Differences in the Carbon Storage Rate between Mangrove Soils in a Disturbed Site and a Non-Disturbed Site in Campeche, Mexico

EVANGELINA RAMIREZ-LARA[1], MARIA DE LA LUZ ESPINOSA-FUENTES[2], ROSA MARIA CERON-BRETON[3], JULIA GRISELDA CERON-BRETON[3], DANIEL CHE-CITALAN[3], BRYAND GARCIA-SIGALES[3], JUAN JOSE LARA-MORALES[3], EDITH LEMUS-JAUREGUI[3], BEATRIZ LEZCANO-DE LA CRUZ[3], MARIO MARTINEZ- DE LA CRUZ[3]
[1]Faculty of Chemical Sciences, Autonomous University of Nuevo León,
Nuevo León, MEXICO
[2]Atmosphere Science Center, National Autonomous University of Mexico,
Ciudad de México, MEXICO
[3]Faculty of Chemistry, Autonomous University of Carmen,
Ciudad del Carmen, Campeche, MEXICO
evangelina.ramirezl@uanl.mx

Abstract: - Carbon sequestration potential was determined in two sites (a non-disturbed site and a disturbed site) in the region of Terminos Lagoon in Campeche, Mexico during June 2019 at two sampling depths, 30 and 60 cm. Significant differences in the measured parameters [pH, conductivity (dS m^{-1}), organic matter (%), organic carbon (%), and carbon storage (Kg C m^{-2})] were not found between sampling depths, demonstrating that soil morphology and water sources were not important, since the sampling was made in the same season and sampling sites were nearby. However, when organic matter content (%), organic carbon content (%), and carbon storage rate (Kg C m^{-2}) were compared between sites, significant differences were found. These differences were attributed to the vegetation structure and the degree of disturbance in each site. Mean carbon storage rate for the non-disturbed site and for the disturbed site were 107.071 and 79.759 Kg C m^{-2} respectively. These findings justify the conservation of mature and dense mangrove forest of the Terminos Lagoon region.

Key-Words: - Carbon sinks, mangrove forests, Terminos Lagoon, Campeche, Mexico.

1 Introduction

Coastal wetlands are important due to their capacity for carbon storage [1]. It has been reported that mangrove soils can contain 3-4 times the C density typically reported for temperate regions [2]. The process of carbon accumulation in wetland vegetation has two paths: First, litter and fine roots provide a significant input of organic carbon to soils; and second, plants enhance in trapping suspended materials from tidal waters [3]. Some factors such as differences in vegetation structure, plant species composition, sources of organic matter, sediment texture, elevation gradients and tidal regimes influence on the variability in mangrove carbon storage [4]. In spite of their environmental importance, during the last decades, in tropical regions, mangrove forests have been cleared for economical purposes, however, appropriate land management could contribute to soil carbon sequestration [5]. At present, there is an increasing concern to obtain wetland ecosystem data for national inventories that support policies in matter of sites management and conservation [6] and for carbon trading [7]. Like many coastlines in urban ecosystems, in some regions of Mexico, mangrove ecosystems coexist with urban zones, resulting in mangrove forest disturbed or decreased in size, being a priority their conservation. This study was carried out in a complex ecosystem near to Carmen Island in Campeche, Mexico, in which an urban zone and mangrove forest coexist, providing carbon storage data for a disturbed and non-disturbed sites.

2 Methods

2.1 Study Site Description

The Terminos Lagoon borders the Southern Gulf of Mexico in Campeche, and three main rivers discharge into the lagoon: Candelaria, Chumpan and Palizada. Fisheries and crude oil extraction in the Gulf of Mexico have generated the urban development of Ciudad del Carmen, the largest town located at the west edge of Carmen Island. Since the vast wetlands are surrounding the Terminos Lagoon and Carmen island, this region has been designated as a wetland of international importance (Ramsar) [8]. The Terminos Lagoon is surrounded almost completely by mangrove forest, with three dominant species: *Rhizophora mangle L.* (red mangrove)., *Avicenia germinans L.* (black mangrove) and *Laguncularia racemosa Gaertn. F* (white mangrove) [9]. This area has three climatic seasons: rainy (from June to September), cold fronts (from October to March), and dry (from April to May) [10]. However, wetlands in this area are impacted by urbanization, fisheries, wastewater discharges, industrialization and agriculture, being the land cover the systemic indicator of environmental change which has been detrimentally affected [11].

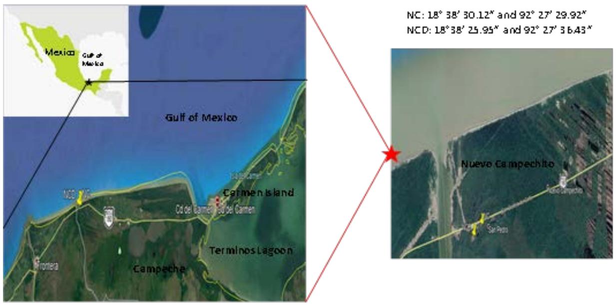


Fig.1. Sampling Sites Location

2.2 Field Sampling

Sampling campaign was carried out from June 13 to June 18 of 2019. Two sampling sites in Terminos Lagoon Region (Nuevo Campechito) were selected, the first site was a mangrove forest in a non-disturbed site, which was labeled as NC; the second site was a mangrove forest under anthropogenic exploitation and can be considered as a disturbed site, since it has suffered frequent high intensity burning, labelled as NCD. Transects were established in a representative area of mangrove forest in each sampling site. The location of the selected areas for this study is shown in Figure 1. Three sampling plots of 4 m x 12 m in each site were selected considering free access to the zone, risks, mangrove vegetation structure and distribution. Three sampling points of 1 m^2 approximately for each sampling site were selected to obtain composite sample at 30 and 60 cm depth. A total of 48 soil samples with replicates were taken.

2.3 Chemical Analysis

All field samples were processed in the laboratory following standard protocols for quantifying carbon storage in mangrove soils. All visible organic matter (roots, pneumatophores and leaves) were removed from the soil samples prior to further analysis. Soil pH was measured with a pH meter Thermo- Orion model 290A by using a 1:2 soil/water solution; whereas Electrical Conductivity was measured with a CL35 conductivity meter by using a 1:5 soil/water solution. Dry Bulk Density was calculated by dividing the dry mass of the soil sample (g) by its volume (cm^3) [12]. Particle size was determined using the hydrometer method [13]. The percentage of contribution of sand (>50 µm), clay (>2 µm) and silt (<2 µm) was measured at each sampling depth. Organic matter content (%) was quantified using loss on ignition (LOI) method, which assumes organic content represents Carbon content, samples were combusted at 450°C for 8 hours [14]. Organic carbon content (%) was determined from organic matter content by multiplying by a factor of 0.4. The Carbon storage rate (Kg C m^{-2}) in soils was calculated as the product of the soil carbon density (g cm^{-3}) and the length (cm) of the respective core section.

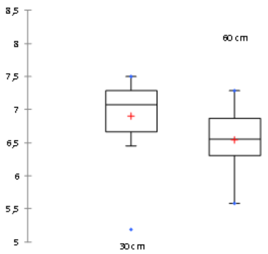
2.4 Statistical Analysis

All statistical analysis was run in XLStat 2016, descriptive, comparative (differences between sampling sites and depths) and relational statistical analysis were performed for each determined parameter at two sampling depths, including carbon storage rate. For all comparative analysis, significant differences were determined at $\alpha<0.05$.

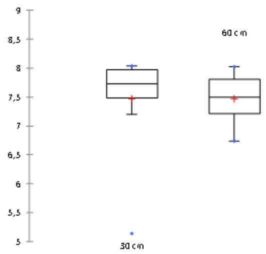
3 Results and Discussion

Figure 2a shows the pH values at 30 and 60 cm depth for the non-disturbed site (NC). pH values at 30 cm depth were neutral (6.908±0.638) whereas at 60 cm depth, soil samples were moderately acidic (6.545±0.487). On the other hand, Figure 2b shows the pH values at 30 and 60 cm depth for the disturbed site (NCD). pH values at both depths, 30 (7.464 ±0.838) and 60 (7.465±0.444) cm were moderately alkaline. pH values at 30 cm were higher than at 60 cm depth in both sites, but these differences were not significant for the non-disturbed site[12]. pH values were higher for the disturbed site, it was expected since, higher pH values are common in burned soils due to fire can alter soil characteristics.

Figure 2c shows the electrical conductivity values (dS m^{-1}) at 30 and 60 cm depth for the non-disturbed site (NC), obtained values at both depths, 30 (23.333±5.661) and 60 (24.142±4.628) cm, showed that soils in NC site are very strongly saline, and significant differences were not observed in conductivity between sampling depths. It was the same case for the disturbed site (NCD) (Figure 2d), where sampled soils were very strongly saline at both depths, 30 (20.242±5.006 dS m^{-1}) and 60 (22.983±4.404 dS m^{-1}) cm [12]. Applying statistical tests (Bartlett, Fisher and Levene), it was found that differences between sampling sites and depths were not significant.



(a)



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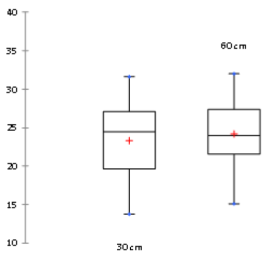

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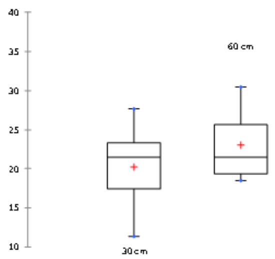
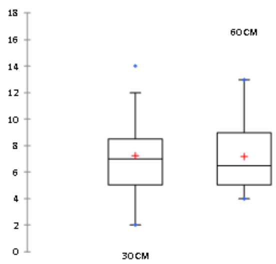


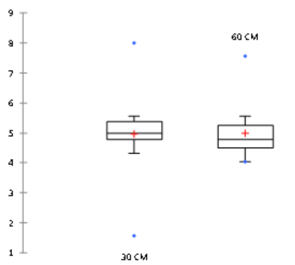
(d)

Fig.2. pH and Electrical Conductivity (dS m^{-1}) at 30 and 60 cm depth for a non-disturbed site (NC): (a), (c) and for a disturbed site (NCD): (b), (d)

In Figure 3a, the organic matter (%) contents are shown for the non-disturbed site (NC) at 30 (7.25±0.001) and 60 (7.16±0.001) cm depth; being mean value slightly higher at 30 cm depth; however, significant differences between sampling depths were not observed. On the other hand, in Figure 3b, organic matter (%) contents are shown for the disturbed site (NCD) at 30 (4.967±1.419) and 60 (5.000±0.931) cm depth; being mean value slightly higher at 30 cm depth; however, significant differences between sampling depths were not observed. Organic matter (%) values were higher in NC than in NCD, suggesting that the perturbation grade plays an important role in the organic matter content. NCD site has suffered frequent high intensity burnings. Slash-and-burn is a common agricultural cropping practice in tropical regions, being the most labour-efficient method used by farmers, who believe that this practice increases crop yields. The problem is that many times, these burnings are not controlled. High intensity frequent burnings reduce the amount of carbon stored in soils, in part because reduced plant growth means less carbon being drawn out of the atmosphere and stored in plan matter. Applying statistical tests (Bartlett, Fisher and Levene), it was found that differences between sampling sites for organic matter were significant. In Figure 3c, organic carbon (%) contents are shown for the non-disturbed site (NC)at 30 (2.9±0.001) and 60 (2.867±0.001) cm depth; showing almost the same mean value at both depths; and as expected, significant differences between sampling depths were not observed. On the other hand, in Figure 3d, organic carbon (%) contents are shown for the disturbed site (NCD) at 30 (1.987±1.419) and 60 (2.000±0.931) cm depth; showing almost the same value at both depths; therefore, significant differences between sampling depths were not observed. In general, organic carbon (%) values were higher in NC than in NCD, suggesting that the disturbance grade plays an important role in the organic carbon content accumulated in a given site. Applying statistical tests (Bartlett, Fisher and Levene), it was found that differences between sampling sites were significant.



(a)



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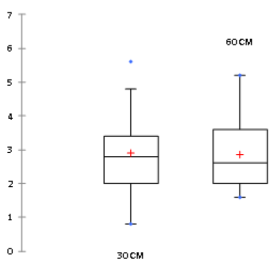

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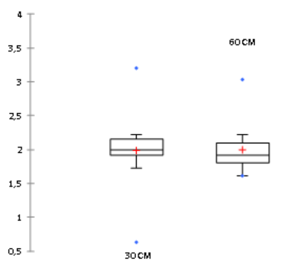


(d)

Fig.3. Organic matter (%) and Organic carbon (%) at 30 and 60 cm depth for a non-disturbed site (NC): (a), (c) and for a disturbed site (NCD): (b), (d)

In Figure 4, soil particle size measured as percentage contribution of sand, clay and silt at 30 and 60 cm depth for NC and NCD are shown. Soil Texture for both sites was sandy loam, being the sandy and silt contribution higher at 30 cm in NCD.

The contribution of sand, clay and silt was almost the same at 30 and 60 cm depth for NC. The sand contribution at NCD was higher in comparison with soils at NC; whereas, the content of clay was slightly higher in soils at NC.

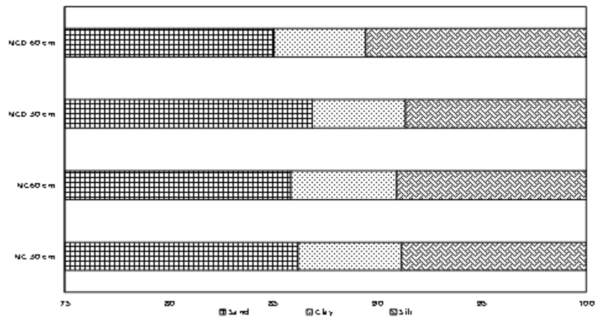
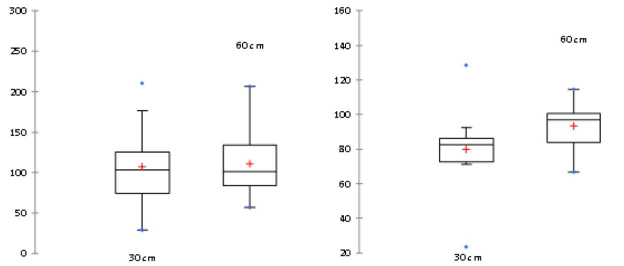


Fig.4. Soil particle size measured as percentage contribution of sand, clay and silt at mangrove forest in the non-disturbed site (NC) and the disturbed site (NCD) at 30 and 60 cm depth.

In Figure 5a, carbon storage rate values are shown for the non-disturbed site (NC), with a mean value of 107.071 Kg C m^{-2}; whereas in Figure 5b, carbon storage rate values are shown for the disturbed site (NCD), with a mean value of 79.759 Kg C m^{-2}. As can be observed from Figure 5, carbon storage rates were higher at 60 cm depth, however, significant differences were not found between sampling depths. Comparing between sites, carbon storage rate was higher at non-disturbed site (NC) in comparison with the disturbed site (NCD), even, in some cases, obtained values at NCD were almost half than obtained at NC, suggesting that the grade of perturbation plays an important role on the carbon storage potential. Applying statistical tests (Bartlett, Fisher and Levene), it was found that differences between sampling sites were significant.

Since soil sampling was made during the same season and given the proximity of the sites to each other; differences in the measured parameters cannot be attributed to soil morphology and hydrologic conditions, and for this reason, significant differences between sampling depths were not found. Commonly, differences between sampling depth are more related to seasonal variability and the influence of water sources (contribution of tides, runoff and rainfall). It suggests that in the case of this study, the observed variability could be closely related to the nature and specific conditions of each sampling site, for example, vegetation structure (density of the forest, dominant species, age and tall of the trees) and degree of site disturbance.



(a) **(b)**

Fig.5. Carbon storage rate (Kg C m^{-2}) for a non-disturbed site (NC): (a) and a disturbed site (NCD): (b) at 30 and 60 cm depth

Carbon storage rate can be related to mangrove tree density or average height. It has been reported that forests with a higher density, taller and older trees have more potential to capture carbon at faster rates in comparison with smaller, shorter and younger trees [15]. During this study, the effects of mangrove vegetation structure on carbon storage were evident. The tallest trees were observed at the non-disturbed site (NC); whereas at the disturbed site, mangrove individual were shorter. The carbon storage rate was positively related to mangrove forest density at non-disturbed site (NC), where mangrove tree density was significantly higher than at the disturbed site (NCD). In addition, it has been reported that the carbon storage rate can be related to the age of a mangrove forest; since older forests have also enough time to accumulate carbon into the soil carbon pools, increasing their storage. Regarding to the age of mangrove individuals, since NC site is non disturbed, the older individuals were observed at this site; whereas at NCD site only young individuals were observed.

Since sandy soil does not promote organic matter retention like clay and silt, a strong relationship between carbon in soils and particle size has been reported [16]. According with this, since the carbon storage rates were significant lower in the disturbed site (NCD) where soils had a higher sand content in comparison with the non-disturbed site (NC), it was found that besides the structure of the vegetation, soil texture is another environmental variable influencing on organic carbon content in soils.

Bi-variate and multi-variate statistical analysis

Tables 1 and 2 show the results for the bi-variate analysis (Pearson correlation Matrix) for NC and NCD, respectively. The non-disturbed site (NC)

(Table 1) showed negative significant correlations between conductivity and sand (-0.717), and for sand with organic carbon (-0.533) and organic matter (-0.533). Electric conductivity is a good overall indicator of soil fertility and it can be used to show the capacity of the soil to store nutrients, in this way, low electric conductivity values are often found in sandy soils with low organic matter levels, whereas, high electric conductivity levels are usually found in soils with high clay content. It could explain the found significant negative correlations. The significant correlation between organic carbon and organic matter with conductivity (0.480) can be explained, since electrical conductivity is influenced by a mixture of physicochemical properties such as texture, organic matter, moisture, salinity and so on. Significant positive correlations between silt-organic matter (0.455) and silt-organic carbon (0.455) indicate that the capacity of a soil to store organic matter is related to the concentration of silt and clay particles, the presence of oxides, and the degree of aggregation. In addition, it is necessary to take into account that the decomposition of organic matter is more rapid in sandy soils than in clay and silt soils, it can explain this positive correlation.

Table 1. Pearson correlation coefficients of the measured variables for the non-disturbed site (NC)

Variables	pH	Conductivity	Sand	Clay	Silt	Organic Matter	Organic Carbon
pH	**1**	0.239	-0.292	0.074	0.272	0.184	0.184
Conductivity	0.239	**1**	**-0.717**	0.135	**0.689**	**0.480**	**0.480**
Sand	-0.292	**-0.717**	**1**	-0.324	**-0.898**	**-0.533**	**-0.533**
Clay	0.074	0.135	-0.324	**1**	-0.126	0.224	0.224
Silt	0.272	**0.689**	**-0.898**	-0.126	**1**	**0.455**	**0.455**
Organic Matter	0.184	**0.480**	**-0.533**	0.224	**0.455**	**1**	**1.000**
Organic Carbon	0.184	**0.480**	**-0.533**	0.224	**0.455**	**1.000**	**1**

Values in bold are different from zero at a significance level of α=0.05

Table 2. Pearson correlation coefficients of the measured variables for the disturbed site (NCD)

Variables	pH	Conductivity	Sand	Clay	Silt	Organic Matter	Organic Carbon
pH	**1**	**-0.638**	0.066	-0.382	0.071	0.056	0.081
Conductivity	**-0.638**	**1**	**-0.467**	0.304	0.326	0.177	-0.019
Sand	0.066	**-0.467**	**1**	0.041	**-0.938**	0.041	-0.333
Clay	-0.382	0.304	0.041	**1**	-0.384	0.386	-0.203
Silt	0.071	0.326	**-0.938**	-0.384	**1**	-0.171	0.378
Organic Matter	0.056	0.177	0.041	0.386	-0.171	**1**	-0.078
Organic Carbon	0.081	-0.019	-0.333	-0.203	0.378	-0.078	**1**

Values in bold are different from zero at a significance level of α=0.05

In Table 2, it can be observed that electrical conductivity showed a negative significant correlation with pH (-0.638). pH influences the physical, chemical and fertility properties of the soil. With respect to the latter, the assimilation of nutrients from the soil is influenced by pH, since certain nutrients can be immobilized under certain pH conditions and not be assimilated by plant. On the other hand, electric conductivity and sand showed a negative significant correlation coefficient (-0.467), since low values of conductivity are commonly found in sandy soils. Finally, a strong negative correlation was found for sand-silt, it can be explained due to intense fires may permanently alter soil texture by aggregating clay and silt particles into stable sand-sized particles, making the soil texture more coarse and erodible.

A principal component analysis (PCA) was applied to the data set of the measured variables in NC site (Table 3). Two factors were required in order to explain 69.3% of the total variability of data.

Table 3. PCA factor loadings for measured variables in NC site

Factor loadings	F1	F2	F3
pH			**0.467**
Conductivity	**0.635**		
Sand	**0.799**		
Clay		**0.483**	
Silt	**0.666**		
Organic Matter	**0.673**		
Organic Carbon	**0.673**		

Only statistically significant loadings are shown

The first component includes Conductivity, sand, silt, organic matter and organic carbon, indicating that soil texture influences on the net mineralization of organic matter and the amount of organic carbon stored in the soils. F2 and F3 factors include clay and pH, respectively.Table 4 shows the results for the PCA Analysis applied to data set of the measured variables in the disturbed site (NCD). Two factors were required in order to explain 63.75% of the total variability of data. The first component included sand and silt. Clay and silt particles provide large specific surface areas and numerous reactive sites at which organic carbon can be sorbed, whereas, the sand particles dominated by quartz particles exhibits only weak bonding affinities to organic carbon. F2 included to pH, conductivity and clay, whereas, F3 included organic matter and organic carbon. Adverse effects of wastes on soil fertility attributes are associated with increases in pH, which may rich the alkaline range and decreases the availability of some micronutrients. In addition, electrical conductivity in soils is regulated by several soil fertility attributes such as pH, organic matter, cation exchange capacity, nutrients, soluble salts and organic ligands.

Table 4. PCA factor loadings for measured variables in NCD site

	F1	F2	F3
pH		**0.586**	
Conductivity		**0.587**	
Sand	**0.874**		
Clay		**0.585**	
Silt	**0.917**		
Organic Matter			**0.682**
Organic Carbon			**0.616**

Only statistically significant loadings are shown

4 Conclusion

This study assessed the differences in carbon storage potential between two sites: a non-disturbed site (NC) and a disturbed site (NCD). Results showed that water sources, soil morphology and hydrology did not influence significantly on the carbon storage rate since the sampling was made during the same climatic season. However, another environmental factors related to the disturbance degree and vegetation structure played an important role increasing the potential to accumulate organic carbon in the studied soils. Therefore, this finding could be a support for decision makers to promote the conservation of mangrove forests in the region of Terminos Lagoon, mainly those mature and dense mangrove forests.

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