Influence of soil salinity on the structural attributes and aboveground biomass carbon in a mangrove community of Mallorquin swamp in Barranquilla, Colombia

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(1) Title and Author Information

Influence of soil salinity on the structural attributes and aboveground biomass carbon in a mangrove community of Mallorquin swamp in Barranquilla, Colombia

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(2) Abstract

Recent studies suggest that mangrove forests have an exceptional capacity of capturing and storing carbon. However, the relationship between this ecosystem service and environmental factors is less studied. Here, we evaluate how environmental conditions influence tree community composition and carbon storage in Mallorquin swamp, an urban mangrove ecosystem in Barranquilla, Colombia. We measured mangrove tree community composition, vegetation structure, soil pH and salinity in 18 circular plots located in areas with Low, Medium, and High salinity. Using published allometric equations and wood density database, we estimated total aboveground biomass. Our results show significant soil salinity differences among the sampling areas, especially during the dry season. Nonetheless, we found small differences in soil pH across stations regardless of the season. *Avicennia germinans* was mostly associated with Low salinity areas, *Laguncularia racemosa* with Medium salinity areas, and *Rhizophora mangle* in High salinity areas. Observed differences in tree height, abundance, and vertical structure were noteworthy, with the Low salinity area hosting significantly taller and bigger trees and a larger carbon stock. Carbon stock estimates were 4098.6 Mg C for Low, 104.6 Mg C for Medium, and 1761 Mg C for High salinity areas. These findings highlight the significance of local environmental factors in mangrove conservation efforts, particularly in urban areas like Barranquilla; contributing to our understanding of the relationship between mangrove ecosystems and carbon cycling; emphasizing the need for targeted conservation efforts to protect these vital coastal habitats.

Keywords Mangrove, aboveground biomass, carbon, soil salinity, Mallorquin swamp, climate change.

(3) Introduction

Mangroves are widely recognized as the main carbon sinks among tropical forests (Donato et al 2011; Kauffman et al 2013), contributing to climate change mitigation (Murdiyarso et al 2015; Kauffman et al 2020; Gomes et al 2021). Despite representing only 0.81% of the world's tropical forests (Spalding and Leal 2021; Monga et al 2022), mangroves store up to

five times more carbon per hectare than any terrestrial forest (Donato et al. 2011). However, knowledge about carbon capture and storage in this type of ecosystem is still scarce in some countries in Africa, South America, and Southeast Asia (Fourqurean et al. 2014).

Abiotic factors, such as hydroperiod and topography, have an impact on mangrove species composition and richness (Travieso-Bello et al 2005; Flores-Verdugo et al 2007). These abiotic parameters (among others) contribute to the physical and chemical properties such as salinity and soil nutrient availability mediated by pH (Flores-Verdugo et al 2007; Alsumaiti and Shahid, 2018), which affect species' ability to photosynthesize and absorb carbon dioxide from the atmosphere (Parida and Das 2005; Sitoe et al 2014; Rodríguez-Rodríguez et al 2018; Agraz-Hernández et al 2020). Although it is well recognized that large-diameter trees contribute to aboveground biomass (AGB) stocks, salinity have a considerable negative direct impact on AGB stocks; as salinity levels increase above 25 psu, the presence of large-diameter trees and their contribution to AGB stocks may be compromised (Ahmed et al. 2023). Furthermore, areas with moderate or low salinity may support a greater diversity of species adapted to those conditions (Boto et al. 1984), while high salinity zones exhibit lower diversity and complexity (Joshi and Ghose 2014). These findings demonstrate that both salinity levels and the predominance of specific tree species impact the distribution of AGB stocks and the species diversity in mangrove ecosystems.

There are few quantitative estimates or studies of carbon storage in mangroves along the Caribbean coast of Colombia, and none in the department of Atlántico (Blanco-Libreros et al 2015; Monsalve and Ramírez 2015; Yepes et al 2016; Bolivar et al 2018; Perdomo-Trujillo 2020). Along the Caribbean coast of Colombia, abiotic factors known to influence mangrove forests are highly variable. For example, closer to the mouth of large rivers such as the Magdalena, water salinity is low and coastal erosion is high. This lack of information makes it difficult to obtain large-scale carbon data, which would support national initiatives for mitigating climate change (Bolivar et al. 2018).

The Mallorquin swamp is one of the places in Colombia with the largest extension of urban mangrove forests, located off the coast of Barranquilla, the largest city in the Caribbean region of Colombia. Abiotic conditions are highly variable due to the construction of the "Tajamar" training wall between 1922 and 1935. This construction significantly altered the hydrodynamics of the estuary and Magdalena River delta, leading to noticeable changes in the morphology of the coastline, and a sustained loss of approximately 650 hectares of wetlands to the west of Tajamar (Fuentes Delgado 2022; Torres-Marchena et al. 2023). Currently, its mangrove forests are composed mainly of four species: *Avicennia germinans*, *Rhizophora mangle*, *Laguncularia racemosa*, and *Conocarpus erectus* (INVEMAR 2005*;* Garcés-Ordóñez 2016).

Over 20,300 inhabitants live around the Mallorquin swamp. Illegal housing developments with inadequate access to healthcare, education, and employment opportunities fuel the population growth in this area (Pineda et al. 2023). The mangrove ecosystem in the area is severely degraded, primarily because of human activities such wastewater discharge, deforestation, illegal land occupations, and solid waste disposal (Berrocal et al. 2018). There

have been vast changes in water flux into the swamp that potentially have altered its pH and salinity, among other abiotic factors. For example, the isolation of the Magdalena River to improve its navigability from the swamp, has significantly reduced the fluxes of sediment and freshwater to the mangrove ecosystem. As a result, after the Tajamar was built, these fluxes that had formerly enriched the delta and the "Mallorquin swamp" lagoon system to the west, were predominantly shifted offshore (Restrepo & López 2008; Torres-Marchena et al 2023).

Previous studies in the area have focused on studying the mangrove forest composition and ecosystem quality. According to INVEMAR (2005), Mallorquin is characterized by high salinity and prolonged droughts, which have led to the near disappearance of *R. mangle*. In its place, more resilient species like *A. germinans* and *L. racemosa* have increased in number. Benavides (2019) highlighted the environmental concerns of the Mallorquin swamp, including zones with reduced oxygen levels and a substantial load of organic matter and fecal coliforms. These issues have led to detrimental effects on aquatic life development. This is further supported by Castro-Rodríguez et al (2018) findings, which demonstrated that mangrove plants play a crucial role in altering sediment chemistry and distribution patterns of key variables like carbon, nitrogen, and sulfur. These changes may have implications for the overall health of the ecosystem. Moreover, Universidad del Norte (2005) discovered the presence of heavy metals like cadmium, chromium, and lead in the swamp, potentially associated with the 'Las Flores' landfill, which operated from approximately 1970 to 1990 (Navarrete 2022). The accumulation of these pollutants adds to the already complex challenges faced by the Mallorquin ecosystem. These studies collectively shed light on the multifaceted nature of the swamp's environmental issues and emphasize the need for research that addresses how certain physicochemical parameters influence the mangrove community of this location.

It is recognized that anthropogenic activities have a direct impact on soil quality, which directly affects the structure, productivity, and distribution of mangrove trees (Alsumaiti and Shahid 2018). To date, no studies have examined the influence of physicochemical parameters of soil, such salinity and pH, on the structural attributes and the AGB of this mangrove community in this area. Our study aims to address this knowledge gap by examining how soil abiotic variables impact the diversity, structural characteristics, and AGB of the mangrove forests within the Mallorquin swamp in Barranquilla, Colombia.

Given Mallorquin's disturbance history, we expect to observe differences in the composition and structure of mangrove forests that result in differences in carbon content of AGB across the swampland. Specifically, we expect that the area closer to freshwater influx such as the Magdalena River will be composed of taller and bigger trees that store the largest amount of carbon. In areas in which there is higher influence of salt water or water influx has been decreased, we expect a less complex mangrove forest with a lower carbon stock. Understanding how these anthropogenic changes in abiotic variables influence the mangrove forest are key to predicting the conservation and restoration trajectories and accurately estimate the carbon stock of this important urban mangrove.

(4) Methods

- Study area

This research was carried out in the mangrove forests of the Mallorquin swamp (650 ha), located in the north of the city of Barranquilla, in the Atlántico department, at the Colombian Caribbean coast (11°2′47.04″ N, 74°50′48.12″ W) (Fig. 1). The Mallorquin swamp is a coastal lagoon of great relevance for the region since it was declared a RAMSAR Site (Decreto 3888 de 2009) and comprises one of the largest extensions of mangrove forests in the Atlántico department (Castro et al. 2022). Rainfall is extremely seasonal, with two drought periods, the first one between December and March, and the second one between July and August. The months from September to November experience the highest levels of precipitation. The mean annual temperature is 28°C, with a mean annual relative humidity of 80% and an annual precipitation total of 900 mm (Villadiego and Velay-Dabat 2014).

We established three sampling stations located within the Mallorquin swamp with varying fresh and saltwater influence (Fig. 1). The Rio station (33.6 ha), located in the northeast area of Mallorquin, was characterized for having mostly fresh water through a direct connection with the Magdalena River through three concrete box culverts. The Laguna station (74.8 ha) was set in the area known as Punta de Felix and has the influence of both the Magdalena River and the Caribbean Sea, making its waters an almost even mixture of fresh and salt water. Finally, the Mar station (9 ha), located in the north end of Mallorquin was characterized by having greater influence of the Caribbean Sea due to its proximity to the Puerto Mocho Beach, making its waters mostly salty.

- Field measurements

Within each sampling station, we located six circular plots with a radius of 7 m which are ideal for estimating the structure, biomass, and carbon stock of mangrove forests (Kauffman et al 2013). We measured diameter at breast height (DBH), total height (TH) and basal area (BA) for all trees of the three species present with DBH ≥ 5 cm in each plot. The species dominating the ecosystem and exhibiting the highest ecological significance were *Avicennia germinans*, *Rhizophora mangle* and *Laguncularia racemosa*. To measure soil's salinity and pH, we took a soil sample in the center of the plot once during the rainy season of 2020 and one during the dry season of 2021. The samples were taken to the environmental engineering laboratory at Universidad del Norte and analyzed using a Multi 3420 meter by WTW. We took two soil samples for each plot and each season. In addition, pH and salinity levels were measured three times for each soil sample taken.

- Carbon estimation of AGB

AGB for each tree in a plot was estimated using the mangrove forest specific allometric equation in Chave et al (2005): Biomass (Kg) = 0,0509 x ρ x DAP^2 x HT, where 0.0509 is a multiplicative coefficient, ρ is the species-specific wood density (g/cm^3), DBH is the diameter at breast height (cm) and HT is the total height (m). The specific wood density of *Avicennia germinans* (0.7764 g/cm^3), *Rhizophora mangle* (0.8977143 g/cm^3) and

Laguncularia racemosa (0.61 g/cm^3) were obtained from the Global Wood Density Database (Chave et al. 2009; Zanne et al. 2009). Carbon stock was estimated as 0.5*Biomass (Kauffman et al. 2013). Carbon contents in Kilograms were converted to Megagrams (Mg).

- Statistical analysis

To evaluate the effect of salinity and pH on compositional and structural characteristics of mangrove forests, we took a multilevel approach in which we first evaluated differences in abiotic characteristics among plots, then evaluated changes in mangrove forest composition and structure, and lastly, evaluated differences in above ground carbon stock. First, we evaluated the differences in physicochemical variables among plots using an analysis of similarity (i.e., ANOSIM) based on the bivariate Euclidean distance matrix constructed using soil pH and salinity. We also tested for univariate differences among stations to separate the effects of pH and salinity independently. We grouped plots based on the station they were established on, Rio, Mar or Laguna. The significance of the ANOSIM was estimated using 1000 randomizations of the physicochemical distance matrix. We ran three separate ANOSIM, the first one using the average of the measurements taken during the dry and rainy season and two different ones including measurements during the dry and rainy seasons separately.

Second, we used a non-metric multidimensional scaling analysis based on the Bray-Curtis dissimilarity index to evaluate the differences in plant community composition among plots and stations and generalized linear models assuming gamma distributed error to compare tree height, size and forest vertical stratification, carbon stock, and diversity using the effective number of species. Basal area was used as abundance metric for each species for computing diversity indices. The effective number of species was estimated using the exponent of the Shannon diversity index (Jost 2006). We estimated the uncertainty in the coefficients and the predictions using parametric Bootstrap by simulating 1000 datasets of the dependent variables using the best fitting model and re-estimating the parameters and predicted values. The confidence intervals for the models and predictions are given by the 2.5 and 97.5 quantiles of the distribution of the estimations with the 1000 simulated datasets. For each of the response variables, we compared a null model with intercept only with a model including station as independent variable using the Bayesian Information Criterion (BIC). We assumed strong evidence in favor of the model with the lowest BIC when the difference in BIC between the null and alternative model was larger than 4 BIC units.

(5) Results

The analyses of similarity based on the bivariate Euclidean distance matrix showed significant differences in physicochemical variables among stations during both the dry (ANOSIM statistic R=0.6, p=0.001) and the rainy (ANOSIM statistic R=0.3, p=0.02) seasons and across the year (ANOSIM statistic R=0.41, p=0.002); with much stronger differences during the dry than during the rainy season (Fig. 1). The univariate analysis showed that the stations vary consistently in salinity and much less according to pH as revealed by the R statistic of the ANOSIM (Salinity ANOSIM statistic R=0.4, p=0.001; pH ANOSIM statistic

R=0.25, p=0.02). The station with the highest levels of soil salinity was Laguna, followed by Mar and finally the Rio station (Fig. 1). From now on we will refer to the Rio, Mar and Laguna stations as Low, Medium and High salinity stations respectively. Although the ANOSIM showed significant differences in soil pH consistent with station groups, visually these differences are much less pronounced than for salinity (Fig. 1).

Community composition was different among stations. While plots in the Low salinity station were mostly associated with *Avicennia germinans*, *Laguncularia racemosa* was mostly associated with Medium salinity plots (Fig. 2A). This is evident by the position of the species scores in relation to the plot scores. The closer a species score is to a plot score, the higher the association of that species with that plot. The plots in High salinity were the most heterogeneous showing differences in composition, some of them similar to plots in Medium salinity and others to the Low salinity stations and one plot mostly composed of *Rhizophora mangle* trees (Fig. 2A). We found significant differences in tree height, abundance (measured as basal area), vertical vegetation structure and carbon stock among stations but not in tree diversity (Fig. 2B-E, Table 1). In general, the Low salinity station was composed of significantly taller and bigger trees and a significantly higher vertical stratification resulting in a significantly larger carbon stock, compared to the plots in the Medium and High salinity stations. The latter two stations showed significant differences only in tree basal area in which the Medium salinity station had larger trees than the High salinity station. Given the area of the mangrove forests in each station, we estimate that Carbon stock is 4098.6 (2092-6105.3) Mg C in the Low salinity station, 104.6 (53.4-155.7) Mg C in the Medium salinity station and 1761 (898.9-2623) Mg C in the High salinity station.

(6) Discussion

In this study, we attempted to evaluate the effects of salinity and pH on mangrove forest community composition and carbon storage in an urban swampland in Northern Colombia. Our results show that salinity conditions and pH vary significantly within the Mallorquin Swamp, influencing tree structure and carbon storage. Nonetheless, salinity differences are much more pronounced than soil pH differences. The differences in soil salinity were more pronounced during the dry season, potentially imposing strong limitations for growth and recruitment of mangrove trees. Furthermore, we found strong differences in community composition, vegetation structure and carbon storage among areas with different levels of salinity. Specifically, we found that salinity negatively influenced mangrove tree size and carbon stock but not diversity. In fact, although the relationship was not significant, tree diversity was lower in Low salinity soils compared to medium salinity soils.

The observed significant differences in physicochemical variables among stations during both the dry and rainy seasons, as well as across the year, highlight the dynamic nature of the Mallorquin swamp in Barranquilla, Colombia; as it has been reported in other mangrove ecosystems (Satheeshkumar and Khan 2009; Vijaya Kumar and Kumara 2014). These variations are attributed to factors such as temperature, salinity, and rainfall, which can impact the water quality and sediment characteristics of the mangroves (Satheeshkumar and Khan 2009; Vijaya Kumar and Kumara 2014). The dry season is related to lower water levels

and higher salinity, whereas the rainy season delivers higher water levels and decreased salinity (Satheeshkumar and Khan 2009; Vijaya Kumar and Kumara 2014). The variations in physicochemical properties between the dry and rainy seasons indicate that environmental conditions affect mangrove trees periodically, influencing leaf chlorophyll content and morphology (Flores-De-Santiago et al. 2012). Notably, during the rainy season, chlorophyll concentration increases in mangroves under poor conditions, whereas healthy plants exhibit little fluctuation across seasons (Flores-De-Santiago et al. 2012).

The observed variation in community composition among the Low, Medium, and High salinity stations, highlight the influence of soil salinity on the distribution of mangrove species within the Mallorquin swamp. *Avicennia germinans*, the black mangrove, is well-adapted to low salinity environments, as evidenced by its dominance in the Low salinity station. This characteristic may be due to the seasonal supply of fresh water and, consequently, nutrients (Smith 1992; Woodroffe 1992) as has been demonstrated in other mangroves on the Colombian Caribbean Coast (Cardona and Botero 1998; Rodríguez-Ramírez et al 2004). Furthermore, *A. germinans* has anatomical and morphological adaptations that allow it to tolerate and grow in a wide range of salinity (Yanez-Espinosa and Flores 2011) that could reach up to 90 psu (Lonard et al. 2017). In response to high salinity, the wood anatomy of *A. germinans* exhibits increased vessel wall thickness, vessel frequency, and fiber lumen diameter, balancing hydraulic efficiency and mechanical stability (Yáñez-Espinosa et al. 2009). Morphological adaptations include pneumatophores, which are specialized roots that aid in gas exchange, and thick leaves with salt glands for salt excretion (Gonzalez Rodriguez et al. 2012). However, López et al (2011) showed that *A. germinans* trees decrease significantly in height and basal area at salinity levels between 10 and 30 psu. Also, the production of new leaves and the leaf specific area of *A. germinans* are reduced as salinity increases (Suárez and Medina 2005).

In contrast, the Medium salinity station was dominated by *Laguncularia racemosa*, showcasing its remarkable adaptability to moderate saline conditions. Consistent with Torres-Duque (2019) and INVEMAR (2018), a decrease in the abundance of *A. germinans* along with an increase in *L. racemosa* indicates areas undergoing regeneration. This pattern reflects with the rapid colonization capacity of *L. racemosa* during secondary succession processes in mangrove ecosystems, as described by Soares et al. (2003) and Paula et al. (2016). The rapid colonization of *L. racemosa* in new territories is linked to its stomatal traits, with a greater number of smaller stomata enhancing gas exchange and photosynthetic rates. This adaptation allows for increased nutrient uptake and faster growth compared to other mangrove species (Bai et al. 2023).

Although the High salinity station exhibited a heterogeneous composition, *Rhizophora mangle* was the most dominant and abundant in this station (Fig. 2A), suggesting a certain degree of tolerance to higher salinity, challenging traditional associations of this species with lower salinity environments (Lopes et al. 2019). These results suggest that *R. mangle* thrives along tidally influenced coasts due to effective propagule transport by tidal currents (Ellison and Farnsworth 1993; Tovilla and Orihuela 2002). This species establishes itself on the forest edges, occupying perpetually flooded areas (Monroy-Torres et al. 2014). It possesses an

extensive internal airflow system, where air travels through stem aerenchyma to stilt roots, delivering oxygen to the growing root sections in anoxic substrates (Evans et al. 2005). It also shows a greater number of morphoanatomical functional traits affected by salinity in juveniles compared to adults, suggesting a higher adaptability to high salinity in the latter (Sánchez et al. 2021). These adaptations are associated with managing high salinity by enlarging hypodermal hyaline cells, which enhances the storage capacity for Cl- and Na+ ions in their vacuoles (Werner and Stelzer 1990; Sánchez et al. 2021).

The presence of significantly taller and bigger trees, as well as a larger carbon stock in the Low salinity station, is supported by several studies. Specifically, Rahman et al. (2015) found that salinity can influence carbon stock in the Sundarbans mangrove forest, the world's largest mangrove forest, with the freshwater zone showing the highest stock. Moreover, Ahmed et al. (2023) documented that soil salinity had a strong negative effect on growth dominance coefficient, AGB, and AGB gain. An alternative explanation for this pattern is that the forests in the low salinity area tend to be the oldest.

One pivotal aspect contributing to the distinctive characteristics of the Low salinity station is its direct association with the Magdalena River, as documented by Garcés-Ordóñez et al. (2016). This influence emanates from the regulated flow of freshwater facilitated by three box culverts, specialized hydraulic structures designed for the controlled conveyance of liquid fluids. The consistent freshwater input from the Magdalena River shapes the unique environmental conditions of the Low salinity station, fostering conditions conducive to the observed robust vegetation and enhanced carbon stock.

In contrast, the High and Medium salinity stations are characterized by having more saline soils and a higher pH, which could be due to their proximity to the saltwater of the Caribbean Sea and brackish waters of the swamp. These waters tend to have a high pH due to the acid-base balance between atmospheric carbon dioxide absorption and the involvement of calcium carbonate from the leaching of limestone rocks (Bache 1984; Somridhivej and Boyd 2017), which are common in the area's geomorphology (Molina et al 1999; Universidad del Norte 2005; Medivelso et al 2010). These characteristics negatively impacted the heights, basal areas, and carbon storage of the mangroves at the High and Medium salinity stations (Fig. 2). This could be explained by an increase in salt concentration which reduces the soil water potential and makes it difficult for plants to absorb water (Parida and Das 2005; Perri et al 2018); leading to a gradual reduction in leaf stomatal conductance and photosynthetic carbon fixation (Rodríguez-Rodríguez et al. 2018). This ultimately results in a decrease in mangrove forest biomass (Suárez and Medina 2005).

Studies in Colombia have shown that carbon storage in mangrove forests' AGB ranges from 37.9 to 102.1 Mg C ha^{-1} (Blanco-Libreros et al 2015; Perdomo-Trujillo 2020), with our study estimating it at 49.6 Mg C ha^{-1}. These variations are influenced by the conservation level of mangrove forests. For instance, in Turbo, a town located in the Gulf of Urabá in the department of Antioquia, deforestation and sedimentation led to the lowest carbon estimate (37.9 Mg C ha^{-1}), while the Rinconada sector of the Ciénaga Grande de Santa Marta in the department of Magdalena, the largest coastal wetland in Colombia, showed the highest value

(102.1 Mg C ha^{-1}), benefiting from freshwater input (Perdomo-Trujillo 2020). *Avicennia germinans* was the major contributor to AGB and carbon in both locations. Our study in the Mallorquin swamp reported a carbon value of 49.6 Mg C ha^{-1}, lower than estimates in Cispatá Bay in the Colombia's Caribbean (64.85 Mg C ha^{-1}) and Bahia Málaga in the Colombia's Pacific coast (71.9 Mg C ha^{-1}). These differences may be due to coastal geography and climate (Blanco-Libreros and Álvarez-León 2019). The Pacific coast's deltas and high precipitation favor carbon storage, contrasting with the Caribbean's drier climate and fewer mangroves in wetlands and lagoons (Pérez et al 2018; Perdomo-Trujillo 2020), as seen in the Mallorquin swamp.

Notably, these carbon figures far exceed other estimates worldwide. For instance, Mexico's Sian Ka Biosphere Reserve has the lowest estimation at 2.6 Mg C ha^{-1} (Adame et al. 2013),while Yap Island in Micronesia boasts the highest estimation globally at 434.8 Mg C ha^{-1} (Donato et al. 2011), showcasing the significant variability in mangrove carbon reserves across different regions.

One aspect of the Mallorquin coastal swamp that we did not mention in this study but is noteworthy to consider is its dynamic history, product of human intervention. As we mentioned before, the construction of the training wall on the Magdalena River significantly altered currents and sediment deposition. The Mar station, with medium salinity is the geologically newest formation product of those shifts after the construction of the training wall. Thus, an alternative explanation to the differences in vegetation structural composition may be the recent geological history of the area. We encourage further research in the dynamic nature of this system and how these anthropogenic changes may influence mangrove forests and carbon stocks.

Our study in the Mallorquin swamp has provided crucial insights into the complex interplay between environmental factors and mangrove ecosystems. By focusing on the effects of salinity and pH on mangrove community composition and carbon storage, we have uncovered significant variations in tree structure and species distribution across different salinity stations. These findings are particularly relevant in the context of urban wetlands, where human activities can exacerbate environmental stressors, highlighting the importance of targeted conservation efforts in such areas.

Furthermore, our study contributes to the broader scientific understanding of mangrove resilience and adaptation strategies. The identification of species-specific responses to salinity, such as *Avicennia germinans* tolerance to low salinity and *Rhizophora mangle* adaptability to higher salinity, underscores the ecological complexity of mangrove ecosystems. This knowledge is essential for designing effective management and restoration plans that consider local environmental variations and species characteristics, supporting the long-term sustainability of mangrove habitats worldwide.

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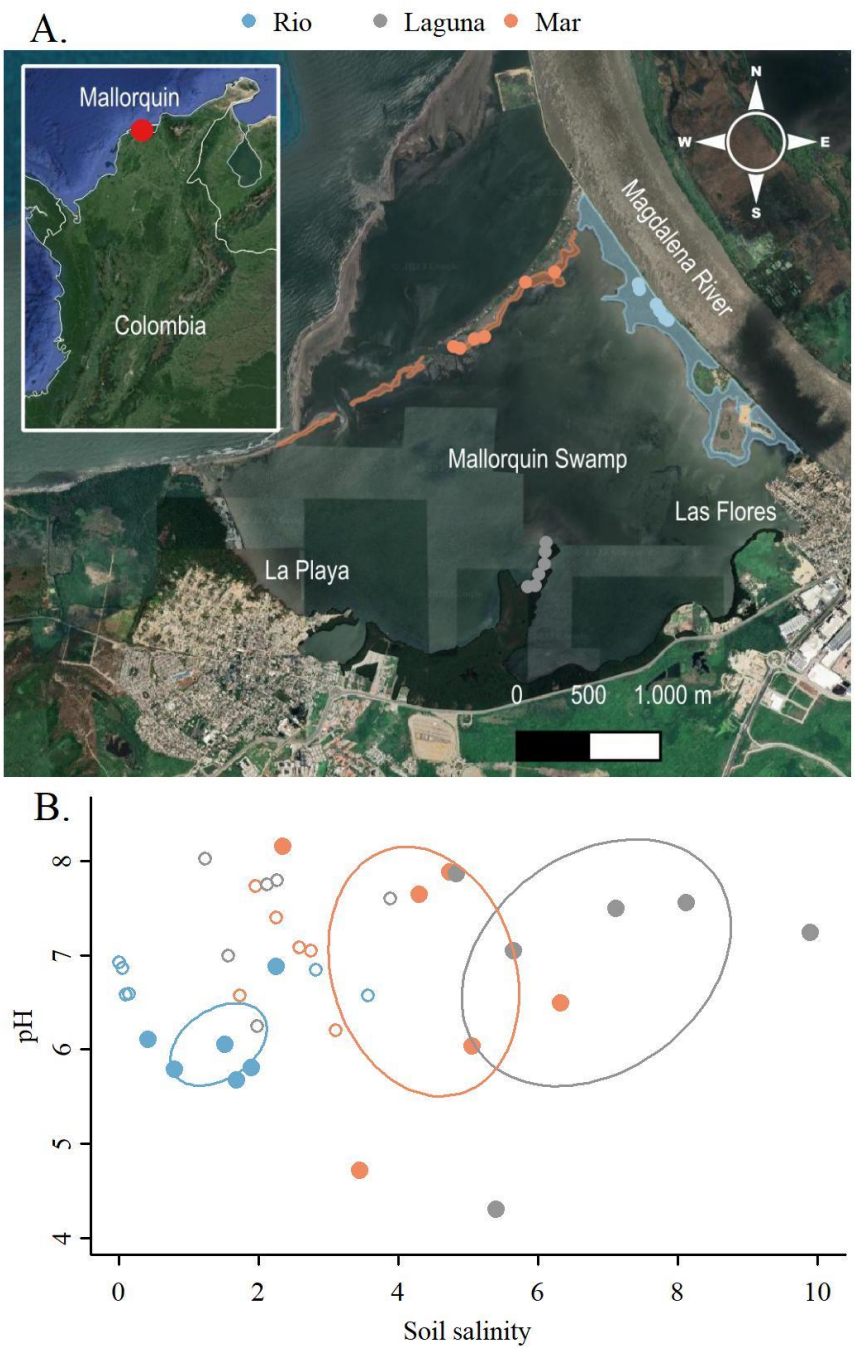

Fig. 1 Location of the urban swamp of Mallorquin showing the locations of the physicochemical and vegetation sampling plots (A.) and the measurements of soil water and salinity (B.) during the rainy (open circles) and dry seasons (solid circles). The colored polygons are ellipses describing the grouping based on the centroid and one standard deviation of the physicochemical measurements on each plot during the dry season. Contrary to our expectations, the saltiest region was Laguna, followed by Mar and finally the least salty region was Rio. Polygons show each station´s total area

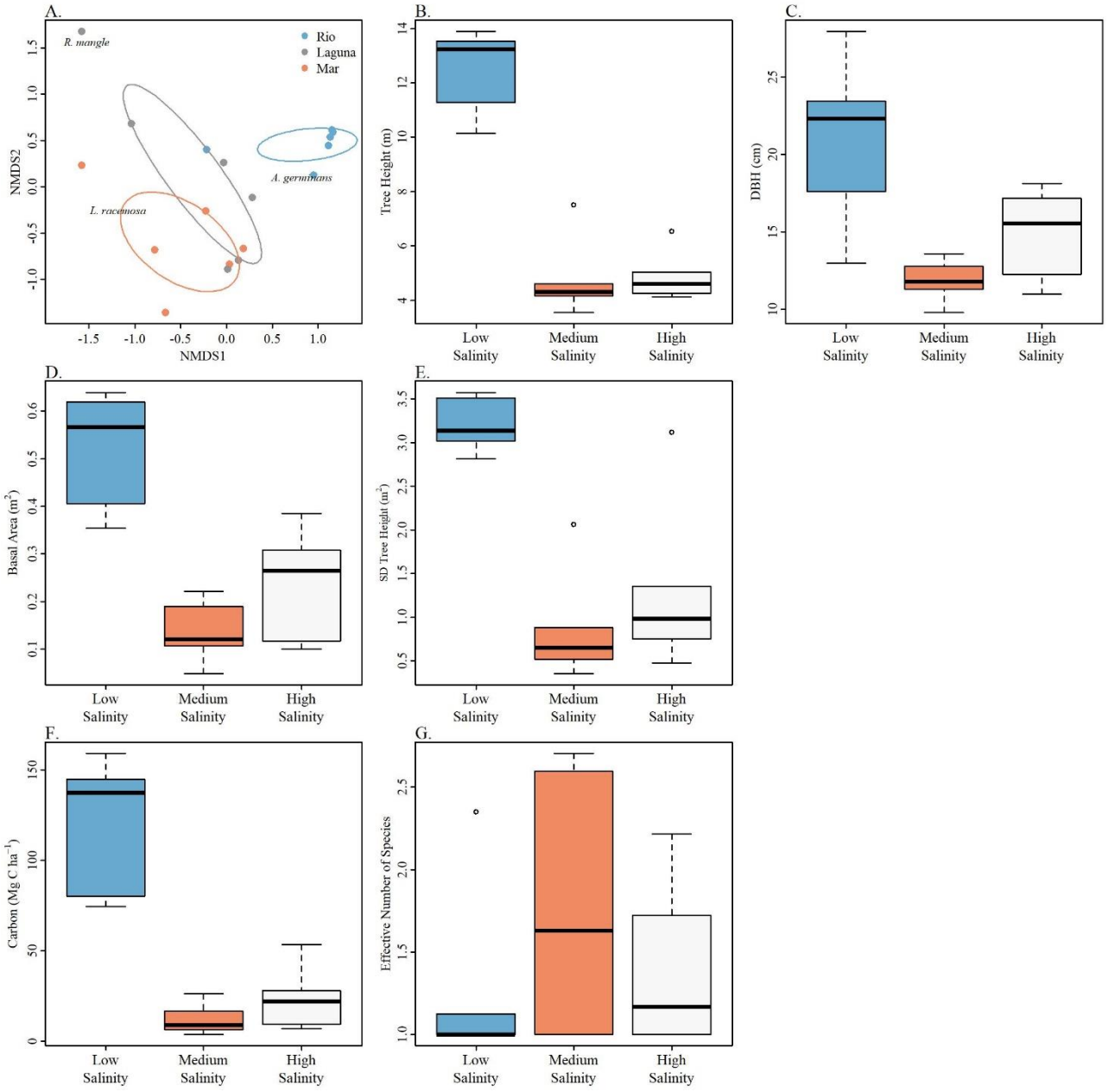

Fig. 2 Community composition and vegetation structure of the plots in each of the three stations. Panel A. shows the results of a non-metric multidimensional scaling analysis with the position of each of the plots based on their compositional similarity. The closer the two points are together, the more similar they are. Species in the figure show to which plots these species are mostly associated. Panels B - G show the differences in tree height, Diameter at Breast Height (DBH), tree abundance (Basal Area), vegetation structure (SD tree height), carbon stock (Mg) and diversity by station, respectively. Low Salinity corresponds to Rio, Medium to Mar and Low to Laguna. Colors in the boxplots follow the colors in Panel A

	Rio	Mar	Laguna	ΔBIC
Tree Height (m)	12.6 (10.4-14.7)[a]	4.9 (4-5.7)[b]	4.7 (3.9-5.5)[b]	32
DBH (cm)	21.1 (17.9-24.4)[a]	11.9 (10-13.7)[b]	14.9 (12.6-17.2)[b]	12.3
Basal Area (m2)	0.5 (0.4-0.7)[a]	0.2 (0.2-0.3)[b]	0.1 (0.1-0.2)[c]	14.2
SD Tree Height (m2)	3.2 (1.6-4.8)[a]	1.3 (0.7-1.9)[b]	0.9 (0.4-1.3)[b]	10.2
Carbon Stock (Mg)	1831.6 (934.9-2728.3)[a]	174.8 (89.2-260.4)[b]	353.1 (180.2-525.9)[b]	22.1
Diversity	1.2 (0.8-1.7)[a]	1.4 (0.9-1.8)[a]	1.8 (1.2-2.3)[a]	3

Table 1 Model estimates showing and their confidence intervals in parenthesis showing significant differences in Tree height, Tree size, forest vertical structure, carbon stock and diversity. ΔBIC shows the difference in Bayesian information criterion between the model with station as independent variable and the null model with no explanatory variable. ΔBIC > 4 units indicate strong evidence in favor of the alternative model suggesting differences in dependent variables among stations. Letters in the super index show groups of stations with significant and non-significant differences in vegetation structure. The groupings were based on the overlap of the 95% Confidence Intervals of the mean