ISSN: 2310–3469 RNPS: 2347
Revista Cubana de Ciencias Forestales. 2020; September-December 8(3): 456-467

CFORES
REVISTA CUBANA DE CIENCIAS FORESTALES

Translated from the original in spanish

Original article

Arboreal biomass and economic carbon assessment of the Cerro Tres Puntas of Pilasca (Salas-Motupe, Lambayeque, Perú)

Biomasa arbórea y valoración económica de carbono del Cerro Tres Puntas de Pilasca (Salas-Motupe, Lambayeque, Perú)

Biomassa arbórea e valoração econômica do carbono do Cerro Três Pontas de Pilasca (Salas-Motupe, Lambayeque, Perú)

Guillermo Eduardo Delgado Paredes[1*] https://orcid.org/0000-0001-5769-8209

Felipe Zuñe Da Silva[1] https://orcid.org/0000-0001-5810-9031

Cecilia del Carmen Vásquez Díaz[1] https://orcid.org/0000-0002-3229-5048

Boris Esquerre Ibáñez[1] https://orcid.org/0000-0003-2283-8106

Jorge Antonio Fupuy Chung[1] https://orcid.org/0000-0003-2007-1490

Consuelo Rojas Idrogo[1] https://orcid.org/0000-0003-3525-6711

[1]Universidad Nacional Pedro Ruiz Gallo. Perú.

[*]Correspondence author: guidelg2015@yahoo.es

Recibido: 7 de junio de 2020.
Aprobado: 30 de septiembre de 2020.

ABSTRACT

The work was developed in the Cerro Tres Puntas de Pilasca, in the district of Salas-Motupe, Lambayeque region, Perú. The objective of the study was to determine its tree biomass, accumulated carbon and economic valuation. For this purpose, four linear transects were established covering 11.4 ha of the total 2,975 ha of the study area. In each transect were evaluated the height and diameter (1.30 cm above the ground) e" 5.0 cm of all tree individuals. Also, botanical collections were made for their identification. 410 individuals were registered, comprised of 17 species, 17 genera and 10 families. The estimated biomass in the four transects gave an average of 796.62 t ha^{-1}, which transformed into tons of carbon gave 1 460.6 t CO_2 ha^{-1}, meaning an economic valuation of 28 963.70 USD per ha. The families that contribute more biomass to the Cerro Tres Puntas de Pilasca were Moraceae and Lauraceae, with 8 457.95 t ha^{-1} and 5 738.79 t ha^{-1} respectively, while in the rest of the families the biomass was less than 1 000 t ha^{-1}. Cerro Tres Puntas de Pilasca proved to be an important forest with high biomass values for the region of Lambayeque.

ISSN: 2310–3469 RNPS: 2347
Revista Cubana de Ciencias Forestales. 2020; September-December 8(3): 456-467

Keywords: Aerial biomass; Tropical dry forest; Carbon sequestration; Native tree species; Perú.

RESUMEN

El trabajo se desarrolló en el cerro Tres Puntas de Pilasca, en el distrito de Salas-Motupe, región Lambayeque, Perú. El objetivo del estudio fue determinar su biomasa arbórea, el carbono acumulado y la valoración económica. Para ello, se esTablecieron cuatro transectos lineares que abarcaron 11,4 ha del total de 2 975 ha del área de estudio. En cada transecto fueron evaluados la altura y el diámetro (a 1,30 cm por encima del suelo) ≥ 5,0 cm de todos los individuos arbóreos. Asimismo, se realizaron colectas botánicas para la identificación de los mismos. Se registraron 410 individuos, comprendidos en 17 especies, 17 géneros y 10 familias. La biomasa estimada en los cuatro transectos arrojó una media de 796,62 t ha^{-1}, la que transformada en toneladas de carbono arrojó 1 460,6 t CO_2 ha^{-1}, significando una valoración económica de 28 963,70 USD por ha. Las familias que aportan mayor biomasa al cerro Tres Puntas de Pilasca fueron Moraceae y Lauraceae, con 8 457,95 t ha^{-1} y 5 738,79 t ha^{-1} respectivamente, mientras que en el resto de familias la biomasa fue menor de 1 000 t ha^{-1}. El Cerro Tres Puntas de Pilasca demostró ser un importante bosque con altos valores de biomasa para la región de Lambayeque.

Palabras clave: Biomasa aérea; Bosque tropical estacionalmente seco; Captura de carbono; Especies arbóreas nativas; Perú.

RESUMO

O trabalho desenvolveu se no Cerro Três Pontas de Pilasca no distrito de Salas-Motupe, região Lambayeque, Perú. O objetivo de estudo foi determinar a sua biomassa arbórea, o carbono aglomerado e a valoração econômica. Com este fim estabeleceram se quatro transeptos linhares que abrangeram 11,4 ha duma totalidade de 2 975 há da extensão de estudo. Em cada uns dos transeptos avaliados, a altura e o diâmetro (a 1,30 cm por acima do terreno) ≥ 5,0 cm de todos os indivíduos arbóreos. Mesmo assim, realizaram se coletas botânicas para a identificação dos mesmos. Registraram se 140 indivíduos, compreendidos em 17 espécies, 17 gêneros e 10 famílias. A biomassa estimada nos quatro transeptos resultou uma meia de 796,62 t ha^{-1}, que transformada em toneladas de carbono, trouxe como resultante 1 460,6 t CO2 ha^{-1}, o que significa uma valoração econômica de 28 963,70 USD por há. As famílias que aportaram maior biomassa ao Cerro Três Pontas de Pilasca, foram *Moraceae* e *Lauraceae*, com 8 457,95 t ha^{-1} y 5 738,79 tha^{-1} simultaneamente, mesmo que no resto das famílias, a biomassa foi menor de 1 000 t ha^{-1}. O Cerro Três Pontas de Pilasca demostrou ser uma importante floresta com altos valores com altos valores de biomassa para a região de Lambayeque.

Palavras chave: Biomassa aérea; Floresta tropical estacionalmente seca; Captura de carbono; Espécies arbóreas nativas; Perú.

INTRODUCTION

The greatest threat of our times that confronts humanity and that involves and compromises all its actors is global warming, verified by the increase of the atmospheric temperature due to the great emissions of Greenhouse Gases (GHG) such as carbon dioxide (CO_2) - the most important due to the amounts that are emitted -, methane (NH_4), nitrogen oxides (NO_x) and chlorofluorocarbons (CFC). In this sense, tropical forests play an indispensable role in the global terrestrial carbon cycle (Houghton, 2005), having quantitatively significant carbon reservoirs, stored in

the form of biomass (Pan *et al*., 2011; Feldpausch *et al*., 2012; Pooter *et al*., 2016). However, such extensions threaten a steady reduction in areas due to intense deforestation, habitat fragmentation and land use changes (Song *et al*., 2018).

Among terrestrial ecosystems, forest systems are particularly remarkable, since their arboreal articulation retains large amounts of atmospheric carbon, compared to other types of vegetation (Albritton and Dokken, 2001). Therefore, one of the most important processes in the forest balance stands out, the carbon cycle (C), a chemical element and the main formator of biological matter. The carbon cycle consists of several stages, ranging from its absorption by plants to its transformation into biomass (Brown, 1997). It is estimated that tropical trees absorb ~72 Pg C from the atmosphere per year (Beer *et al.*, 2010). In addition, it is estimated that the carbon stock of tropical forests exceeds 370 Pg C (Pan *et al.,* 2011). These carbon sinks represent an intense flow of continuous mitigation of one of the most important greenhouse gases. It should be noted that tropical forests are subject to global appreciation for the services they provide to mitigate GHG concentrations. In this sense, the reduction of GHG emissions and the reduction of global temperature are patterns of global interest. However, estimating the size of carbon resources over time is an arduous and almost impossible task, even when considering a set of complex variables and interactions of different elements of an ecosystem (Mitchard, 2018). Other studies on carbon capture and storage have been conducted in various ecological environments in Latin America, although not precisely in seasonally dry tropical forests. Such is the case of a destructive sampling carried out in Granma, in the Sierra Maestra of Cuba (Toirac *et al*., 2018).

Among Peruvian's impressive biomes is one of the world's most fragile and threatened ecosystems, the Tropical Seasonal Dry Forest (TDS) (Apgaua *et al*., 2014). In the ecological context of biomass and carbon studies, the seasonally dry tropical forests of the Lambayeque region have little information available, because the vast majority of studies are in the private sector. However, a relevant study reported that in the various types of dry forests located in the hamlet of El Choloque (Tongorrape, Motupe, Lambayeque), in nine circular plots of 30 m radius, within an area of 159.3 ha, the capture and storage of C, as a mitigation against climate change, was analyzed in the species *Bursera graveolens*, *Loxopterygium huasango*, *Prosopis limensis* and *Parkinsonia praecox*, obtaining a potential of capture of C by primary biomass (foliage and leaf litter) of 0.52 t C ha^{-1}, a potential of storage of C at the level of the aerial biomass (major branches and shaft) of 4.23 t C ha^{-1} in a forest with an average age of 25 years and in the soil of 42.19 t C ha^{-1} (Chávez, 2018).

Considering that there are still gaps in the estimation of biomass and carbon accumulation, as well as their valuation in the dry forests of the Lambayeque region, the objective of this research was to determine these elements in the Cerro Tres Puntas de Pilasca, Salas, Lambayeque region (Perú), as a real contribution of the seasonally dry tropical forests of the Lambayeque region.

MATERIALS AND METHODS

Study area

The study area was located in the Pilasca farmhouse, 5 km from the district of Salas, in the province and region of Lambayeque, Peru (Figure 1), at the coordinates 6°14'16,23"; S 79°35'34,81" W and 6°12'46,46" S; 79°33'59,58" W, comprising In addition, the Cerros Tierra Blanca and Gato, which belong to the Salas district and the Cerro Tres Puntas , which belongs to the Motupe district, covering an extension

of approximately 2,975 hectares, with an elevation between 1,545 and 1,986 meters a.s.l. The area corresponds to a very rough and dangerous topography, with enormous rocks and deep, dry ravines and scarce rocky clearings where primitive and subsistence agriculture thrives, predominating medium and large sized trees and shrubs no higher than 5 m high, as well as a very varied herbaceous vegetation.

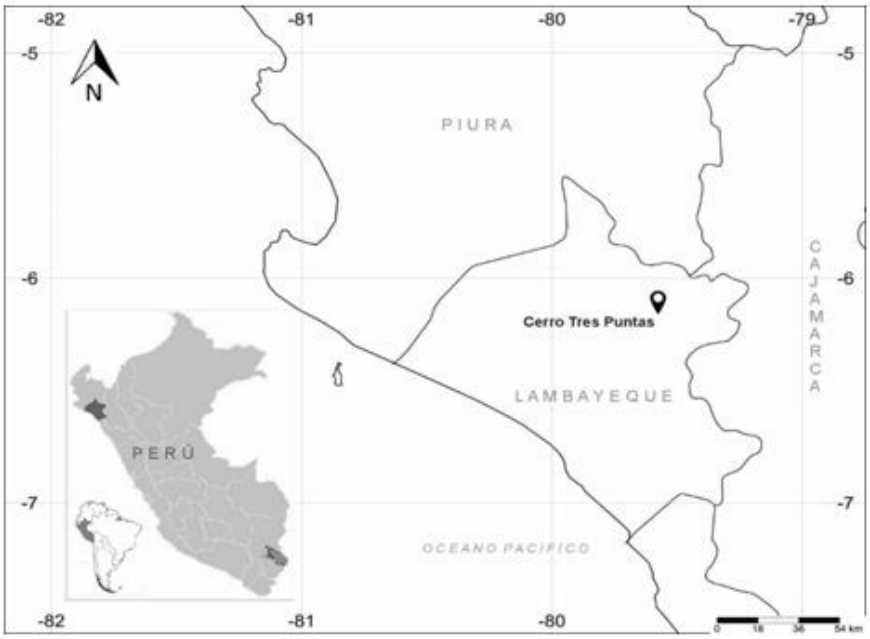

Figure 1. - Map of the Lambayeque region (Perú)

Sample collection and processing

The field work was carried out between the months of March and June 2018. Due to the difficult accessibility and dangerousness of the terrain, the Gentry woody plant sampling method (1995) was used, with adaptations for the study area. Four sampling units (line transects) were established in the field, covering 11.4 ha, as indicated in the work of Delgado-Paredes *et al.*, (2020). In each transect, the height and diameter (1.30 cm from the ground) ≥ 5 cm of all tree individuals were recorded. Likewise, botanical collections were made for their subsequent identification. botanical samples were identified from physical-virtual literature, consultations to specialists and visits to herbaria. All families were classified according to APG IV (APG, 2016). Finally, they were deposited in the Pedro Ruiz Gallo Herbarium (HPRG).

Data analysis

To facilitate the logical-structural interpretation of the study, the arboreal individuals were classified according to their dendrometry and botanical identification. The biomass calculation was estimated from the allometric ratio for tropical trees, as a function of diameter, height and wood density. For the calculation, it was used the formula of Chave *et al.*, (2014): B = 0.0673*(De*((Di)^2)*A)^0.976; Where,B = Biomass (t ha^{-1}), De = Density (g cm^3), Diameter (cm), A = Height (m). For the density of each tree the database present in The World Agroforestry Centre (ICRAF) was used. When no data were obtained at the species level, results were used at the genus or family level. When no data were obtained, a global average of 0.62 g cm^3 was used. Finally, average estimates of biomass by family were compared and correlated with altitude, the latter from linear regression, choosing as confidence parameters the r-square (R2) and significance less than 5 %. All the calculations,

analysis and graphs were made through the statistical environment R 3.6.3 (R Core Team, 2020).

For the valuation calculation, the carbon conversion from the total biomass obtained was used, using Brown and Lugo's (1992) formula: C=B*0.5, where C = Carbon (t C ha^{-1}) and B = Biomass (t ha^{-1}). Subsequently, to define the value of carbon, the formula described by the IPCC (2003) and Mogas and Riera (2005) was used, where one ton of C is equal to 3,667 tons of CO_2 and was adjusted to the value proposed by the Electronic System for Negotiating Carbon Dioxide Emission Rights ($SENDECO_2$, 2017) and the Banco de la Nación del Perú (BN) as of December 2018, where one ton of CO_2 is equivalent to US$19.83 per hectare.

RESULTS AND DISCUSSION

There were 410 individuals recorded, comprised of 17 species, 17 genera and 10 families. Table 1 shows the relationship of arboreal species registered in the four transects evaluated in the seasonally dry forest of Cerro Tres Puntas (Salas-Motupe, Lambayeque, Peru), highlighting the Fabaceae family with the highest number of species (Table 1).

Table 1. - Arboreal species present in the evaluated area of the Cerro Tres Puntas seasonally dry tropical forest species present in the evaluated area of the Cerro Tres Puntas seasonally dry tropical forest (Salas-Motupe, Lambayeque, Perú)

Nº	Family	Species	Common name	No indiv.
1	Anacardiaceae	*Loxopterygium huasango* Spruce ex Endl.	hualtaco	20
2	Boraginaceae	*Cordia lutea* Lam.	overo	29
3	Burseraceae	*Bursera graveolens* (Kunth) Tr. & Pl.	palo santo	4
4	Fabaceae	*Albizia multiflora* (Kunth) Barneby & J.W. Grimes	angolo	8
5		*Caesalpinia glabrata* Kunth	charán	5
6		*Erythrina smithiana* Krukoff	frejolillo	32
7		*Pithecellobium excelsum* (Kunth) Mart.	chaquiro	21
8		*Prosopis limensis* Benth.	algarrobo	9
9		*Senna atomaria* (L.) Irwing & Barneby	chapa	15
10		*Vachellia macracantha* (Willd.) Seigler & Ebinger	faique	154
11	Lauraceae	*Beilschmiedia sulcata* (Ruiz & Pav.) Kostern	palta de zorro	1
12	Malvaceae	*Eriotheca ruizii* (K. Schum.) A. Robins	pasayo	6
13		*Guazuma ulmifolia* Lam.	guazumo	11
14	Moraceae	*Ficus obtusifolia* Kunth	higuerón	17
15	Olacaceae	*Ximenia americana* L.	ciruelillo	17
16	Sapindaceae	*Sapindus saponaria* L.	choloque	6

In the diameter classification, individuals with minimum diameters of 5.0 and maximum of 219.9 cm were recorded, resulting in the diameter class of 10 to 19.9 cm with the largest number of individuals (128) (Figure 2), while in the analysis of the altimetric class, up to 39.9 m in height were recorded, resulting in the altimetric class of 5 to 9.9 m with the largest number of individuals (205) (Figure 3).

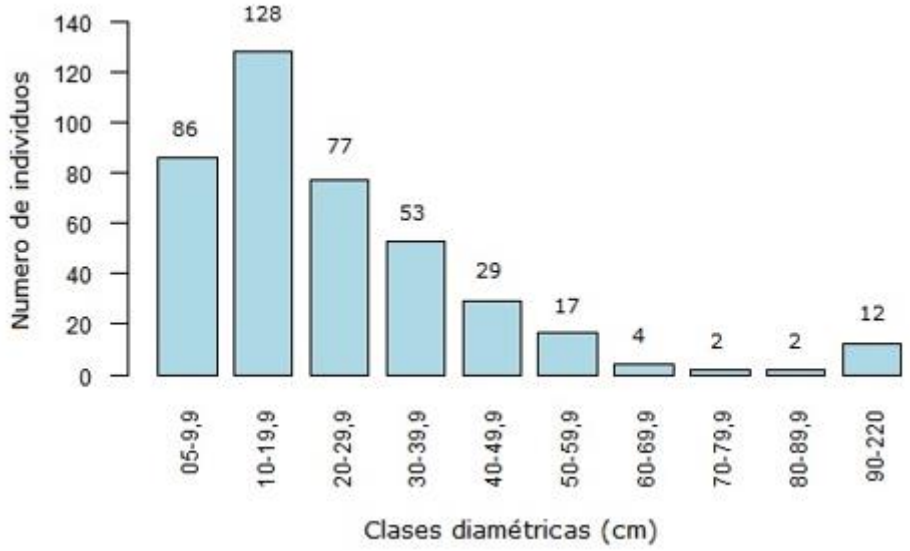

Figure 2. - Diameter structure of arboreal vegetation in the evaluated area of the Cerro Tres Puntas seasonally dry tropical forest (Salas-Motupe, Lambayeque, Perú)

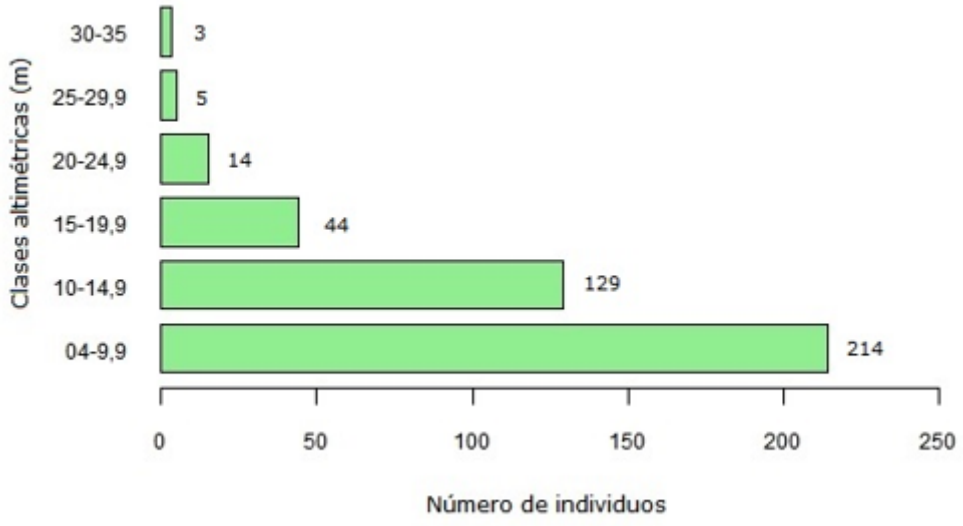

Figure 3. - Altimetric structure of arboreal vegetation in the evaluated area of the Cerro Tres Puntas seasonally dry tropical forest (Salas-Motupe, Lambayeque, Perú)

The estimated biomass for the four transects evaluated in the Cerro Tres Puntas seasonally dry tropical forest yielded an average of 796.62 t ha^{-1}, where the lowest values corresponded to transects one and two with S 288 t ha^{-1}, increasing in transect three up to 428 t ha^{-1}, while in transect four the increase was up to more than five times with 2 182.11 t ha^{-1} (Figure 4). It was also observed a trend in the increase of biomass at the same time that the altitude increased. However, no significance was found for the relationship (R^2= 0.48; *P*=0.29) (Figure 4). Likewise, it could be seen that the families that contribute the most biomass to the Cerro Tres Puntas de Pilasca were Moraceae and Lauraceae, with 8,457.95 t ha^{-1} and 5,738.79 t ha^{-1}, respectively, while in the rest of the families the biomass was less than 1,000 t ha^{-1} (Table 2), even though these values usually vary with the number of species and individuals sampled.

Figure 4. - Biomass (t ha^{-1}) of arboreal vegetation and its relationship to altitudinal levels in the evaluated area of the Cerro Tres Puntas seasonally dry tropical forest (Salas-Motupe, Lambayeque, Perú). T= transect

Table 2. - Biomass (t ha^{-1}) of arboreal vegetation and its relationship with altitudinal levels in the evaluated area of Cerro Tres Puntas seasonally dry tropical forest (Salas-Motupe, Lambayeque, Perú)

Families	N° Individuals	Biomass (t ha^{-1})
Anacardiaceae	20	502,82
Boraginaceae	29	23,13
Burseraceae	4	103,8
Fabaceae	244	177,42
Malvaceae	17	338,88
Moraceae	17	8 457,95
Olacaceae	17	58,23
Lauraceae	1	5 738,79
Sapindaceae	6	150,94
Ulmaceae	55	997,84

Undoubtedly, these individuals, still preserved at all costs by the Pilasca community, are the most important chronological reference in the forest. In the estimation of total accumulated biomass in community forests in the Frailesca region of Chiapas, Mexico, it was demonstrated that this was in relation to the age of the tree, since older individuals such as the *Pinus maximinoii*, from 40 to 100 years and *Quercus rugosa*, from 20 to 70 years, stored 158 and 117 Mg ha^{-1}, respectively, while younger individuals such as *Quercus robur*, from 20 to 40 years, stored only 5.9 Mg ha^{-1}of carbon, (Rodriguez-Larramendi *et al.*, 2016). This close relationship between

normalized diameter (m), tree age and photosynthetic processes that lead to biomass accumulation and carbon sequestration in different forest species has been observed in other species such as *Gliricidia sepium* and *Leucaena leucocephala*, in silvopastoral systems (Gómez-Castro *et al*., 2010), where atmospheric carbon sequestration increased with age.

These kinds of studies, in the seasonally dry tropical forests of Perú and especially in the seasonally dry tropical forests of northern Perú and even more so in the Lambayeque region, are almost non-existent. In a forest of Tongorrape, Motupe (Lambayeque), with an average age of 25 years, where the species *Bursera graveolens*, *Loxopterygium huasango*, *Prosopis limensis* and *Parkinsonia praecox* were evaluated, with diameter > 5.0 cm, the potential of carbon capture by primary biomass (foliage and leaf litter) was 0.52 t C ha^{-1}, to which was added the aerial biomass (major branches and shaft) of 4.23 t C ha^{-1}, in the lapse of five months (Chávez, 2018); Figures that only allow a slight comparison with the results obtained in the study presented, carried out in the Cerro Tres Puntas.

Regarding the economic valuation of the Cerro Tres Puntas seasonally dry tropical forest, determined from the transformation of tons of biomass into tons of carbon, from 796.62 t ha^{-1} of biomass was obtained 398.31 t C ha^{-1}. Likewise, it was found that there are 1 460.6 t CO_2 ha^{-1}, which when multiplied by the value of CO_2 in December 2018, according to SENDECO_2 and the Banco de la Nación del Perú was 28 963.70 USD per hectare.

CONCLUSIONS

The study of the arboreal biomass, accumulated carbon and economic valuation of the BTES, Cerro Tres Puntas de Pilasca (Salas-Motupe), of the Lambayeque region, determined an average of 796.62 t ha^{-1}, identifying the species *Ficus obtusifolia* (*Moraceae*) and *Beilschmiedia sulcata* (*Lauraceae*) as the ones with the highest biomass with 8 457.95 t ha^{-1} and 5 738.79 t ha^{-1}, respectively, as well as the transformation of tons of carbon that reached 1 460.6 t CO_2 ha^{-1}, meaning an economic valuation of 28 963.70 USD ha.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Ernesto Hashimoto Moncayo, Vice-Rector of Research at the Universidad Nacional Pedro Ruiz Gallo (Lambayeque) and the administrative officers Héctor Valdiviezo Castillo and Melissa Saldarriaga Heros, for the facilities that made the execution of the study possible. Also, to the community members of Pilasca, Froilán Sánchez and Isabel Valencia, for their guide services in the numerous ascents to the Cerro Tres Puntas.

REFERENCES

ALBRITTON, D. L. y DOKKEN, D. J., 2001. Climate change 2001: synthesis report. R. T. Watson (Ed.). Cambridge, UK: Cambridge University Press. 389 p. Disponible en: https://www.ipcc.ch/site/assets/uploads/2018/03/front-1.pdf

APG (Angiosperm Phylogeny Group), 2016. An update of the Angiosperm Phylogeny Group classification for the order sand families of flowering plants: APG IV. Botanical Journal of the Linnean Society, 2016, vol. 181, no 1, p. 1-20. Disponible en: https://onlinelibrary.wiley.com/doi/abs/10.1111/boj.12385

APGAUA, D. M. G., DOS SANTOS, R. M., PEREIRA, D. G. S., DE OLIVEIRA MENINO, G. C., PIRES, G. G., FONTES, M. A. L. y TNG, D. Y. P, 2014. Beta-diversity in seasonallydry tropical forests (SDTF) in the Caatinga Biogeographic Domain, Brazil, and its implications for conservation. Biodiversity and Conservation, vol. 23, no 1, p. 217-232. Disponible en: https://link.springer.com/article/10.1007/s10531-013-0599-9

BEER, C., REICHSTEIN, M., TOMELLERI, E., CIAIS, P., JUNG, M., CARVALHAIS, N., RÖDENBECK, C., ARAIN, M., BALDOCCHI, D., BONAN, G., BONDEAU, A., CESCATTI, A., LASSLOP, G., LINDROTH, A., LOMAS, M., LUYSSAERT, S., MARGOLIS, S., OLESON, K., ROUPSARD, O., VEENENDAAL, E., VIOVY, N., WILLIAMS, C., WOODWARD, F. y PAPALE D., 2010. Terrestrial gross carbon dioxide uptake: global distribution and covariation with climate. Science, vol. 329, no 5993, p. 834-838. Disponible en: https://science.sciencemag.org/content/329/5993/834

BROWN, S., 1997. Estimating biomass and biomass change of tropical forests: a primer. Vol. 134. Food & Agriculture Organization (FAO). Disponible en: https://books.google.com/books/about/Estimating_Biomass_and_Biomass_Change_of.html?id=uv-ISezvitwC

BROWN, S. y LUGO, A., 1992. Above ground biomass estimates for tropical moist forests of the Brazilian Amazon. Interciencia, vol. 17, pp.8-18. Disponible en: https://www.researchgate.net/publication/305348793_Aboveground_biomass_estimates_for_tropical_moist_forest_of_the_Brazilian_amazon

CHAVE, J., RÉJOU-MÉCHAIN, M., BÚRQUEZ, A., CHIDUMAYO, E., COLGAN, M.S., DELITTI, W.B,C., DUQUE, A., EID, T., FEARNSIDE, P.M., GOODMAN, R.C., HENRY, M., MARTÍNEZ-YRÍZAR, A., MUGASHA, W.A., MENCUCCINI, M., NELSON, B.W., NGOMANDA, A., NOGUEIRA, E.M., ORTIZ-MALAVASSI, E., PÉLISSIER, R., PLOTON, P., RYAN, C.M., SALDARRIAGA, J.G. y VIEILLEDENT, G., 2014. Improved allometric models to estimate the above ground biomass of tropical trees. Global Change Biology, vol. 20, pp. 3177-3190. Disponible en: https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.12629

CHÁVEZ, J.P., 2018. Captura y almacenamiento de carbono de los bosques estacionalmente secos de la costa norte (Lambayeque), como mitigación frente al cambio climático. En: Accepted: 2018-06-05T18:06:26Z, Universidad Nacional Agraria La Molina, (Consulta: 13 junio 2020). Disponible en: http://repositorio.lamolina.edu.pe/handle/UNALM/3346.

DELGADO-PAREDES, G.E., VÁSQUEZ-DÍAZ, C., TESÉN-NÚÑEZ, F., ESQUERRE-IBAÑEZ, B., ZUÑE-DA SILVA, F. y ROJAS-IDROGO, C., 2020. Vegetación arbórea del Cerro Tres Puntas de Pilasca, (Salas-Motupe), Lambayeque, Perú. Revista Mexicana de Ciencias Forestales, vol. 11 (58). Disponible en: https://www.semanticscholar.org/paper/Vegetaci%C3%B3n-arb%C3%B3rea-del-Cerro-Tres-Puntas-de-Per%C3%BA-Paredes-V%C3%A1squez-D%C3%ADaz/63848ecfac65a446d6a1658230130ca754e614d3

FELDPAUSCH, T., LLOYD, J., LEWIS, S., BRIENEN, R., GLOOR, M., MONTEAGUDO, A., LOPEZ-GONZALEZ, G., BANIN, L., ABU, K., AFFUM-BAFFOE, K., ALEXIADES, M., ALMEIDA, S., AMARAL, I., ANDRADE, A., ARAGÃO, L., ARAUJO, A., ARETS, E., ARROYO, L., AYMARD, G., BAKER, T., BÁNKI, O., BERRY, N., CARDOZO, N., CHAVE, J., COMISKEY, J., ALVAREZ, E., DE OLIVEIRA, A., DI FIORE, A., DJAGBLETEY, G., DOMINGUES, T., ERWIN, T., FEARNSIDE, P., FRANÇA, M.,

FREITAS, M., HIGUCHI1, N., HONORIO, E., IIDA, Y., JIMÉNEZ, E., KASSIM, A., KILLEEN, T., LAURANCE, W., LOVETT, J., MALHI, Y., MARIMON, B., MARIMON-JUNIOR, B., LENZA, E., MARSHALL, A., MENDOZA, C., METCALFE, D., MITCHARD, E., NEILL, D., NELSON, B., NILUS, R., NOGUEIRA, E., PARADA, A., PEH K., PENA, A., PEÑUELA, M., PITMAN, N., PRIETO, A., QUESADA, C., RAMÍREZ, F., RAMÍREZ, H., REITSMA, J., RUDAS, A., SAIZ, G., SALOMÃO, R., SCHWARZ, M., SILVA, N., SILVA-ESPEJO, J., SILVEIRA, M., SONKÉ, B., STROPP, J., TAEDOUMG, H., TAN, S., TER STEEGE, H., TERBORGH, J., TORELLO-RAVENTOS, M., VAN DER HEIJDEN, G., VÁSQUEZ, R., VILANOVA, E., VOS, V., WHITE, L., WILLCOCK, S., WOELL, H. y PHILLIPS, O., 2012. Tree height integrated into pantropical forest biomass estimates. Biogeosciences, p. 3381-3403. Disponible en: https://www.biogeosciences.net/9/3381/2012/bg-9-3381-2012.pdf

GÓMEZ-CASTRO, H., PINTO-RUIZ, R., GUEVARA-HERNÁNDEZ, F. y GONZÁLEZ-REYNA, A., 2010. Estimaciones de biomasa aérea y carbono almacenado en Gliricidia sepium (Lam.) y Leucaena leucocephala (Jacq.) y su aplicación en sistemas silvopastoriles. ITEA, vol. 106, pp. 256-270. Disponible en: https://dialnet.unirioja.es/servlet/articulo?codigo=3773696

GENTRY, A.H., 1995. Diversity and floristic composition of neotropical dry forests. En: Bullock, S.H., Mooney, H.A. y Medina, E. (Eds.). Seasonally Dry Forests. Cambridge, University Press, Cambridge, UK. pp. 146-194. Disponible en: https://www.cambridge.org/core/books/seasonally-dry-tropical-forests/diversity-and-floristic-composition-of-neotropical-dry-forests/4482CBC6F9FD8E01E0F6D30E9B7156A4

HOUGHTON, R. A, 2005. Aboveground forest biomass and the global carbon balance. Global Change Biology, vol. 11, no 6, p. 945-958. Disponible en: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2486.2005.00955.x

IPCC (Intergovernmental Panelon Climate Change). 2003. Good practice guidance for land use, land-use change and forestry, Japan: Institute for Global Environmental Strategies (IGES) IPCC. 628 p. Disponible en: https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

MITCHARD, E. T. A, 2018. The tropical forest carbon cycle and climate change. Nature, vol. 559, no 7715, p. 527-534. Disponible en: https://www.nature.com/articles/s41586-018-0300-2

MOGAS, J. y RIERA, P., 2005. El valor de la fijación de carbono en los programas de forestación. Boletín económico de ICE, Información Comercial Española, No 2834, pp. 13-28. Disponible en: https://dialnet.unirioja.es/servlet/articulo?codigo=2009701

PAN, Y., BIRDSEY, R. A., FANG, J., HOUGHTON, R. A., KAUPPI, P. E., KURZ, W. A., PHILLIPS, O. L., SHVIDENKO, A., LEWIS, S. L., CANADELL, J. G., CIAIS, P., JACKSON, R. B., PACALA, S. W., MCGUIRE, A. D., PIAO, S., RAUTIAINEN, A., SITCH, S. y HAYES D., 2011. A large and persistent carbon sink in the world's forests. Science, vol. 333, no 6045, p. 988-993. Disponible en: https://science.sciencemag.org/content/333/6045/988

POORTER, L., BONGERS, F., AIDE, T., ALMEYDA, A., BALVANERA, P., BECKNELL, J., BOUKILI, V., BRANCALION, P., BROADBENT, E., CHAZDON, R., CRAVEN, D., ALMEIDA-CORTEZ, J., CABRAL, G., DE JONG, B., DENSLOW, J., DENT, D.,

DEWALT, S., DUPUY, J., DURÁN, S., ESPÍRITO-SANTO, M., FANDINO, M., CÉSAR, R., HALL, J., HERNANDEZ-STEFANONI, J., JAKOVAC, C., JUNQUEIRA, A., KENNARD, D., LETCHER, S., LICONA, J., LOHBECK, M., MARÍN-SPIOTTA, E., MARTÍNEZ-RAMOS, M., MASSOCA, P., MEAVE, J., MESQUITA, R., MORA, F., MUÑOZ, R., MUSCARELLA, R., NUNES, Y., OCHOA-GAONA, S., OLIVEIRA, A., ORIHUELA-BELMONTE, E., PEÑA-CLAROS, M., PÉREZ-GARCÍA, E., PIOTTO, D., POWERS, J., RODRÍGUEZ-VELÁZQUEZ, J., ROMERO-PÉREZ, I., RUÍZ, J., SALDARRIAGA, J., SANCHEZ-AZOFEIFA, A., SCHWARTZ, N., STEININGER, M., SWENSON, N., TOLEDO, M., URIARTE, M., BREUGEL, M., VAN DER WAL, H., VELOSO, M., VESTER, H., VICENTINI, A., VIEIRA, I., BENTOS, T., WILLIAMSON G. y ROZENDAAL, D., 2016. Biomass resilience of neotropical secondary forests. Nature, vol. 530, no 7589, p. 211-214. Disponible en: https://www.nature.com/articles/nature16512

R CORE TEAM, 2020. A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. Disponible en: https://www.gbif.org/es/tool/81287/r-a-language-and-environment-for-statistical-computing

RODRÍGUEZ-LARRAMENDI, L.A., GUEVARA-HERNÁNDEZ, F., REYES-MURO, L., OVANDO-CRUZ, J., NAHED-TORAL, J., PRADO-LÓPEZ, M. y CAMPOS, R.A., 2016. Estimación de biomasa y carbono almacenado en bosques comunitarios de la región Frailesca de Chipas, México. Revista Mexicana de Ciencias Forestales, vol. 7, pp. 77-94. Disponible en: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-11322016000500077

SONG, X. P., HANSEN, M. C., STEHMAN, S. V., POTAPOV, P. V., TYUKAVINA, A., VERMOTE, E. F. y TOWNSHEND, J. R., 2018. Global land change from 1982 to 2016. Nature, 2018, vol. 560, no 7720, p. 639-643. Disponible en: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6366331/

SENDECO$_2$ (Sistema Electrónico de Negociación de Derechos de Emisiones de Dióxido de Carbono)., 2017. SENDECO$_2$, La Bolsa de CO2. Disponible en: https://www.sendeco2.com/

TOIRAC, W., VIDAL, A, y BARRERO, H., 2018. Modelos de biomasa aérea verde en plantaciones de Pinus maestrensis en la Sierra Maestra, Cuba. Avances, Centro de Información y Gestión Tecnológica, vol. 20, pp.254-263. Disponible en: http://www.ciget.pinar.cu/ojs/index.php/publicaciones/article/view/371. Fecha de acceso: 21 jan. 2019.

Conflict of interests:
The authors declare not to have any interest conflicts.

Authors' contribution:
The authors have participated in the writing of the work and analysis of the documents.