Quantification of Organic Matter and Physical-Chemical Characterization of Mangrove Soil at Hooker Bay, San Andres Island - Colombia

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Abstract — The soils play an important role in the CO_2 capture, a major gas in climatic channel. The goal of this study was to quantify, during the dry season, the organic carbon content of the mangrove wetland located in Hooker Bay, San Andres Island, Colombia. The changes in the concentration of organic matter through soil profile were evaluated. A structural analysis of the mangrove wetland was carried out in order to relate it to the physical-chemical parameters (pH, salinity and dissolved oxygen) and to the organic matter. The mangrove soil studied contains an average of 173,96 kg C/m^2 in the first top 100cm of depth. There were neither significant differences among the depths evaluated ($p < 0,05$) nor correlations between the organic matter in the physical-chemical parameters. The mangrove wetland studied has a low structural development. Three species with decreasing IVI (Index Value Importance) were found: *Rhizophora mangle* > *Avicennia germinans* > *Laguncularia racemosa*.
The mangrove soil studied has a high potential as carbon reservoir in the form of organic matter because it is one of the ecosystems that accumulates larger carbon quantities.
Keywords — Mangrove, Organic Matter, IVI.Keywords

1 Introduction

Mangroves are facultative halophytes communities growing in tropical and subtropical coasts. These forests have physiological and morphological adaptations that help to develop in areas frequently flooded with highly saline water, contain about 84 species collected in about 39 genera, many of which are not related Phylogenetically.
[1],[2],[3],[4],[5],[6],[7],[8].
The importance of mangroves can be summarized in ecological and economic aspects. The ecological significance lies in the same ecosystem services, such as a high net primary production, accompanied by a significant production of organic matter and nutrients, functioning as a source of matter and energy, which exports to neighboring ecosystems [9]. Another service of the mangrove ecosystem, is to provide a wide diversity of habitats and thus serve as a shelter for many organisms either in the initial stages of its development or throughout its life cycle, deer also be a substrate for the development of various microorganisms, maintaining a wide diversity [9],[10].
They behave as anti-erosion barriers protecting the shoreline from direct wave, serve as sensors of sediments, also have been characterized as evapotranspiration systems and generating rainfall. Mangroves have been suggested as organic carbon sinks grades [11],[12],[13],[14],[15].
Most mangroves on the island of San Andrés are distributed on the east side, called Mount Pleasant, Salt Creek, Bay Sound, Smith Channel and mangroves in the study; Bay Hooker with 34.40 ha. In the western part of the island is a mangrove only about 1.2 has been known as The Cove, the whole area is estimated to 96.98 ha, Figure 1. [16].

Concern about environmental issues and in particular by climate change growing in recent years, more so after the publication of the fourth report in 2007, the IPCC (Intergovernmental Panel on Climate Change), which draw conclusions such as global warming due to climate change is unequivocal and is evidenced by the increase in average air temperature and ocean, widespread melting of snow and ice and rising global average sea level. This phenomenon has been driven by the variation in concentrations of greenhouse gases (GHGs) and aerosols in the atmosphere, carbon dioxide (CO2) is the most important GHG,[16].

The importance of the soil, is that one of the same ecosystem services is to serve as a reservoir for carbon dioxide, so much so that the soil is the largest reservoir of carbon that is in interaction with the atmosphere, storing about three times the biomass that makes up the vegetation and about twice the carbon that is retained in the atmosphere [13], [18].
In the present study the carbon is quantified as organic matter stored in the soil of mangrove Hooker Bay, plus find concentration gradients along the

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profile and seeks to establish relationships between soil physicochemical parameters and the structure and composition mangrove forest.

2 Study Area

San Andrés Archipièlago, Providencia and Santa Catalina is located in the intertropical zone, influenced by the northeast trade winds [19]. San Andres Island is located between 12 ° 29 'and 12 ° 36' north latitude and 81 ° 41 'and 81 ° 43' west longitude [19]. The climate is humid tropical, annual mean temperature 27.4 ° C, with a range of just over 1 ° C between the months with higher values (May to September) and lowest (December to March) but the effects of this temperature is reduced by the presence of northeasterly winds that cool the area [19]. San Andrés had its origin from a collapsed volcanic cone whose base is currently more than 1000 m depth which was covered with limestone reef formed from the Oligocene-M, thus configuring an atoll. During the Pliocene and Pleistocene part of the atoll experienced a gradual tilt towards its eastern side, leaving emerged a considerable portion of the Miocene limestone structures in the western part. [20].
The east coast of the island is dominated by the coral sand containing whitish good drainage and shallow groundwater level, on the west side soils tend to be more clay-textured surface plane. In the mangroves there are deposits of minerals that give birth to poorly developed soils and poorly drained (Fluvaquents) and organic accumulations that cause the formation of poorly developed soils Histosols Tropofibrists [21].

Fig1. Study Area, Mangrove Bay Hooker (Circle) and main mangrove San Andres Island [22].

3 Materials And Methods

3.1 Land Phase

For the analysis of forest structure eight plots of 100m^2 (0.01 ha) (Fig. 2) were established following the methodology of CARICOMP [23], each determining the number of individuals, record the DBH (diameter at breast height) at 30 cm from the root higher for *Rhizophora mangle* and 1.3 m in height for other species, this was done for all individuals with DBH greater than 2.5 cm. With the help of a clinometer and tape recorded the height with reference to the highest branch.
The soil samples were made 26 separate stations so that they form a grid of 90 meters edge (Fig.2). At each station there were three holes and samples were taken at three different depths: 0-30 cm, 30-60 cm and 60-100 cm. Each of the levels collected a soil volume of approximately 2400 cm^3, derived from a combination of the same depth of the three holes. In each hole lod dissolved oxygen was recorded with an Oximeter Ox12-SCHOTT. The pH with a multi-parameter Multi 350i. The salinity was recorded using a refractometer VISTA A366ATC, this activity was taking in situ pore water after the excavation.

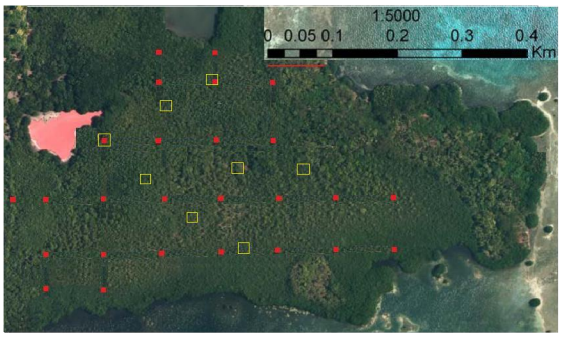

Fig.2, Distribution of vegetation study plots (big picture) and location of soil sampling stations (small squares) [24].

3.2 Laboratory Phase

The soil was dried at 105C ° for 72 hours, after being dried was passed through a 2 mm mesh to eliminate the presence of rootlets and other plant materials[25].
To determine the texture was used Bouyoucos method[26].Bulk density was determined by taking the weight of a known volume[26]. The real density was measured by the pycnometer method after sifting the soil with a 250µm sieve [27].
To quantify the organic carbon is used the Walkley-Black methods and Loss On Ignition (LOI), the first is a wet oxidation with potassium dichromate, the second quantifies the weight lost by burning the sample in a muffle furnace at 350 ° C, after being dried for 72 hours at 105 ° C [27],[25].

4 Data Analysis

In the analysis of vegetation data the formula (π [DAP/2] ^{2}) was used to estimate basal area [2], and the formula used by [28], to calculate the index value importance (IVI), which reflects the dominant

species within an area coverage and of aggregating the relative frequency, relative dominance and relative density of each species. For quantification of organic matter by Walkley-Black method was performed with a standard curve with Sucrose R^2 = 9.99 E-01 described by the linear equation: Y = 1.44 E-0, 2x-1, 71E-0 3.

At each station and each level was determined by the average depth of organic matter and their respective standard deviation, using both methods (LOI, Walkley-Black), then through a one-way ANOVA compared the levels of organic matter quantified by Walkley-Black method. To test the hypothesis of organic matter by LOI method was used nonparametric Mann-Whitney test applied to test hypotheses on data with normal distribution. The two previous analysis in order to find differences in the concentration of organic matter along the profile. In calculating the total carbon content in the form of organic matter is taken into account only the data found p45 Walkley-Black method and according to [29],[30], these are more accurate and precise than the method LOI Then, once the results obtained using the following formula to estimate the total organic carbon:

$$Ms = (Ae)\ (Pt)\ (DA)$$
$$COT = (Ms)\ (\%\ OM)\ (\%\ RM)\ (\%\ CMC)$$

Where (Ms) is the mass of soil (Ae) Study Area (Pt) working depth (DA) Bulk density (% MO) percentage of organic matter obtained (% RM) percentage of recovery method (% BMC) Percentage of carbon that makes up the organic matter (TOC) Total Organic Carbon. TOC is then divided by the area of study to express the result in kilograms of carbon per unit area (Kg C/m2) so they became comparable with the results of work done in different types of ecosystems and land use . The values found in the physicochemical parameters (pH, salinity, dissolved oxygen, texture) were averaged for each station and grouping the three levels deep.

Multivariate analysis for the data of pH, salinity, dissolved oxygen, texture and organic matter (Walkley-Black), was to find the key components to reduce the multidimensionality of the data, establish who explains the variability between stations and to obtain a bivariate correlation matrix, this matrix is obtained by calculating the Pearson correlation coefficient for each pair of variables. Was used considering the program Minitab 15 statistical significance level p <0.05 for all tests. If you are using Word, use either the Microsoft Equation Editor or the MathType add-on.

5 RESULTS

5.1 Forest structure

According to the observations and field data, the Mangrove Bay Mangrove Hooker is a characteristic of a fringe or border. In this mangrove was found a prevalence of three species *Rhizophora mangle, Avicennia germinans* and *Laguncularia racemosa.* The average height of this forest was 6.34 m ± 2.33 m, with an average density of 266 individuals per 0.1 ha.

As for the relative dominante, iot was found that the dominant species is *R mangle*, with 42.36%, followed by *A germinans* with 37.47% and finally, *L racemosa* with 20.15%.

The IVI (Importance Value Index) allows to compare the ecological weight of the species found in an ecosystem. For the mangrove considered in this study, the IVI was *R mangle*> *A germinans*> *L racemosa.* As for the characteristics of the forest, the same proportions were reported by [31],but with equal relative dominance between *R mangle* and *A germinans* mangrove, with a total of 37% for each. In terms of average height, there was a difference of 1 m which can be attributed to the methodology and the reference point for the maximum height.

5.2 Soil parameters

Soil texture showed a percentage of 53.17% sand, 27.8% and 18.98%clay, silt, that characterize this type of soil as a sandy clay loam soil witha bulk density of 0, 9 ± 0.2 g/cm3 and real density of 1.34 ± 0.5 g/cm3.

In the pore water pH values were close to neutral and equal to 6.14 ±0.30, dissolved oxygen was relatively low, was found on average 0.17 ± 0.17 mg / ml. The salinity ranged between 35 to 79 ‰, depending on the distance of sampling from the sea, with higher concentrations in the middle of it and the sea nearby stations showed low salinity.

5.3 Organic Matter

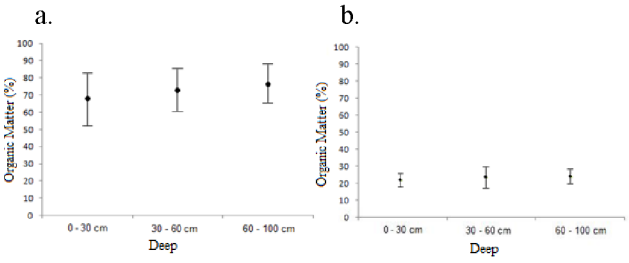

Fig.3. Percentage of organic matter measured by the methods a.Loss On Ignition (LOI) and b. Walkley-Black.

The results of organic matter measured by the method Loss-on-ignition (Fig 3.a), distribution was

not normal, having an average of 72.42% ± 12.54 for the whole station. It noted an increase in the concentration of organic matter in deeper. Organic matter measured by the Walkley-Black method (Fig 3b) showed a normal distribution and average percentages of 22.89% ± 4.85 for all seasons. Revealed an increase in concentration with increasing depth.

The study found that in all fields and levels of the study area the average organic matter corresponds to 22.89% of the total land mass.You should assume that the experimental method retrieves only 76% of organic matter and carbon represents 65% of it[25].

It was found that the mangrove soil Hooker Bay, with an approximate area of 34.4 ha, a meter deep, has stored a total of 59842.7 tons of organic carbon. In general, the mangrove forest floor Hooker Bay has an organic carbon content averaged 173.96 kg C / m^2, but this average may range from 106.09 to 257.57 kg/m^2.

Table 1. shows the results of Pearson correlation coefficients corresponding to the value at the top and the p-value of hypothesis testing (bottom number).

	pH	Salinity	Oxygen mg/ml	% Sand	%Clays	% Silt
Salinity	0,054					
	0,817					
Oxygen mg/ml	-0,458**	0,369				
	0,037	0,1				
% Sand	-0,241	-0,265	0,454**			
	0,293	0,245	0,039			
%Clays	0,209	0,472**	-0,326	-0,917		
	0,363	0,031	0,149	0		
% Silt	0,162	-0,303	-0,447**	-0,592**	0,22	
	0,483	0,182	0,042	0,005	0,337	
%Organic matter	-0,084	0,027	0,245	0,286	-0,145	-0,402*
	0,718	0,907	0,284	0,209	0,531	0,071

Values highlighted in red represent a linear, values double asterisk are those correlation statistically significant at 95%, while those with a single asterisk have a 90% statistical correspondence.

Given the above, outcomes are evident such as the inverse relationship between pH and oxygen concentration. Evidenced in Table1, the oxygen is directly proportional to the percentage of sand and anegative linear correlation with the silt. It shows a negative correlationwith a relatively low value of the percentage of silt and organic matter, with a significance level of 90%. In general, Table 1 shows that the siltsshow a negative correlation with the percentage of sand, with the concentration of oxygen and to a lesser extent with organic matter. Itindicates that the clays are directly related to salinity.

6 Analysis Of Results

In general, the mangrove has a low degree of structural development which is reflected in a high density of individuals, low average heights and average basal areas, all this is consistent with those reported by [16]. Similarly, reports [18], Hooker Bay mangroves historically has had serious human intervention processes that triggers stressors such as the presence of hydrocarbons and forest clearing. Taking into account the frequency and density of the species found, confirmed the field observations, which states that individuals are not evenly distributed in the study area, but there is a training patches or edges of species that depend variations in topography and soil conditions. This creates a segregation of species that most authors suggest may be due to the tolerance that they have high concentrations of salt, the edges of the mangroves are dominated by R mangle and corresponds to those places where values salinities are close to the sea (35 ‰), while species such as A germinans was found in areas with salinities up to 79 ‰, to the center of the mangroves, there are areas where you can find mixtures of the two previous species L racemosa, a species that has the lowest percentage of frequency, density and relative dominance [15],[8].

The importance value index for the species found in the ecosystem under study was greater for R mangrove species with optional features, developing in areas with high tidal influence and in areas where salinity is 30% higher than the sea , though these areas their growth and development is poor. A germinans and L racemosa have some habitat specificity, A germinans preferably develops in areas with high salinity, L racemosa is a species that has been characterized as a pioneer, often in areas where there have been tension in the ecosystem processes [8].

6.1 Soil parameters

The soil under study had low bulk density due to the high amount oforganic material they have, the result is consistent with that found in [32], which found an inverse relationship between organic matter content and soil bulk density of mangroves in southern Florida (USA). The actual density is relatively high due to the characteristics that have soils with high sand content from its parent material, rocks of coral origin [33].

The pH values found were close to neutral (mean 6.14 ± 0.30),consistent with the work done by [32],but contrast with those reported by [30],where pH values are listed with basic trend, from 7.8 to 8.2. Has not reported any trends in the spatial distribution of mangrove soil pH, there also was no relationship between this parameter and the structure of the forest.

Dissolved oxygen was relatively low and typical of mangrove soils where the prevailing condition is permanent waterlogging. Dissolved oxygen did not show any gradient along the study area. We found awell defined concentration gradient in the interstitial salinity, whichbehaves growing from the edges toward the center of the mangrove where values were recorded between 70 and 79 ‰ in contrast to the stations near the sea where

concentrations were between 35 to 40 ‰.

6.2 Organic Matter

The values found of organic matter found by loss on ignition method are high and show that this method may overestimate the soil organic matter, the combustion process can release some structural water associated with clays, in addition to burning compounds containing inorganic carbon, so that the method gives results with high percentages [34].
As to the behavior along the profile, we found no statistically significant differences in the concentration of organic matter through the depth, but it shows an increase in concentration with increasing depth under the two methods of determination (LOI and WB), although the organic matter measured by the Walkley-Black method has a lower standard deviation that reflects the accuracy of the method. Results No significant differences in the concentration of organic matter may be because the degree of flooding may have influence on the quasi-homogeneous distribution, as [35], the soluble fraction of organic matter may cause it to move vertically percolation of water through the profile.

The average organic matter can be found in comparative Table.2 which showed the organic carbon content in different soil types and uses. Note that soils subjected to intense human activity tend to have low organic carbon content, decreasing from 15% to 40% organic matter with the traditional tillage for a period of one year [36]. Likewise, soil type histosols have higher carbon content [35]. The values of organic carbon in mangrove Hooker Bay highlight the importance of this ecosystem organic carbon sequestration in the form of organic matter, since the processes between soil and vegetation play an important role in reducing concentrations major atmospheric CO_2 in climate change mitigation. With the results we must stress the determination of organic carbon in soil of mangrove and other ecosystem services. All this should result in policies aimed at their preservation.

Table 2, organic carbon content found in mangrove soil Hooker Bay San Andres Island Colombia, compared with other types and land uses.

Location/or type of organic soil	Organic Carbon Restored Kg C/ m^2	Reference
Olimpic Mountain ,USA	3,5 – 14,5	[14]
China Tropical and subtropical herbaceous swamps Soils Ander coniferous Forest broadleafs Rice soils Uplands Sabana grassland	. 40,0 19,6 19,2 12,6 9,4 10,5	[14]
Brazil Virgen Jungle Secondary jungle Savanna Soil Oxisol	. 13,0 – 37,0 10,0 – 20,0 9, 0 – 16,0 12,0 – 24,0	[14] , [35]
Agricultural Land Histosol	2,0 – 10,0 9,0 – 191,0	[14],[35]
Histosol (Región circumpolar norte)	6 – 130	[38]
African Savanna Soil With cultivation (top 30cm) Natural Savanna (top 30 cm)	 1,6 6,1	[39]
Mangrove soli Tabasco (México)	47 – 82	[14]
Mangrove study : Bahía Hooker, San Andrés-Isla Colombia	**173,96**	Here

6.3 Multivariate Analysis

The inverse relationship between pH and oxygen concentration could be explained by these two variables depend on the state of oxidereduction in soil, the degree of water logging of the soil can negatively affect the pH, therefore it is found in mangrove soil pH values with a tendency to acidity: 6.14 to 6.25 [12]. It also follows from the results of the table.1, which dissolved oxygen is directly proportional to the percentage of sand and a negative linear correlation with silt, these results are about the size of particles thatallow pore space and aeration higher for the case of sand and otherwise in the case of silt, which does not allow the formation of spaces for aeration and accumulation of oxygen.
Although the principal component analysis is a regression equation to explain the organic matter in light of the other variables (organic matter = 24.9 to 3.39 pH - 0.0518 SALINITY – OXYGEN + 0.71 +0.252 percentage ARENAS CLAY 0.296 percenta ge) was not cross correlation to determine the behavior of organic matter, although the literature establishes a relationship of dependency

between the concentration of organic matter and variables such as texture, oxygen, climate and others [26].

6 Conclusions

In general, the mangrove forest Hooker Bay belongs to the mangrove fringe or edge type, with a relatively low structure development, there is uneven distribution of plant communities appears to be mainly governed by salinity, which plays a role can be interpreted in two ways: as a stressful factor or a factor that eliminates competition by favoring certain species.

Although no significant differences between the depth levels established, is the first study to quantify the organic matter in the soil found that it has a great ability to capture carbon in the form of organic matter due to its high ground biological activity translated into higher productivity.

Characterized as an important alternative in the process of climate change mitigation.

Due to the large number of factors affecting soil physical and chemical parameters of these ecosystems, the variability of them is very high in relatively small spaces. There is also a close relationship between soil physicochemical parameters and the structure and composition of the forest and this in turn affects soil properties.

Linking forest structure and soil physicochemical parameters is complex, but it is necessary to increase knowledge in the processes taking place in it to understand the movement and cyclization of matter and energy in these ecosystems.

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