5
2	9,05	11,85	10,4	217	283	0.23	23
3	11,85	14,65	13,2	347	630	0.51	51
4	14,65	17,45	16,0	202	832	0.68	68
5	17,45	20,25	18,8	159	991	0.81	81
6	20,25	23,05	21,6	107	1098	0.89	89
7	23,05	25,85	24,4	84	1182	0.96	96
8	25,85	28,65	27,2	30	1213	0.98	98
9	28,65	31,45	30	6	1218	0.99	99
10	31,45	34,25	32,8	10	1228	100	100
11	34,25	38,20	36,2	3	1232		

Li: límite inferior, Ls: límite superior; X: marca de clase; fi: frecuencia absoluta,

Apolinario and Peláez (2018) recorded 1000 individuals per hectare of Polylepis Incana and Polylepis sericea, distributed in 11 diameter classes; on the other hand, Taipe (2018) reported 650 to 855 individuals per hectare of P. incana, results that are similar to what was reported in our study; Paucar (2018) estimated the aboveground biomass of P. flavipila, reporting that individuals reached diameters between 10 and 30 cm. The dasometric measurements of the diameter 50 centimeters (D50), total height (ht), number of branches (NR) and crown diameter (DC) of the 11 Polylepis racemosa trees evaluated, the statistical indicators, show that the mean of the D50, ht, NR and crown DC is 21.64, 460, 3.36, 480.63 cm respectively and the coefficient of variation ranges between 27, 48 to 43, 63, the standard deviation (sd) of the cup D50, ht, NR and DC reached values of 0.92 to 162.25 and the coefficient of variation (CV) varies between 27.48 and 43.63 values that are at the level of high variability (> 25%). Apolinario and Peláez (2018) obtained similar results for P. racemosa and P. Incana, the diameter ranged from 6 to 18 cm. Studies by Barthlott et al. (2005); Barreto (2011) and Vanclay (2006) report that the coefficients of variation are greater than 50%. Herrera (2019) considers that the distribution of dasometric variables depends on the age and size of the individuals under study and the soil and climatic characteristics.

Tabla 2 Estadísticos descriptivos de variables dasométricas.

N° árbol	D50 (cm)	ht (cm)	N° de ramas	Ø de copa (cm)
1	7,5	180	2	195
2	10,4	260	2	275
3	13,2	310	3	327
4	16	380	3	410
5	18,8	470	3	477
6	21,6	520	4	535
7	24,4	500	4	536
8	27,2	560	3	587
9	30	580	4	595
10	32,8	600	4	626
11	36,2	700	5	724
Mean	21,64	460	3,36	480,63
Sd	9,39	159,43	0,92	162,25
CV (%)	43,63	43,39	27,48	33,75

NR, DC

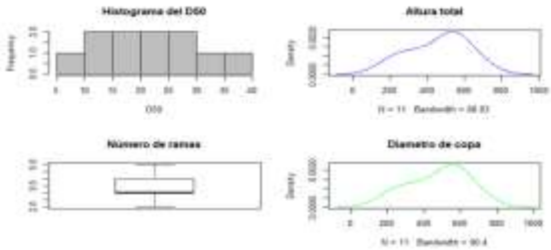

Figure 4: Histogram of frequencies of the D50, ht,

The class mark of D50 centimeters (Figure 4) ranges from 7.5 to 36.2; The total height (HT) is distributed from 180 to 700 cm, the number of branches from 2 to 5 and the crown diameter from 195 to 724 cm. Taipe (2019) estimated the biomass and carbon sequestration in P. incana determining that the total height, average diameter and density of the trees reached coefficients of variation of 10.96%; 5.38% and 14.9% respectively; Salas, (2002) provides that the coefficient of variation is greater than 50% in relict forests.

Table 3: Aboveground biomass of the 11 Polylepis racemosa trees.

Árbol	D50 cm	ht m	N° de ramas	Ø Copa m	Componentes (kg) Fuste	Ramas	Follaje	Biomasa total (kg)
A	7,5	1.80	2	1,95	6,398	1.863	4,141	12,402
B	10,4	2.60	2	2,75	21.906	8.191	8,727	38,824
C	13.2	3.10	3	3,27	24,803	9.192	6,963	40,959
D	16	380	3	4,10	26,066	10.881	9,412	46,359
E	18,8	4.70	3	4,77	23,255	11.045	11,883	46,182
F	21,6	5.20	4	5,35	32,243	15.016	12,464	59,723
G	24,4	5.00	4	5,36	33,964	14.746	17,952	66,662
H	27.2	5.60	3	5,87	60.451	28.395	30,537	119,383
I	30	5.80	4	5,95	97,388	38.041	18,972	154,401
J	32.8	6.00	4	6,26	114,631	39.147	20,478	174,256
K	36,2	7.00	5	7,24	113,795	30.534	42,639	186,968

D50: diameter 50, ht: total height, No. of branches: number of branches; Ø Cup: cup diameter.

The total aboveground biomass per individual ranged from 12,402 to 186,968 in P. racemosa trees with D50 7.5 cm; ht 180 cm, crown diameter of 195 cm and D50 36.2; ht 700 cm, crown diameter of 700 cm respectively (Table 5). In P. racemosa trees, the highest amount of aboveground biomass is concentrated in the stem with 55 %, followed in the foliage with 31 % and the least amount in the branches with 16 %. Montalvo et al. (2018) mention that the amount of biomass depends on the number of individuals and the increase in dasometric variables. Similar results were reported by Apolinario and Peláez (2018), in individuals with a diameter of 11.2 centimeters they reached 16.5 kg of biomass; On the other hand, Ginez (2019) in his study of the Polylepis genus found that biomass is distributed 52 % in stem, 33 % in the foliage and 15 percent in the branches, similar results reported by Yepes et al. (2016) determined the aboveground biomass in the Integrated Management district in Colombia was 129.69 t/ha where, in an area of 8 570.9 hectares in mangrove forests, it was estimated that the total carbon stored by this ecosystem is approximately 64,845 t/CO2.

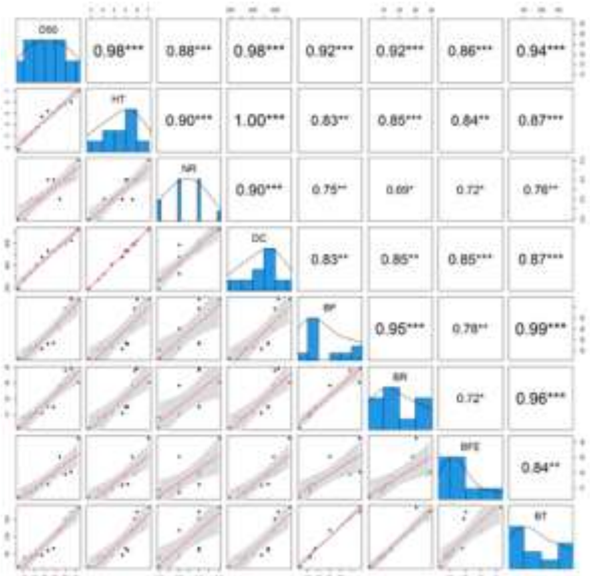

Figure 5: Correlation analysis of dasometric variables to estimate aboveground biomass.

Where LV: total biomass (kg); D50: diameter 50 centimeters (cm); ht: total height, NR: number of branches (kg), DC: crown diameter; BF: stem biomass (kg); BR: branch biomass, BFE: foliage biomass (kg), * statistical significance.

The correlation of the variables to estimate total aboveground biomass (BT) (Figure 4), D50 and HT presented a higher degree of association with biomass (components and total) compared to NR and DC; indicating that they will be the main variables with r 0.98***; 0.90***; 0.90** and 0.83** respectively.

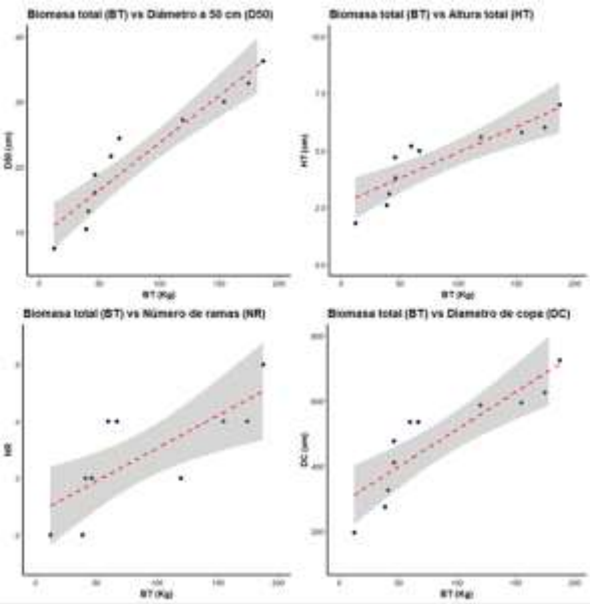

Figure 6: Linear behavior of the relationship between aboveground biomass and dasometric variables.

The dasometric variables D50, ht, NR, DC (Figure 6) in relation to aboveground dry biomass have a positive linear relationship, while Ramírez and Peláez (2018) in their research on the species Polylepis sericea, DAP and biomass have a polynomial correlation.

Table 4: Allometric models adjusted to estimate biomass.

Modelo	Condición	R^2	r^2_{ajus}	RECM	E	Sxy	AIC
1	Rechazado	0,9439	0,9377	15,3212	1,4126	45,9637	31,1178
2	Rechazado	0,9479	0,9421	14,7633	0,0008	44,2900	30,7634
3	Rechazado	0,9623	0,9529	1,7677	-0,001	37,6787	31,2188
4	Aceptado	0,8930	0,8811	21,1663	-0,0001	63,4988	34,2055
5	Rechazado	0,9151	0,9057	18,8494	2,9726	56,5482	3,0979
6	Aceptado	0,9324	0,9248	16,8255	0,3626	50,4766	32,0127
7	Rechazado	0,8874	0,8749	21,7069	3,5908	65,1206	34,4465
8	Aceptado	0,9317	0,9241	16,9077	0,0008	50,7232	32,0592
9	Aceptado	0,7896	0,7662	21,4853	4,8549	56,7531	38,1489
10	Rechazado	0,9499	0,9374	15,3593	1,7972	43,4428	32,5789

R2: correlation coefficient; r2ajus: adjusted correlation coefficient, RECM: root of the mean square error; Sxy: standard estimation error; AIC: Akaike Index:

From the models accepted to estimate the total biomass (Table 4), good adjustments have been obtained, since the average values for R2 and r2ajus were 0.827 and 0.807 respectively. The three models that presented the best statistical indicators were 4, 6 and 8, with minimum R2 and r2ajus of 0.893 and 0.881; as well as RECM, E, Sxy and AIC maximum of 0.362, 63.499 and 34.206, respectively. The three models correctly estimated the biomass of Polylepis, so they were evaluated to see which one meets the assumptions of ANOVA (normality and homogeneity of residues).

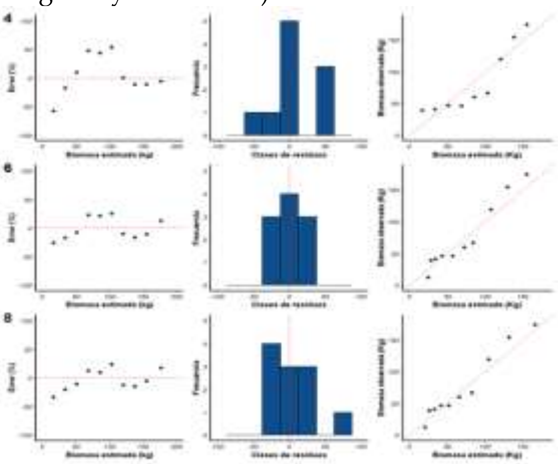

Figure 7 Graphical analysis of the best allometric model to estimate the aboveground biomass of Polylepis racemosa.

Table 5: Normality analysis of allometric model 6 to estimate biomass of the observed values.

Biomasa	
Test	P-valor
Kolmogórov-Smirnov	0,9721
Lilliefors	0,8314
Shapiro-Wilk	0,9129

Figure 7 shows that model 6 presented a better distribution of its residuals with errors of less than 50% (Over-and-underestimate), as well as a better shaped bell in the residual histogram. Agreeing with the correlation matrix and reflecting high values of R2 and adjusted r and low RECM, Sxy and AIC values obtained in the statistical indicators. In addition, using the Kolmogorov, Lilliefors and Shapiro-Wilk tests, the residuals of model 6 were normal, as the p values were greater than 0.05 (Table 7).

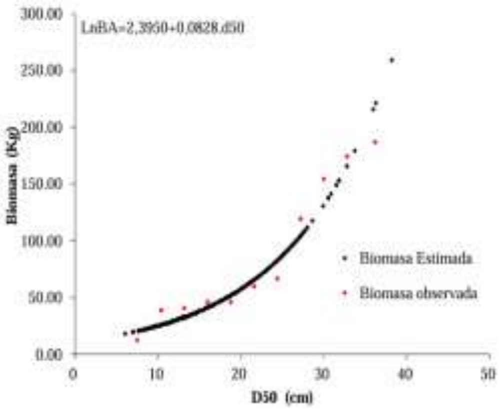

Figure 8: Dispersion of estimated biomass values as a function of D50 cm.

Figure 8 shows the distribution of biomass values as a function of D50 (cm) of the relict of the Polylepis racemosa forest, the equation that best estimates the aboveground biomass is model 6 determined by LnBA=2.394988+0.082807*D50; the one that reaches an R2: 0.932; Adjusted R2 0.925; RECM: 16,826; E: 0.363; Sxy: 50,477 and one AIC 32,013. The results are similar to what was reported by Mírez (2021), who determined that the best model to estimate biomass reached RECM, E, Sxy and AIC, 7.91, 0.2754, 209489 and 21.1927 respectively, while Sarcca (2017) estimated the dry biomass of P. rugulosa, based on the total height and crown diameter using the equation B = 0.16496 [A + B]2.667785.

Table 6: Carbon in Aerial Components.

Árbol	D50	ht	N° de	Ø Copa	Componentes (kg)			Biomasa
	cm	cm	ramas	cm	Fuste	Ramas	Follaje	total(kg)
A	7.5	180	2	195	3,199	1,863	0,931	5,993
B	10.4	260	2	275	10,953	8,191	4,095	23,239
C	13.2	310	3	327	12,401	9,192	4,596	26,189
D	16	380	3	410	13,033	10,881	5,440	29,354
E	18.8	470	3	477	11,627	11,045	5,522	28,195
F	21.6	520	4	535	16,121	15,016	7,508	38,645
G	24.4	500	4	536	16,982	14,746	7,373	39,101
H	27.2	560	3	587	30,225	28,395	14,197	72,818
I	30	580	4	595	48,694	38,041	19,020	105,755
J	32.8	600	4	626	57,3155	39,147	19,573	116,036
K	36.2	700	5	724	56,897	30,534	15,267	102,698

Table 8 shows the average amount of carbon that is distributed in the aerial components of the 11 trees, showing that the least amount of carbon is stored in the tree with D50 of 7.5 cm, ht 180 cm, two branches and a crown diameter of 195 cm stores 5.993 kg, while the largest amount of carbon is stored in the individual with D50 of 36.2 cm, HT of 700 centimeters, with five branches and a crown diameter of 724 that stores 102,698 kg. Finally, Chimbo (2016) mentions that the amount of carbon depends on age and development of dasometric variables.

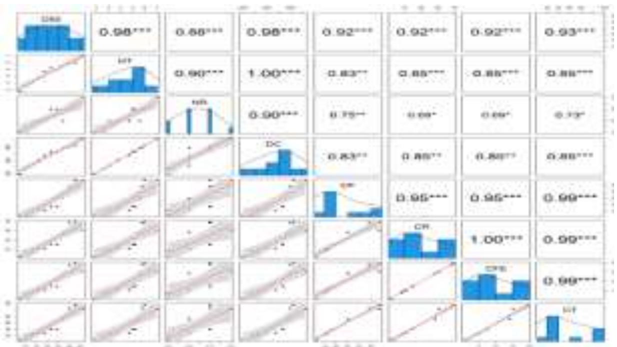

Figure 9 Correlation Analysis of Dasometric Variables for Carbon Sequestration.

Where CC: Carbon Capture (kg); D50: diameter 50 centimeters (cm); ht: total height, NR: number of branches (kg), DC: crown diameter; BF: shaft carbon (kg); BR: carbon of the branches, BFE: carbon in the foliage (kg).

Figure 9 shows the correlation of the variables to estimate the carbon content in the relict forest P. racemosa; D50 and ht showed a higher degree of association with carbon (components and total) compared to NR and DC; indicating that they will be the main predictor variables of the regression models.

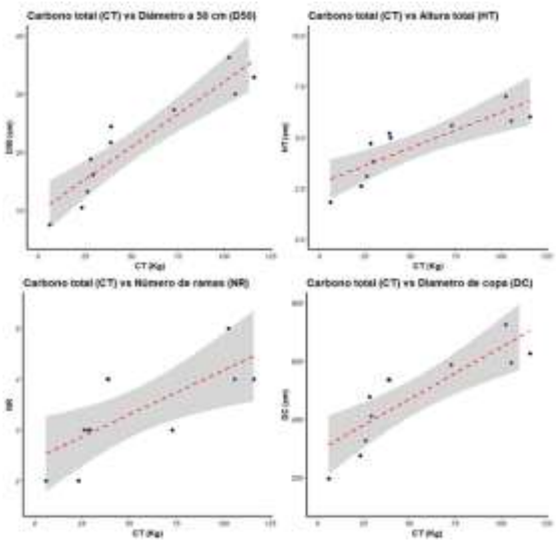

Figure 10: Linear Behavior Of The Carbon Capture Ratio.

The dasometric variables D50, ht, NR, DC, in Figure 10 have a positive linear relationship with respect to carbon sequestration, while Ramos et al. (2018) mention that the relationship depends on the interdependence of variables, while Riascos (2020) considers that DAP and total height with carbon content have a positive linear relationship.

Table 7: Allometric Models Adjusted to Estimate Carbon Content.

Modelo	Condición	R^2	r^2ajus	RECM	E	Sxy	AIC
1	Rechazado	0,8897	0,8775	13,5603	0,3797	40,6808	29,9512
2	Rechazado	0,8913	0,8792	13,4635	0,0006	40,3904	29,8828
3	Rechazado	0,9357	0,9197	1,6940	-0,0003	31,0511	29,3704
4	Aceptado	0,8577	0,8419	15,4038	0,0006	46,2115	31,1692
5	Rechazado	0,8806	0,8674	14,1065	1,6988	42,3195	30,3286
6	Aceptado	0,8333	0,8147	16,6727	0,2588	50,0182	31,9255
7	Rechazado	0,8510	0,8345	15,7597	2,0942	47,2790	31,3874
8	Rechazado	0,8500	0,8333	15,8144	-0,0003	47,4433	31,4205
9	Aceptado	0,3399	0,2666	33,1731	0,0660	99,5193	38,4986
10	Rechazado	0,9116	0,8895	12,8738	1,1806	36,4125	30,8922

R2: correlation coefficient; r2ajus: adjusted correlation coefficient, RECM: root of the mean square error; Sxy: standard estimation error; AIC: Akaike Index.

The models were accepted or rejected according to the significance obtained by the F and t tests (Table 12). Table 9 shows that, from the models accepted to estimate total carbon, regular adjustments have been obtained, since the average values for R2 and r2ajus were 0.677 and 0.641. Only two models (4 and 6) presented better statistical indicators with minimum

R2 and r2ajus of 0.833 and 0.815; as well as RECM, E, Sxy and AIC maximum of 0.259, 50.018 and 31.926, respectively. The two models correctly estimated the biomass of P. racemosa, so they were evaluated to see which one meets the ANOVA assumptions (normality and homogeneity of residues).

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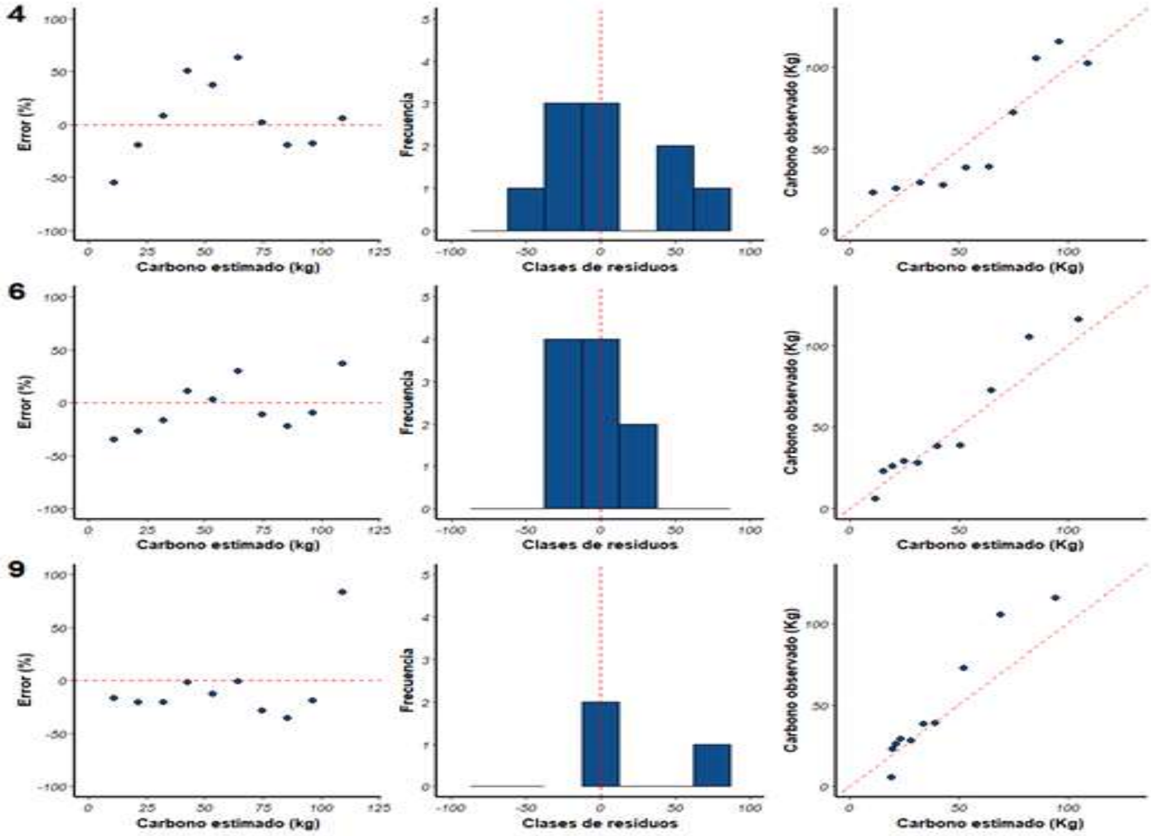

Figure 11: Graphical Analysis of The Best Allometric Model for Carbon Content.

Table 8: Normality Analysis of Allometric Model 6 to Estimate Estimated Carbon

Carbono	
Test	P-valor
Kolmogórov-Smirnov	0,8621
Lilliefors	0,5129
Shapiro-Wilk	0,6635

Model 6 presented a better distribution of its residues with errors of less than 50% (Overestimation and underestimation) (Figure 11), as well as a better shaped bell in the residue histogram. Reflected with high values of R2 and adjusted r and low RECM, Sxy and AIC values obtained in the statistical indicators. In addition, using the Kolmogorov, Lilliefors and Shapiro-Wilk tests, the residuals of model 6 were normal, as the p values were greater than 0.05 (Table 10).

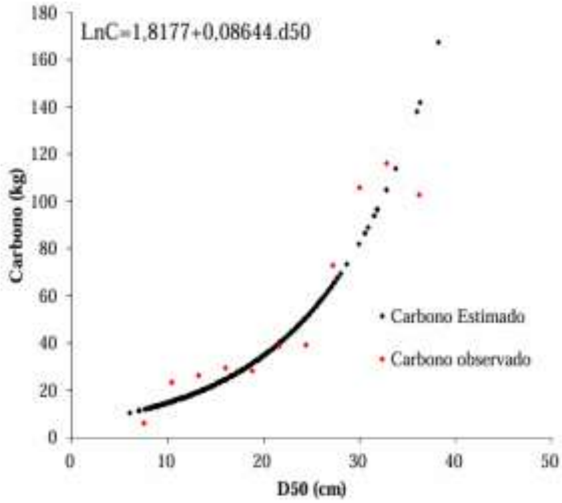

Figure 12: Dispersion of carbon values as a function of D50 cm.

Model 6 (Figure 12) is determined by LnC=1.8177+0.08644. D50; it reaches an R2: 0.833; Adjusted R2 0.815; RECM 16,673; E: 0.259; Sxy: 50.0182 and one AIC 1.926; being the equation that best estimates carbon in the relict forest of P. racemosa with the highest statistical performance. Apolinario and Peláez (2018) adjusted allometric models to determine carbon in Polylepis spp, determining that the model that best estimates carbon is determined by the equation Ln(M) = −2.1757 + 2.025Ln(DAP), while Curo (2019) estimated the carbon in Polylepis using the equation CC = 0.1791DAP2 + 1.0691 ∗ DAP−3.6161, with R2 of 0.8644, agreeing that the dasometric variable that estimates carbon biomass is a function of DAP.

Considering the model LnC=1.8177+0.08644. D50 and the frequency of individuals per ha, it was determined that 23.32 Tn/ha of Carbon and 85.59 Tn/ha of carbon dioxide equivalent (CO2eq) are sequestered, Table 11. Results similar to those obtained by Diego Ribadeneira Falconí, Communication – FONAG. for the páramos area of Ecuador; they are scarce and even rarer for forests of the genus Polylepis. According to the data, the Polylepis incana forest stores the largest amount of carbon of the three environments studied (2400.33 MgC/ha. at 3.62 m depth and 300.96 MgC/ha at 40 cm depth). The lowest values were found in the Polylepis pattern forest (1767.56 MgC/ha at 3.57 m depth and 248.32 MgC/ha at 40 cm depth). The average carbon to rock in all three scenarios was 2048.30 MgC/ha. In Peru, the value of a ton of CO2eq is $7.17 (Lorenzo Eguren, 2020); therefore, the approximate economic value of one ha in the Chalamarca forest is $ 613.7 or 2,393 soles ($1 = 3.9 soles).

Table 11: Estimation Of Carbon Sequestered Per Ha In The Polylepis Racemosa Forest, Chalamarca – Chota.

N° Clase	LI	LS	X	f (1.42 ha)	f (1 ha)	Biomasa estimada/ Individuo (Kg)	Biomasa estimada (Tn/ha)	CO2eq (Tn/ha)
1	6,05	9,05	7,5	66	46	11,82	0,54	1,98
2	9,05	11,85	10,4	217	153	15,19	2,32	8,51
3	11,85	14,65	13,2	347	244	19,35	4,72	17,32
4	14,65	17,45	16,0	202	142	24,65	3,50	12,85
5	17,45	20,25	18,8	159	112	31,40	3,52	12,92
6	20,25	23,05	21,6	107	75	40,00	3,00	11,01
7	23,05	25,85	24,4	84	59	50,96	3,01	11,05
8	25,85	28,65	27,2	30	21	64,91	1,36	4,99
9	28,65	31,45	30,0	6	4	82,68	0,33	1,21
10	31,45	34,25	32,8	10	7	105,33	0,74	2,72
11	34,25	38,20	36,2	3	2	141,02	0,28	1,03
Total				1232	865	-	23,32	85,39

Li: lower limit, Ls: upper limit; X: class mark, to estimate carbon dioxide equivalent (CO2eq) was multiplied by a factor of 3.67 (IPCC, 2014).

5. CONCLUSIONS

The allometric equation that best fits to estimate the aboveground biomass in Polylepis racemosa in the relict forest of Bella Andina is LnBA=2.394988+0.082807*d; with an R2 : 0.932; Adjusted R2 0.925; RECM: 16,826; E: 0.363; Sxy: 50,477; AIC 32.013 and the model for estimating carbon is LnBA=1.8177+0.08644*d; it reaches an R2: 0.833; Adjusted R2 0.815; RECM 16,673; E: 0.259; Sxy: 50.0182 and one AIC 1.926; whereas the null hypothesis is rejected and the alternating hypothesis is accepted that at least one adjusted allometric equation is statistically superior and adequate to estimate aboveground biomass and carbon in Polylepis racemosa trees in the community of Bella Andina.

The relict forest of Polylepis racemosa has 1232 individuals distributed in 11 diameter classes, the largest number of individuals are in classes 10.4; 13.2; 16.0; 18.8 and 21; 6 centimeters with 217, 347, 202, 159 and 107 individuals respectively and the least amount is at the 30.0 class mark; 32; 8 and 36; 2 centimeters with 10, 6 and 3 individuals. A maximum D50 of 38.19 cm and a minimum D50 of 6cm have been recorded.

The equation that best fits to determine the biomass is determined by LnBA=2.394988+0.082807*d; with an R2: 0.932; Adjusted R2 0.925; RECM: 16,826; E: 0.363; Sxy: 50,477; AIC 32,013.

The equation that best fits to determine the biomass is determined by LnBA=2.394988+0.082807*d; with an R2: 0.932; Adjusted R2 0.925; RECM: 16,826; E: 0.363; Sxy: 50,477; AIC 32,013.

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