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Estimation of the carbon stock of calo and chachacomo trees at "Bosque de Zarate" Reserved Zone montane forest

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This study addressed the issue by: (1) estimating the carbon stored in the aboveground biomass of calo and chachacomo trees, (2) identifying economic activities with offsettable emissions using the MINAM "Carbon Footprint Peru" platform, and (3) proposing an alternative funding method for conservation. A total of 27 plots (250 m² each) were evaluated between 3034 and 3200 meters. Tree height and diameter were measured to estimate biomass through allometric equations, then converted into carbon and its CO_2 equivalent. The total aboveground carbon stock was estimated at 329.23 tons of carbon, averaging 6.67 ton C/ha. Chachacomo contributed 5.04 ton C/ha, showing more potential as a carbon sink than calo (3.49 ton C/ha). This carbon stock equals 1208.33 tons of CO_2 equivalent, enough to offset emissions from companies operating in offices, accommodation activities, and food services. These businesses represent a promising market niche for funding conservation through voluntary donations, crowdfunding platforms, or conservation trust funds.

Keywords—Calo, chachacomo, montane forest, carbon reserve.

Estimation of the carbon stock of calo and chachacomo trees at "Bosque de Zarate" Reserved Zone montane forest

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I. Introduction

The Bosque de Zarate Reserved Zone (ZRBZ) protects 545.75 ha of dry cloud forest, a western montane forest located in the San Bartolomé District of Lima, over which limited information on its carbon stock is available [1]. The reduced size and high dispersion of montane forests limit the accuracy of remote sensing systems, posing a challenge to carbon stock estimation methods otherwise useful in Amazon setups [2].

ZRBZ is relict of the once before abundant Andean forests, now scattered over the slopes of northern and central Peruvian Andes [3]. Likewise, by presenting an altitudinal gradient from 1850 m.a.s.l to 3600 m.a.s.l, it presents a diversity of climates along the altitudinal gradient, which harbors great biodiversity and diverse carbon stocks (aboveground biomass, belowground biomass and soil organic carbon). Altitude, precipitation level, and average temperature are climatological factors that influence the carbon storage capacity of montane forests [4].

In ZRBZ, there are more than one hundred species of flora and fauna; of which six endangered species of trees and birds [1]. The predominant forest species are calo (*Oreopanax oroyanus*), chachacomo (*Escalonia resinosa*) and calatillo (*Myrcianthes quinqueloba*) [1] (Fig. 1).

(a) (b) (c)

Fig. 1 Predominant species. (a) Calo, (b) Chachacomo, (c) Calatillo [1]

During the administration of former Minister Antonio Brack (2008-2011), when the ZRBZ was established as a Reserved Zone, park rangers who protected the forest were paid by Servicio Nacional de Áreas Naturales Protegidas (SERNANP), but once his administration ended, this also ended. Although the approximately 1500 visitors per year are not formally charged an entrance fee, their visits bring business to the San Bartolomé community as they require food and accommodations offered by the community.

From the perspective of both actors, the community and the public authorities, it is understood that one of the dilemmas arises from the absence of funding for their surveillance and protection. To begin to solve this, it is necessary to propose alternatives that do not imply a high investment cost and that guarantee the economic sustainability of the community and the conservation of the ZRBZ. In that sense, one option is to evaluate the monetization of ZRBZ's carbon stocks and propose conservation financing alternatives. In recent years, more and more companies are looking to neutralize their carbon footprint. 83% of consumers consider sustainable businesses to be crucial, driving this business trend. In addition, 64% of conscious consumers would pay more for a product with a lower carbon footprint. [5]. This neutralization is done through the financing of emission reduction plans, which buy these carbon credits to achieve it. However, in order for the captured carbon to be sold on the market, an economic valuation is required, as well as certification by an accredited entity. To do this, first of all, you must have an initial estimate of the carbon stored. In this sense, in this research, the evaluation of the carbon stored in the aboveground biomass of the ZRBZ was carried out for the financing of forest conservation management.

II. MATERIALS AND METHODS

A. *Study Area*

The scope of this project was limited to the estimation of the carbon stock in the aboveground biomass of calo and chachacomo within 3034-3200 m.a.s.l at ZRBZ.

B. *Method*

1) *Reconnaissance*

The ZRBZ was first visited from 27/09/23 to 29/09/23. Five 25x10 m plots were established, between 3034 and 3200 m.a.s.l (Fig. 2). The plot size corresponds to recommendations for describing individuals with diameter at breast height (DBH) greater than 10 cm [6], such as the calo and chachacomo trees observed at ZRBZ [7][8]. The height and DBH of the trees within plots were registered (Fig. 3). Consecutively, the (1) mean, (2) variance, and (3) standard deviation were estimated, based on the following equations:

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \cdots + X_n}{n} = \sum_{i=1}^{n} X_i \quad (1)$$

$$S^2 = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1} \quad (2)$$

$$S = \sqrt{S^2} \quad (3)$$

Where:
X_i=Carbon stored in aboveground biomass per plot (ton/ha)
n=number of observations

These estimators were used to establish the number of plots for the study area using the "Winrock Terrestrial Sampling Calculator" equation [6]:

$$n = \frac{(N * s)^2}{\frac{N^2 * E^2}{t^2} + N * s^2}$$

Where:
n = number of plots
E = allowed error
t = statistical sample of the distribution t for a 90% confidence level
N = number of plots in the stratum area
s = standard deviation of stratum h

This tool requires the before mentioned estimators, as well as the study area in hectares, the level of error and the level of confidence. The study area was estimated using ArcGIS software (Fig. 2).

The geographic data used to obtain this value were a single-band raster elevation dataset, contour layers, and the ZRBZ map. The coefficient of variability (CV%) should be between 40 and 50% and the recommended sampling error should be no more than 20% for dry coastal forests, such as ZRBZ. It was established that the confidence level is 90% [7].

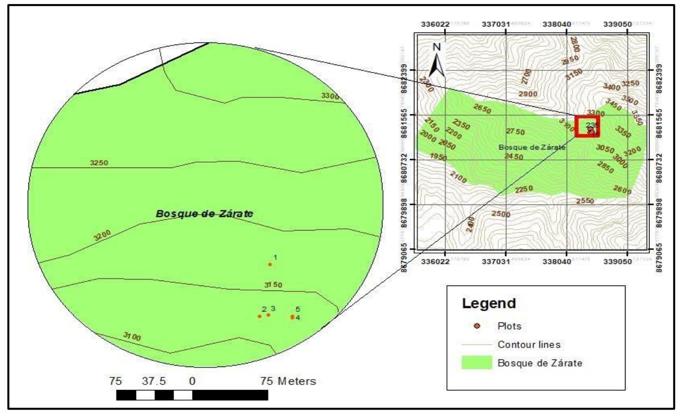

Fig. 2 Location of the five plots for the Reconnaissance phase

2) *Field*

ZRBZ was visited twice, from 01/27/23 to 01/29/2023 and from 08/18/23 to 08/20/23. Dasometric information on calo and chachacomo in the study area were collected.

Dasometric measurements

Twenty-seven plots of 25x10=250 m^2 were established for tree measurement based on the information collected in the reconnaissance phase (Fig. 3).

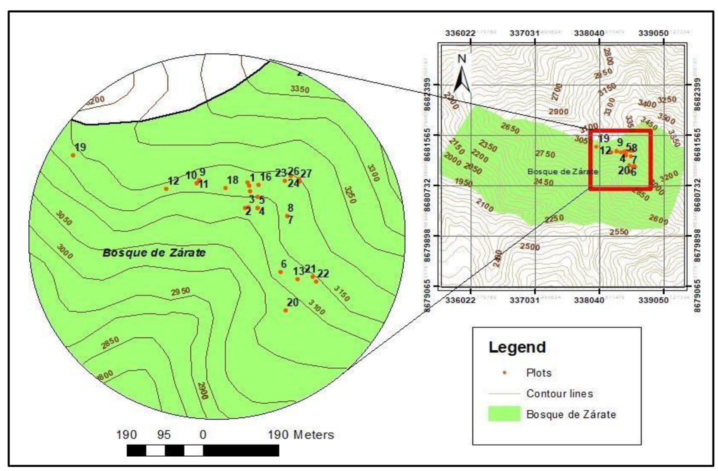

Fig. 3 Field phase sampling plots in the ZRBZ

Tree perimeter was measured at 1.3 m from the ground with a tape measure and divided by π to calculate the DBH. The precise measurement angle and place per tree was adapted to tree trunk morphology as indicated in Fig. 4.

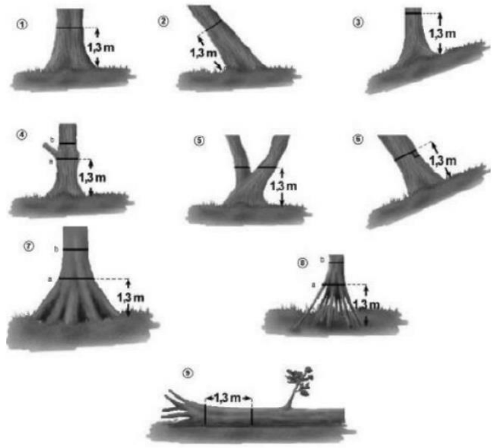

Fig. 4 Technique for measuring DAP. In situations 4, 7 and 8 the position (b) is considered correct for measuring the diameter [6].

The height of trees was measured using two methods: the "Christen's Hypsometric Rule" and the "Trigonometric Method", both considered indirect, since the measurements are made at a distance. Once the results were obtained with both methods, the measurements of both were averaged to estimate the final height of each tree.
For the first method, a metal piece in the shape of a ruler, 30 cm long and a four-meter-long rod was used. We stood at a distance in such a way that the projection of the tree and the stick would fit into the ruler. It was always sought that the ruler be aligned to the inclination of the tree to secure an accurate measurement. The pole was kept next to the tree and aligned with it. Once located at this distance, the measurements marked by the top of the rod and the apex of the tree in the ruler were taken and entered into the following formula:

$$X = r(1 - \frac{p}{h})$$

Where:
X: measurement on the 30 cm ruler (cm)
A: Constant, ruler Size
P: Constant, pole Size (m)
h: Projected tree measurement (m)

Based on the results of this formula, a new scale is constructed on the 30 cm ruler, which is referred to as the "Christen Rule. Measurements with this ruler are also made at a distance at which the entire tree and the rod are projected into it. Then, the measurements are made with the new scale of the ruler from the top of the pole upwards, adding the measurement of the rod to calculate the total height of the tree [8].

The angle α formed by any line of sight with the horizontal is based on trigonometric principles in the second method. There are three main cases for measuring the total height of a roundabout based on the observer's position: from the base to the top of the roundabout, from the top to the base, or from the top to the top [8]. The following are the three equations that were used for the estimation of the height:

A. When the observer is between the base and the apex of the tree, at the same level

$$h = D \times (\tan \alpha + \tan \beta)$$

Where:
h: Total Tree Height (m)
D: Horizontal distance between the observer and the tree (m)
α: Angle of elevation between the observer and the apex of the tree (º)
β: Angle of depression between the observer and the base of the tree (º)

B. When the observer is below the base

$$h = D \times (\tan \alpha - \tan \beta)$$

Where:
h: Total Tree Height (m)
D: Horizontal distance between the observer and the tree (m)
α: Elevation angle between base, observer, and apex of the tree (º)
β: Depression angle between the base of the tree, the observer and the horizontal axis (º)

C. When the observer is above the apex

$$h = D \times (\tan \beta - \tan \alpha)$$

Where:
h: Total Tree Height (m)
D: Horizontal distance between the observer and the tree (m)
α: Angle of depression between the horizontal axis, the observer and the base of the tree (º)
β: Angle of depression formed between the horizontal axis, the observer and the apex of the tree (º)

Wood density

Previously published wood density were used for the species studied, 0.27 gr/cm^3 was used for calo [7] and 0.62 gr/cm3 was used for chachacomo [9].

3) Data analysis
Data was processed with Microsoft Excel spreadsheets for the calculation of carbon and carbon dioxide equivalent stored in the aboveground biomass.

Calculation of biomass and carbon in aboveground biomass (AGB)

Selection of allometric equations of aboveground biomass

The use of allometric equations makes it possible to calculate the biomass of a forest species in a non-destructive way and extrapolate the results to comparable growth situations [6]. "The equations are generated from regression analyses, where the relationships between the mass (generally in dry weight) of the trees and their dimensional data (e.g. height, diameter) are studied" [6]. A pantropical allometric equation [10] was used to calculate the aboveground biomass of calo and chachacomo:

$$AGB = 0.0673 \times (\rho \times D2 \times H)^{0.976}$$

Where:
AGB: Biomasa aérea total (g)
D: Chest height diameter (cm)H: Height (cm)
ρ: Wood density (g/cm3)

Calculation of carbon stored in aboveground biomass

It was estimated based on a conversion factor, since one ton of forest biomass has approximately 0.5 tons of carbon [6].

$$1 \text{ ton biomass} \cong 0.5 \text{ ton C}$$

Carbon dioxide equivalent calculation

It was estimated from a conversion factor, since one ton of carbon contains approximately 3.67 tons of carbon dioxide [6]:

$$1 \text{ ton carbon} \cong 3.67 \text{ ton } CO_2$$

Comparison between the carbon dioxide equivalent stored in the aboveground biomass of the ZRBZ (3034-3200 m.a.s.l.) and the emissions generated by economic activity.

Publicly available emissions reports from five companies by economic activity were selected. Those that were published between 2021 and 2023 according to the list of registrants taught by the Huella de Carbono Perú [11] platform were considered. These results were averaged and a comparative graph was drawn up by economic activity, and the carbon dioxide equivalent collected in the aboveground biomass of the ZRBZ.

III. Results

A. Carbon stock

Individual tree dimensions and therefore AGB ranged within two orders of magnitude for both species. Calo AGB ranged from 3.11 to 102.44 kg per individual, while chachacomo ranged from 4.63 to 115.77 kg per individual (Fig. 5). The carbon stock ranged from 6.22 to 204.88 kg tree^{-1} and from 9.26 to 231.54 in calo and chachacomo accordingly (Fig. 6). Calo and chachacomo thus contribute to ZRBZ carbon stocks with 3.49 and 5.04 ton ha^{-1} respectively (Fig. 7). Although calo trees were larger than chachacomo in terms of height and trunk diameter, the latter stores more carbon. Overall, the total estimated carbon stored in the evaluated area within the ZRBZ is approximately 329.29 tons. (Table 1).

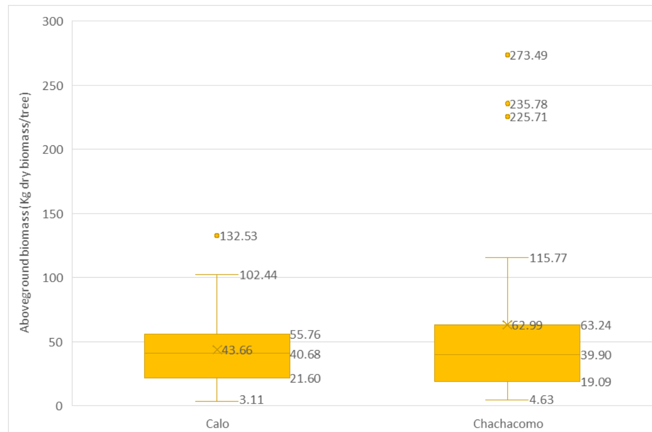

Fig. 5 Aboveground biomass per species (kg tree^{-1}).

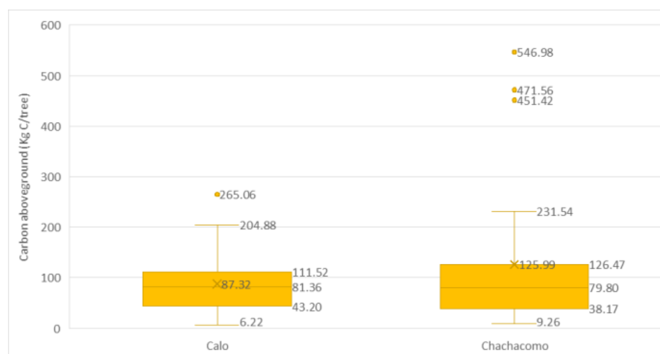

Fig. 6 Carbon stock in AGB (kg C tree^{-1}).

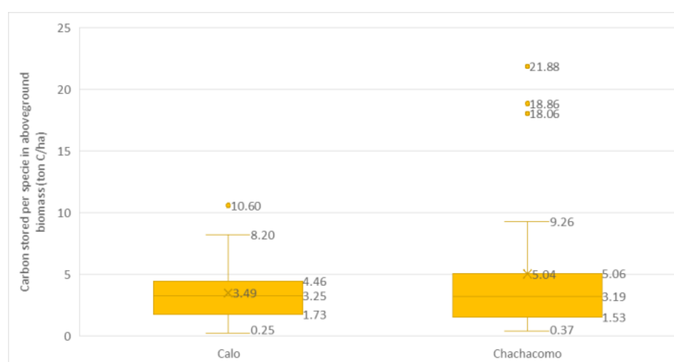

Fig. 7 Carbon stored per species in aboveground biomass (ton C ha^{-1})

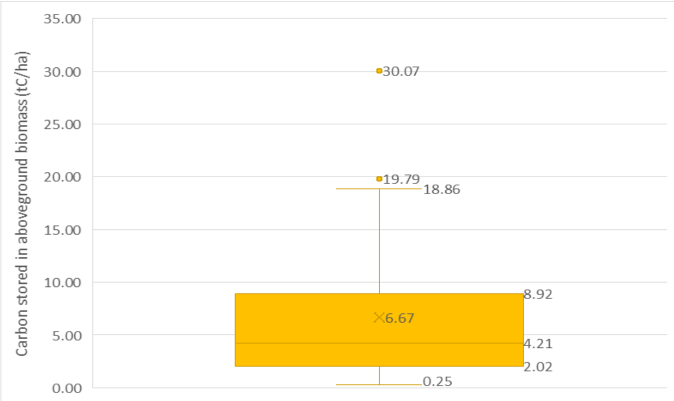

Fig. 8 Carbon stored in aboveground biomass (ton C ha^{-1})

TABLE I
DISTRIBUTION OF FOREST SPECIES ACCORDING TO DASOMETRIC MEASUREMENTS, BIOMASS AND STORED CARBON

Forest measurements	Unit	Average value		
		Forest species		
		Chachacomo	Calo	By tree
Tree height	m	6.75	7.28	7.39
DBH	m	0.35	0.55	0.42
Biomass	kg $tree^{-1}$	62.99	43.66	55.74
Stored carbon	kg $tree^{-1}$	125.99	87.32	77.64
	Ton C	248.77	172.27	329.23
	Ton C ha^{-1}	5.04	3.49	6.67

The contribution of both species to carbon stock is heterogeneous between plots, with the contribution of chachacomo was often larger (Fig. 9). Together, in CO_2 eq, the AGB of calo and chachacomo represent an estimated 1208.27 tons of CO_2 eq within the studied area of the ZRBZ. The average contribution of the calo and chachacomo AGB is 12.81 ton CO_2 eq ha^{-1} and 18.50 ton CO_2 eq ha^{-1} respectively, and 1208.33 CO_2 eq per tree (Table II).

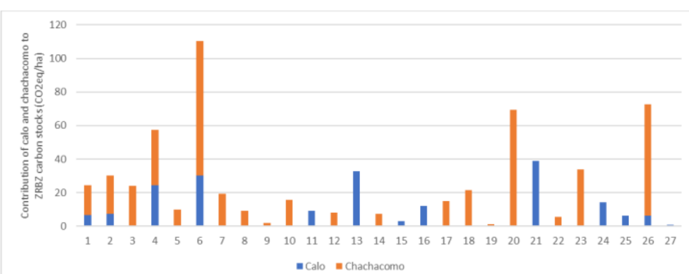

Fig. 9 Contribution of calo and chachacomo to ZRBZ carbon stocks (CO_2 eq ha^{-1})

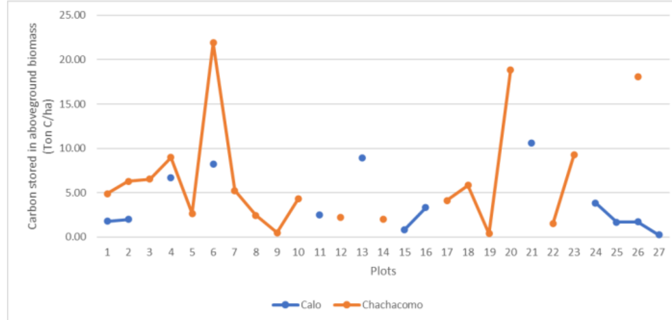

Fig. 10 Dispersion of calo and chachacomo trees per plot at ZRBZ.

TABLE II
AVERAGE CO_2 EQ REPRESENTED IN ABOVEGROUND BIOMASS BY SPECIES. (1) CARBON STORED ACROSS THE ENTIRE ALTITUDINAL RANGE EVALUATED (3034-3200 M.A.S.L) IN TERMS OF TONS OF CARBON DIOXIDE EQUIVALENT.

Carbon Reservoir Type	Unit	Forest species		
		Calo	Chachacomo	By tree
Aboveground biomass	ton CO_2 eq ha^{-1}	12.81	18.50	24.48
	ton CO_2 $eq^{(1)}$	632.30	913.16	1208.27

B. Carbon dioxide equivalent stored in aboveground biomass compared to industry emissions

The carbon accumulated by the aboveground biomass reported here could be sufficient to offset the emissions generated by organizations from the public administration and defense, including those from mandatory social security plans, administrative and support service activities , professional, scientific and technical activities, and accommodation and food services activities (Fig. 11). Figures 12 and 13 show the variability of the carbon footprint across different groups of companies by industry type, in comparison with the carbon dioxide equivalent accumulated in the biomass within the 3034–3200 m.a.s.l range.

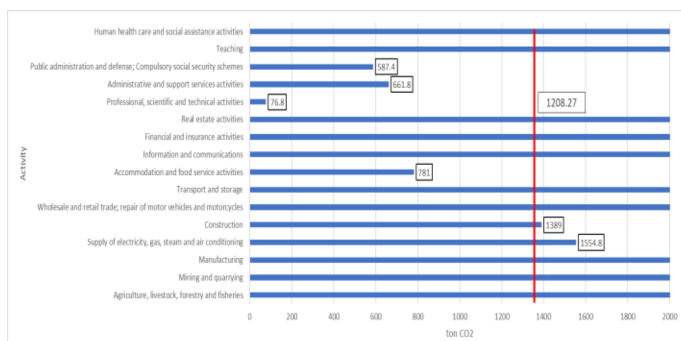

Fig. 11 Average carbon dioxide equivalent emissions by economic activity. The red line represents the our report of carbon stock at ZRBZ.

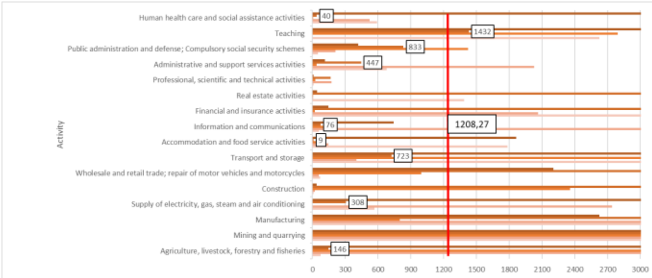

Fig. 12 Carbon dioxide equivalent emissions of Peruvian companies by economic activity compared to that stored in the aboveground biomass of the ZRBZ 3034-3200 m.a.s.l (ton CO_2 eq)

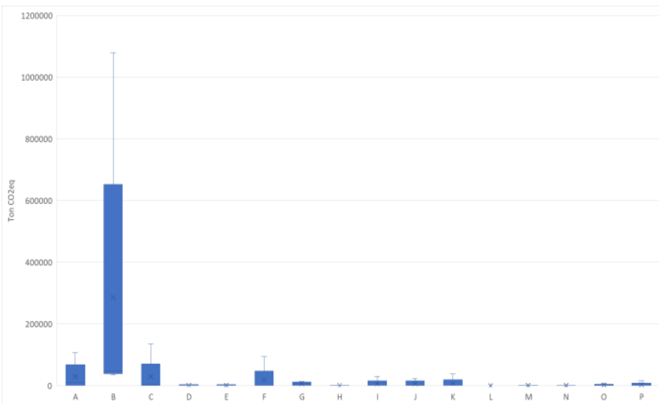

Fig. 13 Box plot of the scale of carbon dioxide equivalent emissions by economic activity (ton CO_2 eq)
(A) Agriculture, livestock, forestry and fisheries, (B) Mining and quarrying, (C) Manufacturing industries, (D) Supply of electricity, gas, steam and air conditioning, (E) Construction, (F) Wholesale and retail trade; repair of motor vehicles and motorcycles, (G) Transportation and storage, (H) Accommodation and food service activities, (I) Information and communications, (J) Financial and insurance activities, (K) Real estate activities, (L) Professional, scientific and technical activities, (M) Administrative and support services activities, (N) Public administration and defense; compulsory social security plans, (O) Education, (P) Human health care and social assistance activities.

III. Discussion

During visits to the ZRBZ, we noticed the tree cover starts at 2900 meters above sea level, which is 150 meters higher than originally described for the area more than 20 years ago (2750–3200 m.a.s.l) [12]. This indicates a historical tree cover loss in this forest. In an interview, President Betsabé Vásquez stated that the forest had been affected by overgrazing, illegal mining, and invasions, which may have been some of the causes of the observed tree cover loss.

Chachacomo and calo contribute 5.04 ton C ha^{-1} and 3.49 ton C ha^{-1}, respectively, to the estimated 6.67 ton C ha^{-1} for the range between 3034 and 3200 m.a.s.l in the ZRBZ. These carbon stocks are lower than those reported for the tropical montane forests of Río Abiseo National Park, San Martín region (lower zone 800–1100 m.a.s.l, 92.4 ton C ha^{-1}; middle zone 1900–2100 m.a.s.l, 87 ton C ha^{-1}; and upper zone 2700–2900 m.a.s.l, 7.9 ton C ha^{-1}) [14], but higher than those reported for the chachacomo forests of San Pedro de Saños (5.997 ton C ha^{-1} at 3600 m.a.s.l) and Talhuis-Pucará (4.770 ton C ha^{-1} at 3800 m.a.s.l) [13]. Forest carbon stocks at Río Abiseo National Park were estimated using the same allometric equation applied in this study. In contrast, San Pedro de Saños and Talhuis-Pucará developed their own allometric equation; however, they share the same life zone as the study area and therefore host the same forest species [13].

The carbon stored in chachacomo trees in San Pedro de Saños and Talhuis-Pucará, 8.61 and 10.48 kg per individual respectively, is lower than the 77.64 kg per individual we report here for ZRBZ (). However, the carbon stock per hectare is similar (5.997 ton C ha^{-1}) compared to that found in the ZRBZ (6.67 ton C ha^{-1}). In this regard, the difference could be explained by the higher carbon storage capacity of the forest species in the ZRBZ. Furthermore, a value of 14.66 ton C ha^{-1} has been reported for the calo tree in the ZRBZ [7], which is higher than the value found in this study (3.49 t C ha^{-1}). This difference is explained by the fact that the previous study was conducted at a lower altitudinal range (2921–2942 m.a.s.l), reinforcing the inverse relationship between altitude and aboveground biomass carbon storage in montane forests [14].

During the field survey, it was observed that between 2900 and 3000 m.a.s.l, calatillo and calo were the predominant species. Within the evaluated altitudinal range, forest species distribution was dominated by chachacomo (62%), followed by calo (approximately 38%).

At the total level of the study area (49.36 ha), an estimated value of 329.23 tons of carbon was calculated for the ZRBZ. The same estimation was made using the reference value from another study area (14.66 tons of carbon per hectare), reporting a value of 8000.695 tons of carbon [7]; however, this large difference is due to the fact that the estimated per-hectare carbon value was extrapolated to the total surface area of the ZRBZ (545.75 ha), which generates high uncertainty, as it is an ecosystem that hosts diverse plant species communities that vary along the altitudinal gradient—validated in the field and previously reported [12]. Therefore, it is reasonable that extrapolating carbon reserves from a forest region to a pasture area leads to an overestimation of the system's reserves.

However, it is important to point out that in tropical forests, altitude is not the only factor affecting carbon storage, as different elevations store relatively similar amounts of carbon. The differences that define carbon reserves are the carbon content, the amount of precipitation an area receives, the average temperature that influences plant growth, and the way in which plants store or recycle nutrients in the soil. Additionally, studies suggest the existence of trade-offs between aboveground and belowground organic carbon reserves along altitudinal gradients in tropical Andean mountain forests. Therefore, to make an accurate extrapolation, soil organic carbon reserves and the evaluated subterranean altitudinal regions must be considered [14].

The evaluated band presents an aboveground biomass equivalent to 1208.27 tons of CO_2eq, identifying within this emissions scale the public administration and defense, including those from mandatory social security plans, administrative and support service activities , professional, scientific and technical activities, and accommodation and food services activities (Fig. 11). However, as shown in Figures 12 and 13, there is significant variability in company data across different economic activities. This variability is attributed to the organizational boundary each company uses in its carbon footprint assessment, the size of the infrastructure, and the nature of the activities that make up their processes.

For example, in the economic activity “Wholesale and retail trade; repair of motor vehicles and motorcycles,” corresponding to the secondary activity, BOSCH REXROTH S.A.C. and SYNTHEC SOLUTIONS S.A.C. conducted sales and repair operations, generating footprints of 69 and 2,206 tons of CO_2 eq, respectively. The organizational boundary of the first company only included the BOSCH REXROTH office, so its carbon footprint is primarily dependent on the size of the infrastructure, energy demand, and the conditioning system, as is the case with many activities in the tertiary activity. In contrast, the second company included not only the office but also a warehouse; however, it is important to mention that in this case, the largest share of emissions came mainly from transportation.

Another aspect to consider is the process that defines their activity, as the more productive the processes are, the greater the likely carbon footprint. For example, MOTOMAQ S.A.C. reports 59 tCO_2eq, while ÓPTICAS GMO PERÚ S.A.C. reports 996 tons of CO_2eq. The former is solely dedicated to sales, while the latter involves "Importation, Manufacturing, Distribution, and Marketing," which results in a larger footprint. Nonetheless, both fall under the same economic activity.

According to the attached data, economic activities related to the primary activity (agriculture, livestock, forestry, fishing, energy, and mining) and the secondary activity (manufacturing industries and construction) tend to have high carbon footprint values. However, values are generally lower in activities corresponding to the tertiary activity (commerce, real estate, education, health, tourism, consulting, except transportation, etc.). As mentioned earlier, the process that defines their activity can alter the footprint outcome, which also applies in the tertiary activity. For instance, in tourism-related companies, the carbon footprint increases for those that include food services. The same occurs in education; for example, many universities have restaurants, such as UTP, which increases their footprint.

Infrastructure size is a factor that is clearly reflected in real estate activity. Its carbon footprint can be offset by the ZRBZ, except in the case of malls and large real estate spaces, which tend to be very large, with high energy and water demands and emissions generated from food services. The same applies to the health activity, as well as to the type of technology used, since the energy demand of the facility depends on it.

Finally, in the case of economic activities or companies that carry out their work from offices, the size of their carbon footprint is usually not that large. Their impact mainly depends on the size of the infrastructure, energy demand, and the conditioning system, which is why they are identified as the type of companies whose emissions could be neutralized by the ZRBZ.

If a complete estimate of the ZRBZ is made, considering the area of the lower altitudinal bands in which forest species are present, as observed in the field (starting at 2900 m a.s.l.), and the estimated value in the evaluated altitudinal band per hectare (6.67 tons of C/ha), then for the 2867–3034 m a.s.l. band (59.40 ha) ≈ 396.20 tons of carbon and the 3034–3200 m a.s.l. band (49.36 ha) ≈ 329.33 tons of carbon, a total of 725.53 tons of carbon ≈ 2662.69 tons of CO_2eq could be stored in aboveground biomass, not including other carbon reservoirs. Considering this projection, not only activitys operating from offices, but also the construction activity, accommodation and food service activities, and the supply of electricity, gas, steam, and air conditioning would fall within the range of emissions that could be offset by the ZRBZ.

The decrease in the proportion of aboveground biomass (AGB) and the abundance of late-successional species have been proposed as indicators of human disturbance in high Andean forests [15]. In this sense, the retreat of the forest would entail both a loss of biodiversity and a reduction in carbon stocks in aboveground biomass. While a potential barrier to implementing a commercial carbon project in this location is the cost inherent to project development, the projection of a loss of carbon stocks rather than an increase would represent an even more significant obstacle. To make a comprehensive estimate of the potential for a carbon project, it must also be considered that there is a forested area above 3200 meters above sea level as a result of reforestation efforts with calo and chachacomo trees carried out by the community of San Bartolomé from June 2022 to the present (2024).

The operating expense for the management of the area is S/76,000 per year [1]. If a forest carbon project is being considered, the associated costs must be taken into account, as well as the potential value that could be achieved through its economic valuation.

The current value of carbon credits for projects in tropical forests ranges from $2 to $5 per ton of CO_2 eq/ha [15], although by the end of 2022, it reached up to $12 [16]. Using this value as a reference and the estimated tons in the studied altitudinal band (1208.27 tons of CO_2 eq), the economic value of the carbon storage ecosystem service could amount to $14,499.24 or S/53,150.54, which would not be enough to cover the area’s management cost.

Moreover, for this estimate to be validated, it must first undergo a verification process by certifying entities (e.g., Verra). This process may take approximately 2 years and cost over 65,000 USD, not including the variable costs related to field measurements and verifications every 3 years, as well as the per-credit fee [17], as shown in Fig. 14 and Table III.

The community of San Bartolomé cannot self-finance a project of this kind, but could turn to alternative financial sources, such as public contributions to fund projects, or voluntary carbon platforms that allow small projects to scale up and sell these credits. Some options to consider include "Plan Vivo" and "Gold Standard." The former supports small-scale projects that expand land use, promote reforestation, and sustainable agriculture [18]. The latter, while slightly more complex in terms of certification, also offers the possibility to certify smaller-scale projects [19], being simpler than Verra. It is also worth noting that it has recently been endorsed by the Peruvian government [20].

Community financing and crowdfunding are also viable alternatives. These platforms can be used to raise funds for small-scale carbon projects and may include platforms like Kickstarter, Indiegogo, or others focused specifically on environmental projects. Another option is to seek financial support, technical assistance, and management tools from non-governmental organizations (NGOs) and local organizations that support conservation and low-impact carbon projects [21].

As previously mentioned, this Reserved Zone is expected to become a Private Conservation Area, which would grant it certain advantages. If that is the case, Supreme Decree No. DS 038-2001-AG states that those responsible for developing tourism and recreational activities within a Private Conservation Area are not required to pay an economic compensation to the State for the use of the natural landscape as a resource (Article 73.5). Therefore, if there were an ecotourism project approved by SERNANP and other competent authorities, the income generated would go directly to the owning community for the conservation of the area.

Additionally, it is established that revenues collected directly from visitor entrance fees to Natural Protected Areas represent the second-largest and fastest-growing source of income. However, it is also noted that the business activity, although it has had limited involvement in conservation, has yet to fully capitalize on the potential of this area, which could become a strategic ally for securing additional funding sources [22].

A financing scheme that could be applied to the ZRBZ in relation to the rural community of San Bartolomé could involve replicating the ecotourism model used by the Tirimbina Biological Reserve in Costa Rica—one of the countries with the most developed ecotourism activity. This is a private National Wildlife Refuge that protects 345 hectares of tropical rainforest. Its conservation model combines tourism, scientific research, and environmental education, which has led to the development of various environmental education programs and activities since 1999. Its main source of funding is ecotourism.

A creative process was initiated to develop what is commonly known in the tourism industry as "products"—that is, activities offered to attract both domestic and international tourists to Tirimbina. First, a tour was designed around one of its most successful income-generating products: the "Chocolate Tour." The exhibit tells the story of cacao as a traditional crop, the biology of the tree and its fruit, the associated Indigenous cultures, their rituals and ceremonies, and the process of making the delicious chocolate known worldwide. At the same time, the collection of scientific information on Tirimbina's bat communities unexpectedly attracted groups of tourists interested in learning about these fascinating mammals, which are often surrounded by negative myths. From there, a product was developed focused on continuing to collect and record data on bats—now within the context of the tourism experience. Finally, these ecotourism activities are complemented by the highly popular "Bird Tour," guided walks, and night walks. All of this is made possible by the existing infrastructure, which includes 25 rooms classified as three-star hotel accommodations, as well as a restaurant with a capacity of no more than 90 people. Additionally, the contact networks established through research have enabled exchanges with international visitors, making environmental education a fundamental part of the reserve's daily life. Another source of income over the years has been donations from companies, individuals, and NGOs. It is important to note that in the community of La Virgen de Sarapiquí, which has safeguarded this natural heritage for years, children have been taught the importance of conservation for sustainable development [23].

The Tirimbina Biological Reserve receives an average of more than 25,000 visitors per year, mostly from Europe and North America. This is enough to fund a payroll of over 30 employees, cover operational expenses, and generate a modest profit during peak tourism months, making the operation both profitable and self-sustaining as a private enterprise [23].

Other financing alternatives could include the implementation of a Payment for Ecosystem Services (PES) mechanism. However, this type of initiative needs to be promoted at the governmental level, as was the case in China with the national "Grain-for-Green" program. This program provided financial compensation to farmers to replace crops with trees on degraded lands. It represents the largest reforestation, ecological restoration, and rural development initiative in history, combining unprecedented investment, broad citizen participation, and the highest recorded level of public engagement [24].

Similarly, the community of San Bartolomé could establish a private Conservation Trust Fund to efficiently manage and allocate resources for conservation activities. For example, a specific trust fund could be created to protect the Zárate Forest, with funding sourced from a variety of contributors, including governments, private donors, and non-governmental organizations (NGOs) [25].

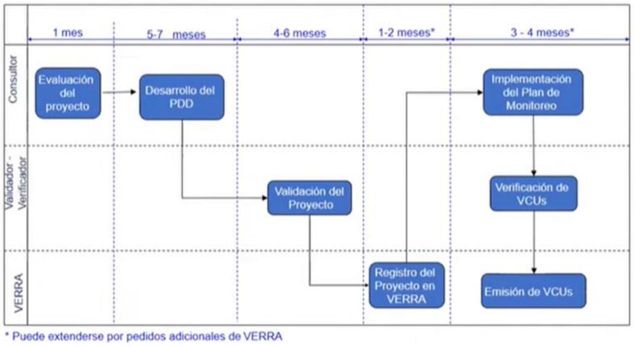

Fig. 14 Verification Carbon Unit (VCU) registration and issuance process [17].

TABLE III
CARBON CERTIFICATION COSTS

CONCEPT	USD
Consulting until registration 25 to 40 thousand Validation (VVB)	25 to 40 thousand Validation 20 to 25 thousand
Monitoring and Verification Consulting (every 3 minutes years)	10 to 20 thousand
Field measurements (every 3 years)	Variable per project
Certification standard (VERRA)	$0.15/credit Verification (every 3 years) 10 to 15 thousand

Note. From "Carbon Credits – The Road to Certification"[17].

IV. CONCLUSIONS

The carbon stocks in the aboveground biomass of the ZRBZ, within the altitudinal range of 3034-3200 m.a.s.l., are 329.23 tons of C, with chachacomo, compared to calo, being the species with the greatest potential to generate more value in relation to carbon storage. This value, equivalent to 1208.27 tons of CO_2, has the potential to offset the carbon footprint generated by companies in the lodging and food service activitys, as well as those operating in office environments. This business profile represents the market niche that could help cover conservation costs through voluntary contributions, channeled via crowdfunding mechanisms or trust funds. Additionally, it is proposed that the Reserved Zone be designated as a Private Conservation Area and that ecotourism be incorporated, based on the experience of the Tirimbina Biological Reserve in Costa Rica.

REFERENCES

[1] SERNANP, *Expediente técnico para el establecimiento de la Zona Reservada Bosque de Zárate*, 2010.

[2] Ministerio del Ambiente, *Estimación de los contenidos de carbono de la biomasa aérea en los bosques de Perú*, Informe N° 2014-17177, 2014. [En línea]. Disponible en: https://minam.gob.pe/libro_carbono.pdf

[3] R. Mires, *El Bosque de Zárate: una travesía por la Lima que no conoces*, Lima: Walter H. Wust Ediciones SAC, 2016.

[4] L. De la Cruz-Amo, G. Bañares-de-Dios, V. Cala, Í. Granzow-de la Cerda, C. I. Espinosa, A. Ledo, N. Salinas, M. J. Macía y L. Cayuela, "Trade-Offs Among Aboveground, Belowground, and Soil Organic Carbon Stocks Along Altitudinal Gradients in Andean Tropical Montane Forests," *Frontiers in Plant Science*, vol. 11, p. 106, 2020. [En línea]. Disponible en: https://doi.org/10.3389/fpls.2020.00106

[5] PerúRetail, "No es solo el plástico. Ahora la tendencia empresarial es el carbono neutral," *PerúRetail*, 6 de noviembre de 2019. [En línea]. Disponible en: https://www.peru-retail.com/sostenibilidad-tendencia-empresarial-es-el-carbono-neutral/

[6] World Agroforestry Centre, *Guía para la determinación de carbono en pequeñas propiedades rurales*, Documento Técnico N°11, 2009. [En línea]. Disponible en: http://www.aecidcf.org.co/Ponencias/2016/septiembre/MI120916-1/Ref.7.Guia_Carbono.pdf

[7] F. Gonzales, *Acumulación de carbono en la biomasa aérea de la planta (Oreopanax oroyanus) del Bosque de Zarate – Huarochirí para los servicios ecosistémicos 2017*, Tesis de licenciatura, Universidad César Vallejo, 2017. [En línea]. Disponible en: https://repositorio.ucv.edu.pe/bitstream/handle/20.500.12692/10873/Gonzales_MF%20JZ.pdf?sequence=1&isAllowed=y

[8] J. Flores Mendoza, "Determinación de altura de árbol y copa," 2023. [En línea]. Disponible en: https://drive.google.com/file/d/1DE_Iivn8852UVq6_S8DF5kbOgjwQbN5E/view?usp=sharing

[9] B. B. Cruz y C. Simon, *Poder calorífico de la madera de Polylepis racemosa R & P. y Schinus molle L. de dos procedencias*, Tesis de licenciatura, Universidad Nacional del Centro del Perú, 2019. [En línea]. Disponible en: https://repositorio.uncp.edu.pe/handle/20.500.12894/5154

[10] J. Chave, M. Réjou-Méchain, A. Búrquez, E. Chidumayo, M. S. Colgan, W. B. C. Delitti, A. Duque, T. Eid, P. M. Fearnside, R. C. Goodman, M. Henry, A. Martínez-Yrízar, W. A. Mugasha, H. C. Muller-Landau, M. Mencuccini, B. W. Nelson, A. Ngomanda, E. M. Nogueira, E. Ortiz-Malavassi, … G. Vieilledent, "Improved allometric models to estimate the aboveground biomass of tropical trees," *Global Change Biology*, vol. 20, no. 10, pp. 3177–3190, 2014. [En línea]. Disponible en: https://doi.org/10.1111/gcb.12629

[11] Ministerio del Ambiente, "Listado de inscritos. Huella de Carbono Perú," [En línea]. Disponible en: https://repositorio.uncp.edu.pe/handle/20.500.12894/5154

[12] I. Franke y N. Valencia, *Zárate: Una Unidad de Conservación*, Museo de Historia Natural, 1984. [En línea]. Disponible en: https://issuu.com/ifrankej/docs/z_rate_una_unidad_de_conservaci_n

[13] C. Gurmendi y W. Orihuela, *Valoración económica de la reserva de carbono de Escallonia resinosa (Ruiz & Pav.) Pers. en San Pedro de Saños y Pucará*, Tesis de licenciatura, Universidad Nacional del Centro del Perú, 2019. [En línea]. Disponible en: https://repositorio.uncp.edu.pe/bitstream/handle/20.500.12894/5320/T010_72371775_T.pdf?sequence=1&isAllowed=y

[14] L. De la Cruz-Amo, G. Bañares-de-Dios, V. Cala, Í. Granzow-de la Cerda, C. I. Espinosa, A. Ledo, N. Salinas, M. J. Macía y L. Cayuela, "Trade-Offs Among Aboveground, Belowground, and Soil Organic Carbon Stocks Along Altitudinal Gradients in Andean Tropical Montane Forests," *Frontiers in Plant Science*, vol. 11, p. 106, 2020. [En línea]. Disponible en: https://doi.org/10.3389/fpls.2020.00106

[15] M. Calbi, F. Fajardo-Gutiérrez, J. M. Posada, R. Lücking, G. Brokamp, and T. Borsch, "Seeing the wood despite the trees: Exploring human disturbance impact on plant diversity, community structure, and standing biomass in fragmented high Andean forests," *Ecology and Evolution*, vol. 11, no. 5, pp. 2110–2172, Feb. 2021, doi: 10.1002/ece3.7182.

[16] Regen Market, "Projects," 2024. [En línea]. Disponible en: https://app.regen.network/projects/1

[17] Verra, "Bonos de carbono - Desarrollo e implementación de proyectos," *YouTube*, Video, 2022. [En línea]. Disponible en: https://www.youtube.com/watch?v=EeHTOFWhb3o

[18] Plan Vivo Foundation – for nature, climate and communities," *Plan Vivo Foundation*. https://www.planvivo.org/

[19] Gold Standard," *Gold Standard*, Mar. 25, 2025. https://www.goldstandard.org/

[20] E. Mandujano and E. Mandujano, "Mercado de carbono: Perú inicia acreditación de estándares internacionales para la reducción de emisiones," *Caretas*, Feb. 12, 2025. https://caretas.pe/politica/mercado-de-carbono-

peru-inicia-acreditacion-de-estandares-internacionales-para-la-reduccion-de-emisiones/
[21]Crowdfunding comunitario Crowdfunding para el desarrollo comunitario marcando la diferencia juntos - FasterCapital," *FasterCapital*. https://fastercapital.com/es/contenido/Crowdfunding-comunitario--Crowdfunding-para-el-desarrollo-comunitario--marcando-la-diferencia-juntos.html#:~:text=El%20crowdfunding%20comunitario%20es%20una%20forma%20de%20crowdfunding,interesados,%20para%20implementar%20sus%20propias%20soluciones%20e%20ideas.
[22]Sociedad Peruana de Derecho Ambiental, *Opciones innovadoras de financiamiento de la conservación*, Boletín N° 25, 10 de agosto de 2017. [En línea]. Disponible en: https://www.actualidadambiental.pe/opciones-innovadoras-de-financiamiento-de-la-conservacion-spda/
[23]Vista de La Reserva Biológica Tirimbina, en Costa Rica: modelo en la conservación del bosque lluvioso tropical, la investigación científica, el ecoturismo y la educación ambiental. https://www.revistas.una.ac.cr/index.php/ambientales/article/view/17165/25552
[24]C. O. Delang and Z. Yuan, *China's Grain for Green program*. 2014. doi: 10.1007/978-3-319-11505-4.
[25]Albán, M. (2008). Fondos fiduciarios como herramienta de apoyo a la conservación de las áreas protegidas. *LetrasVerdes*, *3*. https://revistas.flacsoandes.edu.ec/letrasverdes/article/view/832/800