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Original article

Floristic structure and carbon stored in the biomass of three strategic ecosystems of the Colombian Pacific

Estructura florística y carbono almacenado en la biomasa de tres ecosistemas estratégicos del pacifico colombiano

Estrutura florística e carbono armazenado na biomassa de três ecossistemas estratégicos do Pacífico colombiano

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ABSTRACT

Despite the wide diversity suggested for the Colombian Pacific, to date little has been documented about its flooded forests, which have not allowed management strategies to be undertaken according to the characteristics of the sites. In order to contribute to the knowledge of these ecosystems, the floristic structure was characterized and the carbon stored in the total biomass of three flooded forests (Mangrove, Sajal and Guandal) was estimated. Ten plots of 0.1 ha were established. Individuals with diameter ($D_{1.30}$) > 5 cm and height in meters were measured. Aerial biomass was calculated using allometric equations developed for this type of ecosystem. The Importance Value Index was determined. A Principal Component Analysis was performed to compare the composition and structure of the three ecosystems. Data on number of individuals, basal area, biomass and carbon were compared using the Kruskal-Wallis non-parametric analysis of variance. A total of 1678 individuals were recorded, grouped into 92 species and 38 botanical families. On average, 29.5 MgC ha^{-1} were found stored in total biomass (below and above ground), distributed in Mangrove 37.7 MgC ha^{-1}, Sajal 28.3 MgC ha^{-1} and Guandal 22.4 MgC ha^{-1}. Mangrove presents a greater number of individuals than Guandal and Sajal. Two groups were found: the first dominated by one species and the second with more than three dominant species.

Keywords: Biomass; Flooded forests; Biogeographic Chocó; Mangrove; Colombian Pacific.

RESUMEN

A pesar de la amplia diversidad sugerida para el pacífico colombiano, a la fecha es poco lo que se ha documentado sobre sus bosques inundables, lo que no ha permitido que se emprendan estrategias de manejo acorde a las características propias de los sitios. Para contribuir al conocimiento de estos ecosistemas, se caracterizó la estructura florística y se estimó el carbono almacenado en la biomasa total de tres bosques inundables (Manglar, Sajal y Guandal). Se establecieron diez parcelas de 0,1 ha. Se midieron los individuos con diámetro ($D_{1.30}$) > cinco cm y la altura en metros. El cálculo de la biomasa aérea se efectuó empleando ecuaciones alométricas desarrolladas para este tipo de ecosistema. Se determinó el Índice de Valor de Importancia. Se realizó un análisis de Componentes Principales para comparar la composición y estructura de los tres ecosistemas. Se compararon los datos de número de individuos, área basal, biomasa y carbono a través del análisis de varianza no paramétrico Kruskal-Wallis. Se registraron en total 1678 individuos, agrupados en 92 especies y 38 familias botánicas. En promedio se encontraron 29,5 MgC ha^{-1} almacenados en la biomasa total (subterránea y aérea, distribuidos en Manglar-37,7 MgC ha^{-1}, Sajal- 28,3 MgC ha^{-1} y Guandal- 22,4 MgC ha^{-1}. El Manglar presenta mayor número de individuos que el Guandal y Sajal. Se encontraron dos grupos: el primero dominado por una especie y el segundo con más de tres especies dominantes.

Palabras clave: Biomasa; Bosques inundables; Chocó Biogeográfico; Manglar; Pacifico colombiano.

INTRODUCTION

The Colombian Pacific coast included in the biogeographic Chocó is recognized for its floristic attributes and its wide biological diversity (Klínger 2011, Álvarez *et al.,* 2016; Mena-Mosquera *et al.,* 2020; Torres-Torres *et al.,* 2022), due to its geographic extension, ecological complexity and high amount of endemism. These characteristics have led the region to be considered a conservation *hotspot* (Myers *et al.,* 2000; Galeano 2001; Quinto and Moreno 2014; Álvarez *et al.,* 2016).

Regional-scale studies have described the main floristic characteristics of the tropical rainforest and humid ecosystems of the Colombian Chocó. These investigations have contributed to the explanation of structural and diversity changes through factors such as forest age (Torres-Torres *et al.,* 2016), precipitation (Galeano *et al.,* 1998; Galeano 2001; Quinto and Moreno 2016) and edaphic conditions of the area (Quinto and Moreno, 2014). On the other hand, the carbon storage capacity of these ecosystems has been investigated (Torres-Torres *et al.,* 2017) and the need to carry out this type of studies for community conservation initiatives has been highlighted (Álvarez *et al.,* 2016; Mena-Mosquera *et al.,* 2020).

Despite advances in the knowledge of floristic attributes and on the carbon storage capacity of the low altitude tropical rainforests of the Colombian Pacific coast, to date little has been documented on the variability in composition, structure, diversity and carbon stored in the biomass of the vegetation of the Mangrove, Sajal and Guandal ecosystems of this strategic region of the world, which has not allowed management strategies to be undertaken according to the characteristics of the sites (Álvarez *et al.,* 2016).

In order to contribute to the understanding of the composition and floristic diversity of coastal forests of Bajo Baudó in the Colombian Pacific and the amount of carbon stored in the biomass of woody vegetation of three strategic ecosystems, this research was carried out with the objective of evaluating the structural differences and carbon content of the Mangrove, Sajal and Guandal ecosystems in the municipality of Bajo Baudó, Chocó, Colombia.

MATERIALS AND METHODS

Study area

This research was conducted in natural forests of the Sivirú Community Council in the municipality of Bajo Baudó, Chocó. Geographically it is located between the coordinates 4°57' North latitude and 77°22' West longitude, with an average temperature of 28°C. The specific sampling sites were: Estero Playa Nueva, Rio Sivirú, Rio Dotenedo, Estero las Contras, Estero el Coco, Estero Caimán, Estero el Secadero and Estero el Guamo (Figure 1).

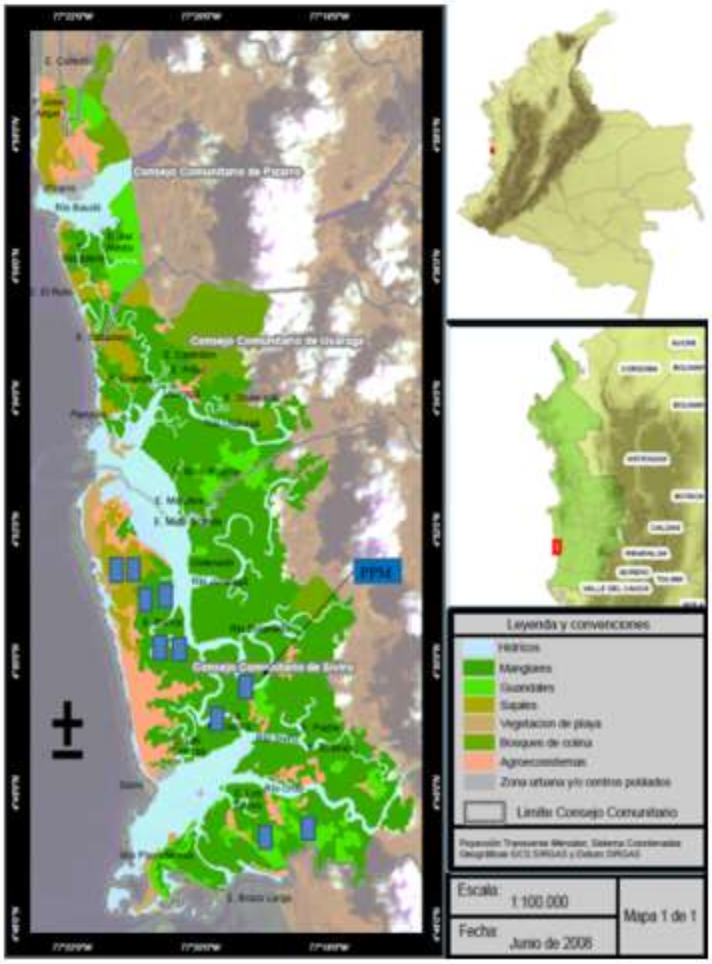

Figure 1. - Location of the sampling units established in Mangrove, Sajal and Guandal ecosystems of Bajo Baudó, Colombian Pacific

Sampling units

Ten 20 x 50 m (0.1 ha) plots were established, two in the Sajal ecosystem, two in the Guandal ecosystem and six in the Mangrove ecosystem (Álvarez *et al.*, 2016; Torres-Torres *et al.*, 2022). All species with diameter at 1.30 m from the ground ($D_{1.30}$) ≥ 5 cm were considered. All individuals were measured for DBH in centimeters (cm) with a diametric tape and height in meters (m) with a 15 m long graduated wooden stick (Figueredo *et al.*, 2017).

Botanical identification

All individuals were identified in the field, indicating the species, genus and/or botanical family. In the case of recorded species whose identification was unknown or doubtful, three botanical samples were collected for plants without flowers and fruits and five for those that did contain these organs. Each sample was annotated with its respective collection number (Torres-Torres *et al.*, 2016; Mena-Mosquera *et al.*, 2020). The botanical samples were transported to the herbarium of the Universidad Tecnológica del

Chocó "Diego Luis Córdoba", Quibdó, Colombia, where they were compared with the existing material and identified using the keys of Gentry (1993). After this, the validity of the scientific name and family were verified in Colombia (Universidad Nacional de Colombia) (http://www.biovirtual.unal.edu.co/ICN/), New York Botanical Garden (https://sciweb.nybg.org/science2/VirtualHerbarium2.asp.html), Trópicos (https://www.tropicos.org/home) and The International Plant Names Index (https://www.ipni.org/).

Biomass and carbon estimation

For the calculation of aboveground biomass, wood density values were assigned to the species recorded in the census. This value was extracted from the Global Wood Density Database (GWDB) (Zanne *et al.,* 2009), which contains information on 2004 species from tropical America. For common species between the inventories of the present study and the BGDM, the Dm value was assigned at the specific level; for uncommon species, the average Dm at the genus level was used, and finally for genera not recorded in the BGDM, the average Dm at the family level was used (Álvarez *et al.,* 2016; Torres-Torres *et al.,* 2017). Finally, biomass was estimated using the equation of Álvarez *et al.,* (2012) developed for tropical rainforest ecosystems (Equation 1).

$$\text{Biomasa} = \exp\left(-2{,}857 + 2{,}081 * \ln D + 0{,}587 * \ln Al + 0{,}453 * \ln Dm\right) \quad (1)$$

Where:

D = Diameter;
Al = Total height;
Dm = Density of wood.

Statistical analysis of data

The basal area (AB) was calculated with the data obtained (Torres-Torres *et al.,* 2022). In addition, the methodology of Lozada (2010) was followed to determine absolute (Aa) and relative (Ar) abundances, absolute (Fa) and relative (Fr) frequencies, and absolute (Da) and relative (Dr) dominances. The Importance Value Index (IVI) was determined, which is the arithmetic sum of the values of Ar, Fr and Dr (Curtis and McIntosh 1951, Figueredo *et al.,* 2017). A Principal Component Analysis (PCA) was performed to compare the composition of the three ecosystems (beta b diversity) and identify sites that shared a combination of structural characteristics, number of individuals/plot, number of species/plot and basal area/plot (Torres-Torres *et al.,* 2022).

Data on number of individuals, basal area, biomass and carbon were compared using the Kruskal-Wallis (K-W) nonparametric analysis of variance and a significant difference multiple range test (LSD). The analyses were performed with PAST software version 3.1 (Hammer *et al.,* 2001).

RESULTS

Floristic structure*.* A total of 1678 individuals were recorded, grouped into 92 species and 38 botanical families. The highest abundance was found in the Guandal ecosystem, which is statistically different from Mangrove and Sajal (Figure 2).

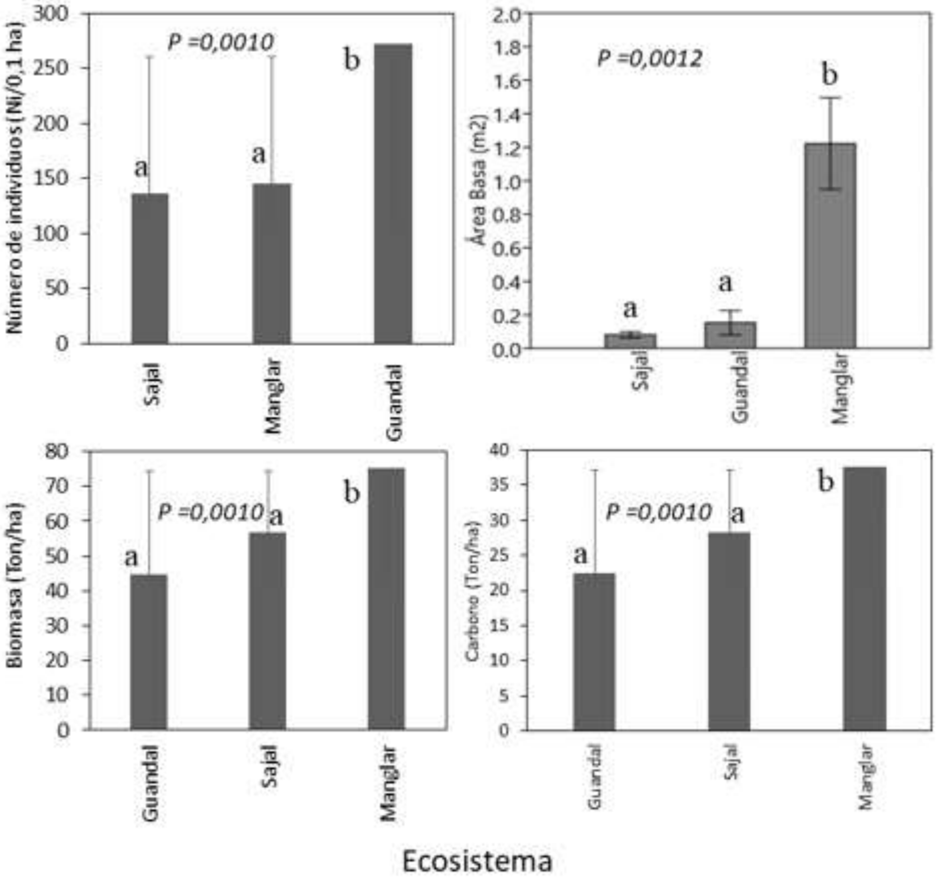

Figure 2.- Kruskal-Wallis analysis with 95 % confidence to compare structure variables in three strategic ecosystems of the Colombian Pacific
Means with a common letter are not significantly different (*P* < 0.05)

On average, 272 individuals 0.1 ha^{-1} were found in the Guandal ecosystem, 145 individuals 0.1 ha^{-1} in the Mangrove and 136 individuals 0.1 ha^{-1} in Sajal (Figure 2).

The floristic information found in the Mangrove and Guandal ecosystems suggests a tendency towards heterogeneity. For the first ecosystem, *Rhizophora racemosa* G. Mey. (IVI= 63.93) and *Pelliciera rhizophorae* Planch. & Triana. (IVI= 60.95) as the most abundant; while for the second one, *Euterpe oleracea* Mart. (IVI= 14.48) and *Carapa guianensis* Aubl. (IVI= 13.62) in the Guandal. In the Sajal, on the other hand, a homogeneous ecosystem dominated by *Campnosperma panamensis* Standl. (known locally as Sajo - IVI=58.29). In the Sajal there were also species with mature individuals, which explains the high dominance of some floristic groups (Figure 3).

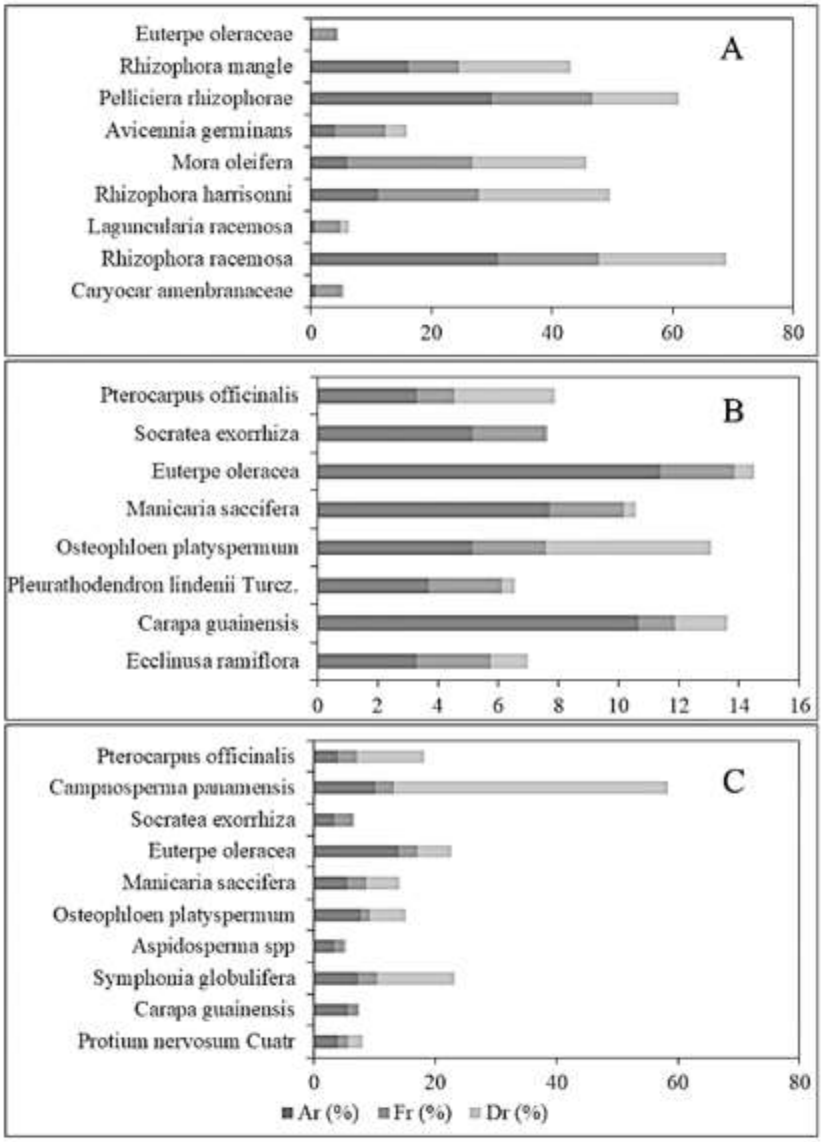

Figure 3. - Importance Value Index - IVI for the dominant species of the Mangrove (A), Guandal (B) and Sajal (C) ecosystems of Bajo Baudó, Colombian Pacific

Principal component analysis (PCA) explains 71 % of the structural variability of the ecosystems studied (Figure 4). Of this total, component 2, with 38 %, separates the 0.1 ha plots of the Sajal ecosystem from the rest of the established plots, with the lowest basal area found at this site. A similar but less important effect is observed between the Mangrove and Guandal, highlighting a similarity in the number of individuals, species and families (Figure 4).

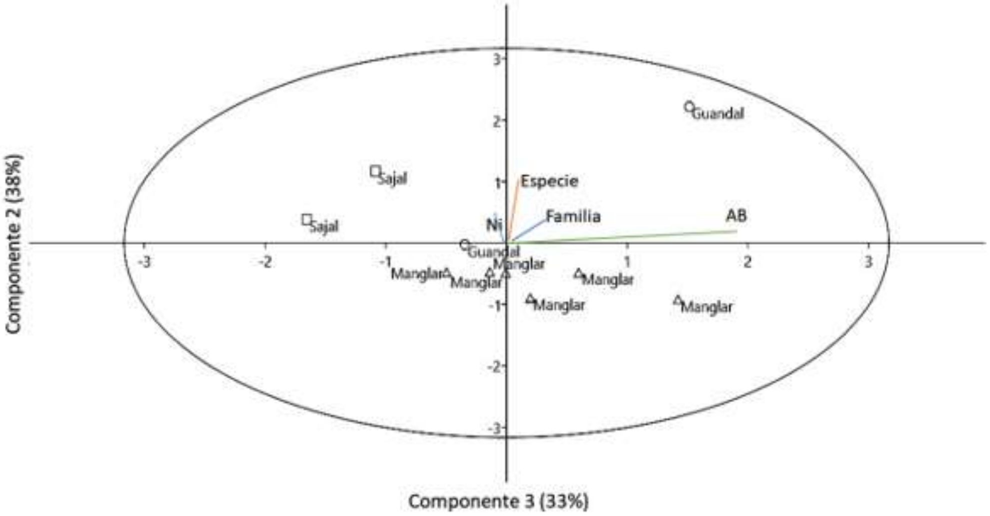

Figure 4. - Principal Component Analysis PCA for the identification of structural types of three strategic ecosystems of Bajo Baudó, Colombian Pacific

AB: Basal Area, Ni: Number of individuals

Carbon stored in total biomass. An average carbon of 29.5 MgC ha^{-1} was found for the three ecosystems. Mangrove forests presented a total carbon (mean ± *SD*) of 37.7 ± 0.54 MgC ha^{-1}, followed by Sajal with 28.3 ± 1.04 MgC ha $^{-1}$ and Guandal with 22.4 ± 0.78 MgC ha^{-1} (Table 1). The biomass and carbon content obtained in the Mangrove is different from that obtained in the other two ecosystems (Figure 2).

Table 1. - Carbon stored in the aboveground and belowground biomass of three strategic ecosystems of the Bajo Baudó, Colombian Pacific

Ecosystem	Number of Individuals	Carbon		
		Subway (Mg ha^{-1})	Aerial (Mg ha^{-1})	Total Carbon (Mg ha^{-1})
Sajal	862 ± 85,96	6,65 ± 1,01	21,6 ± 1,32	28,3 ± 1,04
Mangrove	554 ± 6,23	6,57 ± 0,98	30,9 ± 1,64	37,7 ± 0,54
Guandal	272 ± 15,22	4,77 ± 0,72	24,4 ± 1,23	22,4 ± 0,78
half		6	25,6	29,5

A similarity was observed in the biomass and carbon content of the Sajal and Guandal ecosystems (Figure 2). On the other hand, subway carbon found is similar in the three sites sampled, while for the carbon stored in the aerial biomass there were differences (*P* = 0.0010).

DISCUSSION

Floristic structure. The results of this research (92 species in 1 ha) corroborate that Chocó is one of the richest regions in plant species (Galeano 2001), these results being superior to those reported in studies conducted for this region (Quinto and Moreno 2014; TorresTorres *et al.,* 2016; Álvarez *et al.,* 2016; Mena-Mosquera *et al.*, 2020).

For the structural variables studied, better responses were found for the Mangrove and Guandal ecosystems, which contrasts with the theory that ecosystems that are not in flood zones have a greater number of individuals and abundance of species, due to the fact that in these environments there is greater water drainage and a microclimate is created for the development of a variety of species (Duivenvoorden 1996; Grauel, 2004; Álvarez *et al.,* 2016).

The Sajal ecosystem presents a marked homogeneity, characterized by the predominance of one species (*C. panamensis*), the presence of few species and with mature individuals that are adapted to the swampy environment. This result coincides with that documented by Álvarez *et al.,* (2016), who found these same characteristics in flooded ecosystems of Bajo Calima, on the Colombian Pacific coast.

The differences observed in the PCA analysis (Figure 4) can be explained by the flooding characteristics of the Sajal ecosystem, which determines the development of the dominant populations of sajo (*C. panamensis*), which is defined by Gentry (1993) as a riparian swamp tree, endemic to the biogeographic Chocó and also adapted to the environment offered by this strategic ecosystem (Del Valle 2000). In terms of the number of individuals and basal area, this forest is similar to that suggested for the delta of the Patía and San Juan rivers on the Colombian Pacific coast, but different from the characteristics described by Del Valle (1996) in the Guandal ecosystems of the Patía river in the Colombian Pacific.

Similarly, what is presented in Figure 4, suggests a structural difference of the Saljal with respect to the Mangrove and Guandal, which may be related to the lower level of salinity presented by this ecosystem (Herrera *et al.,* 2016; Agraz-Hernández *et al.,* 2020), which leads to the need to consider this variable in future research.

Carbon stored in the total biomass*.* The total carbon obtained for the three ecosystems (Guandal = 22.4 Mg C ha^{-1}, Sajal = 28.3 Mg C^{-1} ha and Mangrove = 37.7 Mg C ha^{-1}), is in the range suggested for this type of ecosystem (Clark *et al.,* 2001). However, the average carbon for the three sites analyzed (29.5 Mg C ha^{-1}) is higher than the value reported by Luyssaert *et al.,* (2007) (17.28 Mg C ha^{-1}) for 29 tropical moist and flooded forests worldwide.

The mangrove contains more carbon stored in biomass than the Sajal and Guandal (Table 1). This result may be related to structural differences in the sampled areas, especially the number of individuals present per site (Mena-Mosquera *et al.,* 2020). In this regard, Álvarez *et al.,* (2012) and Fauset *et al.* (2015) have indicated that in natural ecosystems, the more individuals there are, the greater the carbon contained in the ecosystem, which tends to increase as the diameter or age of the individuals increases (Torres-Torres *et al.,* 2017).

Malhi *et al.,* (2009) and Aragão *et al.,* (2009) have suggested that the opening of forest clearings by natural or anthropogenic actions favors the significant growth of some trees, which favors the storage and fixation of carbon in strategic ecosystems. The latter may also explain the biomass and carbon content of the Mangrove ecosystem, in which it was observed that despite containing fewer individuals than the Sajal, it contains more carbon. From this it can be inferred that diversity and site conditions influence carbon storage and fixation in the sites sampled (Quinto and Moreno 2017).

Similarly, the result of carbon stored in the mangrove ecosystem is in the range suggested for mangroves in Asia (Kauffman *et al.,* 2013) and below that documented for the Americas (Bernal and Mitsch, 2008; Valdés-Velarde *et al.,* 2011; Marín-Muñiz *et al.,* 2014). These differences may be related to the environmental conditions of the sites (De la Peña *et al.,* 2010).

CONCLUSIONS

The Guandal contains a greater number of individuals than the Mangrove and Sajal. At the floristic level, these ecosystems show a tendency towards homogeneity, where there are 1 to 4 dominant species, which generally contain a large number of mature individuals. Similarly, two structural groups are identified in the study area: the first is Sajal, which are an ecosystem dominated by Sajo (*C. panamensis*) and the second is made up of Mangrove and Guandal, where there is no clearly dominant species. Likewise, it is evident that the ecosystems studied by means of their carbon storage figures make an important contribution to the mitigation and/or adaptation of global climate change; therefore, they provide the opportunity to implement projects that can contribute to the reduction of deforestation and changes in land use. In this way, the territories where the research was carried out could receive economic and environmental benefits for their conservation.

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The authors have participated in the writing of the work and analysis of the documents.