Chapter 4

Estimation of Regional Carbon Storage Potential in Mangrove Soils on Carmen Island, Campeche, Mexico

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Additional information is available at the end of the chapter

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1. Introduction

Warming because of the increasing concentration of greenhouse gases is a global concern. Of all greenhouse gases, CO_2 has the greatest contribution to global warming. CO_2 can be stored in forests through biogeochemical processes governing the exchange between the atmosphere and forestry systems. Although forests are carbon sources, they can also mitigate global warming through carbon sequestration in different plant ecosystems, known as sinks, where carbon is accumulated by absorbing atmospheric CO_2. Carbon is assimilated and stored, both in live biomass (stems, branches, leaves and roots) and dead biomass (litter, wood waste, organic matter from soils and forestry products), and oxygen is released to the atmosphere during this process. Therefore, forests play an important role in the global carbon cycle [1].

IPCC has pointed out the importance of carbon sequestration by vegetation as a low-cost choice to reduce the atmospheric CO_2 content. Tropical forests store almost 50% more carbon than forests located outside the tropics [2]. Among the world's most productive wetlands are the mangroves, which fix and store large amounts of carbon in soils with unique characteristics of salinity, under anoxic and acidic conditions, with frequent flooding. The fact that these systems are productive under extreme conditions has been a point of interest to the scientific community. Therefore, correct management of tropical forests and wetlands constitutes an opportunity to store carbon. In the specific case of mangrove soils, where decomposition rates are low and their ability to store carbon is high, mangrove forests are an attractive alternative for carbon sequestration. Organic matter decomposition constitutes the main flux of carbon and nutrients in most terrestrial ecosystems. In the case of tropical forests, this is regulated by several factors: vegetation species, morphology, C:N ratio, climate, flooding frequency, moisture, salinity, temperature, and so on [3-4].

Mangrove forests have a special adaptation capacity since they can tolerate oxygen deficit, high levels of salinity and different flooding patterns. Mangroves like many other plants have the ability to change the physical and chemical properties of soils in which they occur [5]. The fast-growing young trees absorb about 30% more carbon than mature wood, but an old-growth forest generally stores more carbon in the soil, groundwater and surface vegetation than a plantation of trees with the same size. Latitude, climate, species diversity and other biological factors also affect carbon fluxes in forests [3]. It has been reported that degradation of fresh organic matter is slower in anaerobic environments (such as mangroves), which additionally involves oxidizing agents such as nitrate and microorganisms like bacteria and fungi [6], which only operate when the tannin concentrations are low, because they inhibit growth [7-8]. The presence and abundance of macro invertebrates such as amphipods (crabs) and isopods (cochineal) also accelerates the breakdown of tissues by direct consumption of leaves [6].

Carbon storage in estuarine wetlands is an efficient process with minimal release of greenhouse gases [9-11]. Although these wetlands cover only about 5% of the earth’s surface, they contain around 40% of global soil organic carbon. Mangrove forests cover vast extensions along the coastal zone in tropical regions. Mexico is the fifth country in the world in terms of the size of mangrove cover (655,667 ha). However, this surface is being lost at a yearly rate between 10,000 and 40,000 ha, mainly due to aquaculture, agriculture, deforestation and change in land use. Mangroves in Mexico are distributed within coastal lagoons and deltaic systems of the Gulf of Mexico (Veracruz, Tabasco and Campeche States) and the Pacific Ocean (Baja California, Sonora, Nayarit, Oaxaca and Chiapas) [12-14], with some coastal lagoons having ephemeral mouths which open during the rainy season or by action of the fishermen [5]. In the state of Campeche, mangrove cover accounts for 29.98% of the total mangrove cover in the country, with an extension of 196,552 ha [15]. Along the shoreline of Carmen Island, there are four main mangrove species: *Rhizophora mangle*, *Laguncularia racemosa*, *Avicennia germinans* and *Conocarpus erectus*. It is common to find them in associations, as a result of a succession process depending on the tidal levels that flood them but establishing clear control of one prevailing species or associations of two or three species.

Estimation of the dynamic of net fluxes of carbon between forests and the atmosphere is currently an open question in the main discussion forums about climate change. Sequestration and emission processes comprise a system with four main carbon sinks: vegetation, decomposition of organic matter, soils and forestry products. Since these sinks are interrelated, it is necessary to undertake a comprehensive systemic analysis. However, this is particularly difficult for tropical forests, where data about carbon content in vegetation and soils are scarce or unavailable. In spite of the importance of mangrove forests as carbon sinks, most of the research on carbon storage is focused on terrestrial ecosystems and little attention has been given to this type of ecosystem. Although in Mexico there are 113 Ramsar sites, the location of specific carbon sinks and their potential to sequester atmospheric carbon remains poorly defined, and there are uncertainties concerning carbon stock in wetlands at the local and regional scale. In order to complete carbon storage inventories and to reduce these uncertainties, it is necessary to obtain more local and regional information to support environmental policies to promote conservation and restoration projects as mitigation strategies. Therefore, this study focused on estimating regional carbon storage potential in mangrove soils in six sites uniformly distributed along Carmen Island in the region of Terminos Lagoon, in Campeche, Mexico, considering three climatic periods (cold fronts, called "north season", dry season and rainy season) and at two different soil depths (0-30 and 30-60 cm) during 2009 and 2010.

2. Sampling procedure

2.1. Study area description

The study area is located within the Atasta peninsula in southeastern Mexico in Campeche State, within the natural protected area called "Laguna de Terminos". This area has a warm-humid climate with rains occurring mainly in summer [Am(f)], according to the Köppen classification modified by García [16]. The geomorphology is characterized by marshes and wetlands, with altitudes between 0 to 20 masl, and the annual mean temperature is between 21 to 24.7°C.

Soils in this region are clayey with high fertility and high organic matter content, associated with dominant vegetation of red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*) and buttonwood mangrove (*Conocarpus erectus*) [17]. Climate conditions in this zone show three well-defined periods: dry season (from March to May), rainy season (from June to October) and "north season" (from November to February).

Sampling campaigns were carried out between February 2009 and October 2010 in the three climatic periods. Based on visual inspections, transects were established in a representative area of mangrove forest in each sampling site. They were selected to assure representative regional samples, taking into account the type of vegetation, easy access and the hydrology. The locations of the selected areas for this study are shown in Figure 1:

1.-Puerto Rico (P), located at 18° 36′ 55″ N and 91° 56′ 35″ W. Altitude: 11 masl. A great portion of this area has been deforested to establish farms. The remaining mangrove areas present in this zone correspond to the basin [18]. Three sampling zones were selected (P1, P2, and P3), which were located inland, with minimum ground slope and slow water renewal. Accumulated floodwaters in depressions in these sites correspond to cycling of organic matter and nutrients in a closed ecosystem [19]. Individuals of *Avicennia germinas*, *Rhizophora mangle* and *Laguncularia racemosa* were registered in this site, with dominance of *Avicennia germinans.*

2.-Xicalango (XC), located at 18° 37′ 02″ N and 91° 58′ 20″ W, with dominance of *Avicennia germinans* and *Conocarpus erectus*. Three sampling zones were selected (XC1, XC2 and XC3). The first one was completely flooded, the second one was dry and the last one was partially flooded.

3.-Nuevo Campechito (NC), located at 18° 38′ 28″ N and 91° 57′ 29″ W, with an association of *Conocarpus erectus*, *Laguncularia racemosa* and *Rhizophora mangle*. Three sampling zones were selected (NC1, NC2 and NC3). During the three climatic periods, the first one was flooded all the time, the second one was partiallyflooded and the last one was dry.

4.-Estero Pargo (EP), a 5.3 km long tidal channel on the lagoon side of Carmen Island, located at 18° 39′ 02.8″ N and 91° 45′ 46.9″ W, with an association of *Rhizophora mangle-Laguncularia racemosa* and *Conocarpus erectus*. This site only was flooded by rainfall during rainy and "north" seasons. Three sampling zones were selected (EP1, EP2 and EP3), which were moderately flooded during the dry and rainy seasons.

5.-Bahamitas (BH), located at the border of Términos Lagoon. This site is within the natural protected area named "Términos Lagoon", a Ramsar site since 2004. This site is located at 18° 41′ 57.1′′ N and 91° 41′ 50.7′′ W, with an association of *Rhizophora mangle*, *Laguncularia racemosa* and *Avicennia germinans*. Again, three sampling zones were selected (BH1, BH2 and BH3). This site was always flooded (received regular tidal inundation and was covered with fresh water during the "north" and rainy seasons).

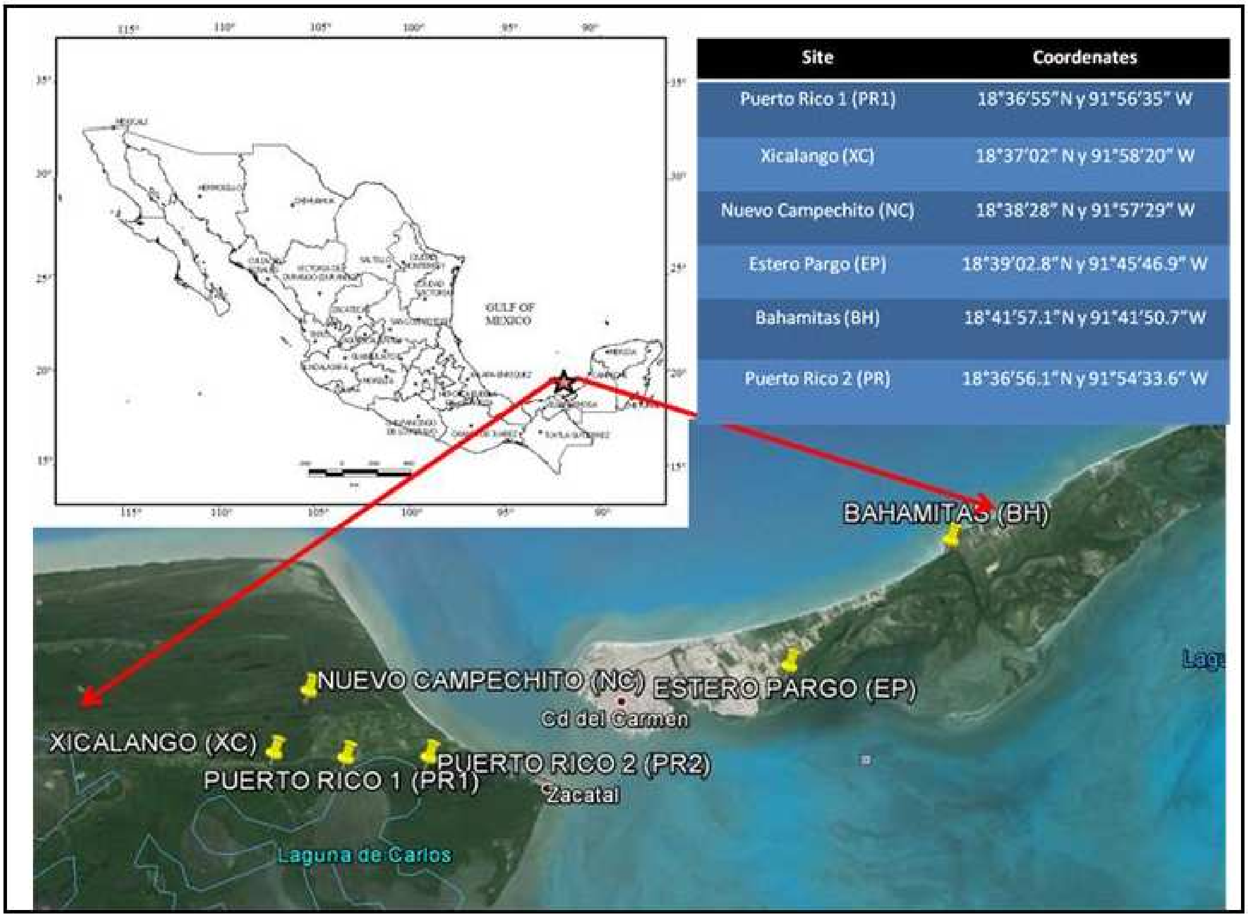
6.-Puerto Rico 2 (R), located at 18° 36' 56.1 "N and 91 ° 54' 33.6" W. The sampling zones selected were R1, R2 and R3. This site shows a great diversity of tropical vegetation, including *Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemosa*, and *Conocarpus erectus*.

2.2. Sampling methodology

The field study was carried out at six sites with three sampling zones for each one, between February 2009 and October 2010. In all sampling sites, the mangrove forest is subject to anthropogenic exploitation and can be considered as perturbed. We performed sampling campaigns to assess seasonal changes in carbon storage, considering three climatic periods: "north" season, dry season and the beginning of the rainy season, with six sampling campaigns. Not all sampling sites had comparable tidal influences during the study period. Some of them were always flooded (received regular tidal inundation and were covered with fresh water during "north" and rainy seasons), whereas other sites only were flooded because of the occurrence of rainfall during rainy and "north" seasons. Three sampling plots of 4 m x 12 m in each site were selected considering free access to the zone, risks, mangrove distribution by species and disturbances (Figure 1, Table 1). Based on visual inspections of the study area, transects were established in a representative area of the mangrove forest, locating three sampling points of 1 m^2 approximately for each of three sampling zones for all sites.

Duplicate soil samples were collected from the ground to 30 and 60 cm depth using a 193.3 cm^3 soil sampler in an area of 48 m^2[20]. The corer was carefully inserted into the soil and pushed down to 0.3 and 0.6 m. Because sampled soils are typically moist, the corer has a one-way check valve that creates a vacuum inside the liner as it is pushed into the soil, and when the device is pulled out it creates a suction force that retains the sample in the tube. This sampling method used was as proposed by Grossman and Reinsch [21] and Bernal and Mitsch [22] for sampling wet or inundated soils.

A total of 326 soil samples with replicates were taken. After extraction, each core was labeled and, sealed using tight-fitting end caps, and sent for laboratory analysis.



Site	Coordenates
Puerto Rico 1 (PR1)	18°36'55" N y 91°56'35" W
Xicalango (XC)	18°37'02" N y 91°58'20" W
Nuevo Campechito (NC)	18°38'28" N y 91°57'29" W
Estero Pargo (EP)	18°39'02.8" N y 91°45'46.9" W
Bahamitas (BH)	18°41'57.1" N y 91°41'50.7" W
Puerto Rico 2 (PR)	18°36'56.1" N y 91°54'33.6" W

Figure 1. Location of the sampling sites.

3. Analytical procedure

Free water was drained away and all biomass and solid materials (shells, roots, leaves, and so on) were removed. Then the samples were ground, dried at room temperature and sieved to pass through a 2 mm mesh. Organic carbon (OC) was quantified by using the ignition method and organic matter (OM) was determined by warming samples to 550 °C during 4 h[22] and the content of organic carbon was estimated by multiplying by a factor of 0.4 [23]. Total nitrogen (NT) was determined according to the semimicro-Kjeldahl method [24]. By this method, 0.5 g of soil sifted through 0.250 mm is weighed and then digested with a mixture of catalyst and sulfuric acid (H_2SO_4), after which it is distillated with NaOH and titrated with H_3BO_3 using a Shiro-Tashiro mixture as indicator [24].

To determine bulk density (Da), we used the test tube technique [25], by which a dry sample is passed through a 2 mm sieve, then a 50 ml plastic test tube is weighed and then 20 to 50 g of sifted soil is added. After this, the sample is placed on a firm surface and then it is hit 30 times per second with a rubber mallet in a vertical trajectory from 0.20 to 0.30 m. Finally, the volume and sample weight are registered [25]. Electrical conductivity (CE) was measured with a CL35 conductivity meter by using a 1:5 soil/water solution [26]. Soil pH was measured with a Thermo Orion model 290A pH meter by using a 1:2 soil/water solution [27]. Texture determination was carried out by the Bouyoucos method using a 5% sodichexametaphosphate solution as dispersant [28].

To estimate the carbon storage rate (CA), the following equation was used:

CA= CO% Da Pr,

Where CA= carbon storage rate, CO% = organic carbon content, Da= density and Pr= soil depth [29].

Descriptive, comparative and relational statistical analyses were performed for carbon storage rate, sampling site, sampling depth and climatic period.

4. Results

4.1. Relative humidity

Figures 2a-2c present the relative humidity (RH) values at 30 and 60 cm depth for all the sampling zones for north, dry and rainy seasons, respectively. Puerto Rico 1, Estero Pargo and Bahamitas showed the highest relative humidity whereas Nuevo Campechito and Xicalango showed the lowest values. Most of the sampling zones showed higher RH at 30 cm depth. Seasonal variation for all the sampling zones showed higher values of RH for the rainy season and the lowest values for the north season.

4.2. Soil texture

Bahamitas (BH) and Estero Pargo (EP) showed sandy texture, whereas the texture was sandy clay loam for Nuevo Campechito (NC), and Xicalango (XC). Puerto Rico 1 (P) and Puerto Rico 2 (R) showed sandy clay texture.

4.3. pH and electrical conductivity

The mean values for pH and electrical conductivity for all sampling sites during the three climatic periods are presented in Figures 3a-3c and Figures 4a-4c. pH ranged from 6.7 to 7.5 for Bahamitas, and from 6.89 to 7.12 for Estero-Pargo. This suggests that neutral soils are dominant in this study area. Significant differences were not found among the three climatic periods and sampling depths in BH. Soils in this site can be considered moderately to strongly saline. Electrical conductivity values were higher during the dry season for BH1 and during the rainy season for BH2 and BH3, where *Rhizophora mangle* and *Avicennia germinans* are the dominant species. The highest values for electrical conductivity in EP was found at 30 cm

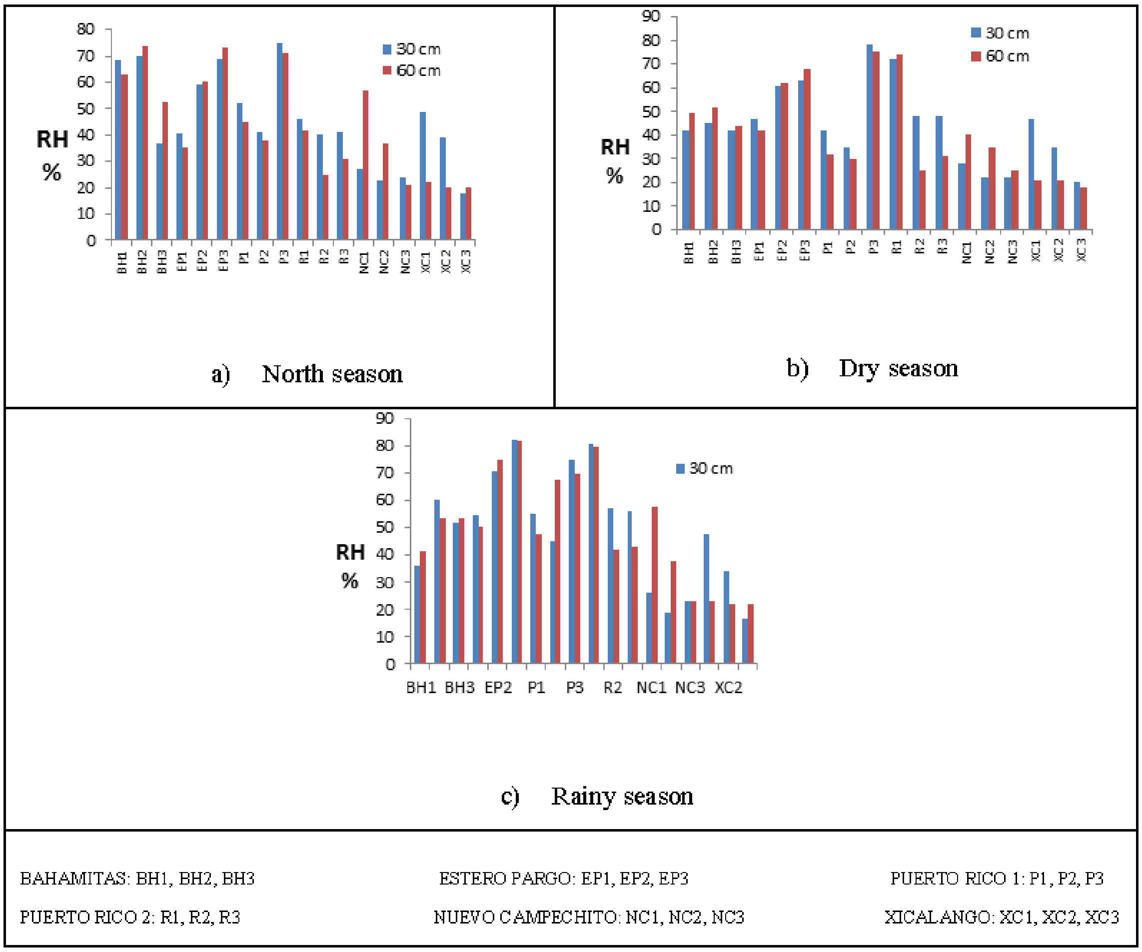
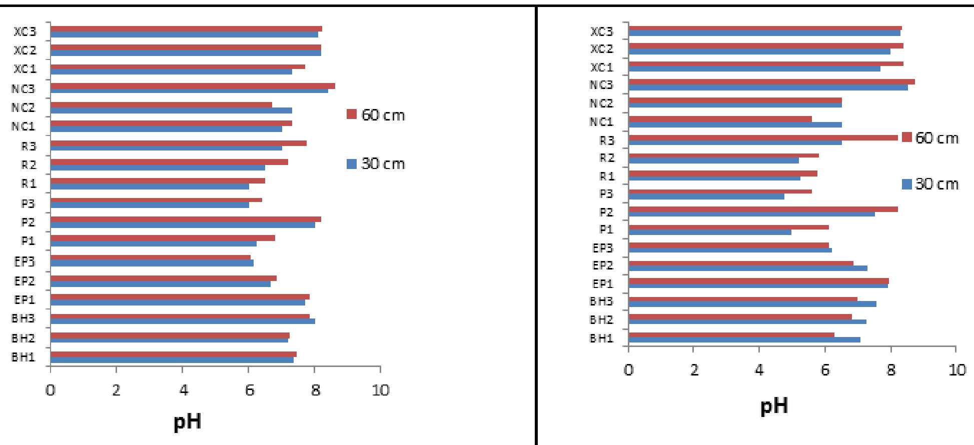


Figure 2. Relative humidity at 30 and 60 cm depth for all the sampling zones during north season (a), dry season (b) and rainy season (c).

depth, being higher during the dry season in EP1 and EP3, where *Conocarpus erectus* and *Rhizophora mangle* are the dominant species.

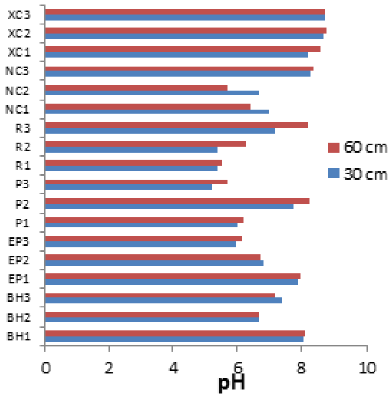
The pH values in Xicalango ranged from 7.96 to 8.35, whereas in Nuevo Campechito, the pH ranged from 6.55 to 8.46, suggesting that the soils are slightly alkaline in these sites and indicating the presence of soluble salts. Soils in these sites were acid, with the lowest pH values (6.5) and high values of electrical conductivity. No significant differences were found for electrical conductivity in NC and XC at 30 and 60 cm depth (ANOVA, $P< 0.05$). The highest values were found during the dry season, being highest for NC at 60 cm and highest for in XC at 30 cm depth.

Electrical conductivity in Puerto Rico did not show a clear pattern of variation regarding sampling depth. Marine aerosols due to its proximity to the coast probably influence its high salinity. Likewise, the low permeability in Puerto Rico soil promotes water accumulation, increasing sodium concentrations and contributing to low micro biota activity in these soils. Moreover, the hydrological characteristics of this mangrove forest are similar to those typical from a basin, characterized by heavy flooding, little or no tidal contact and high salinity. Soil



a) North season

b) Dry season



c) Rainy season

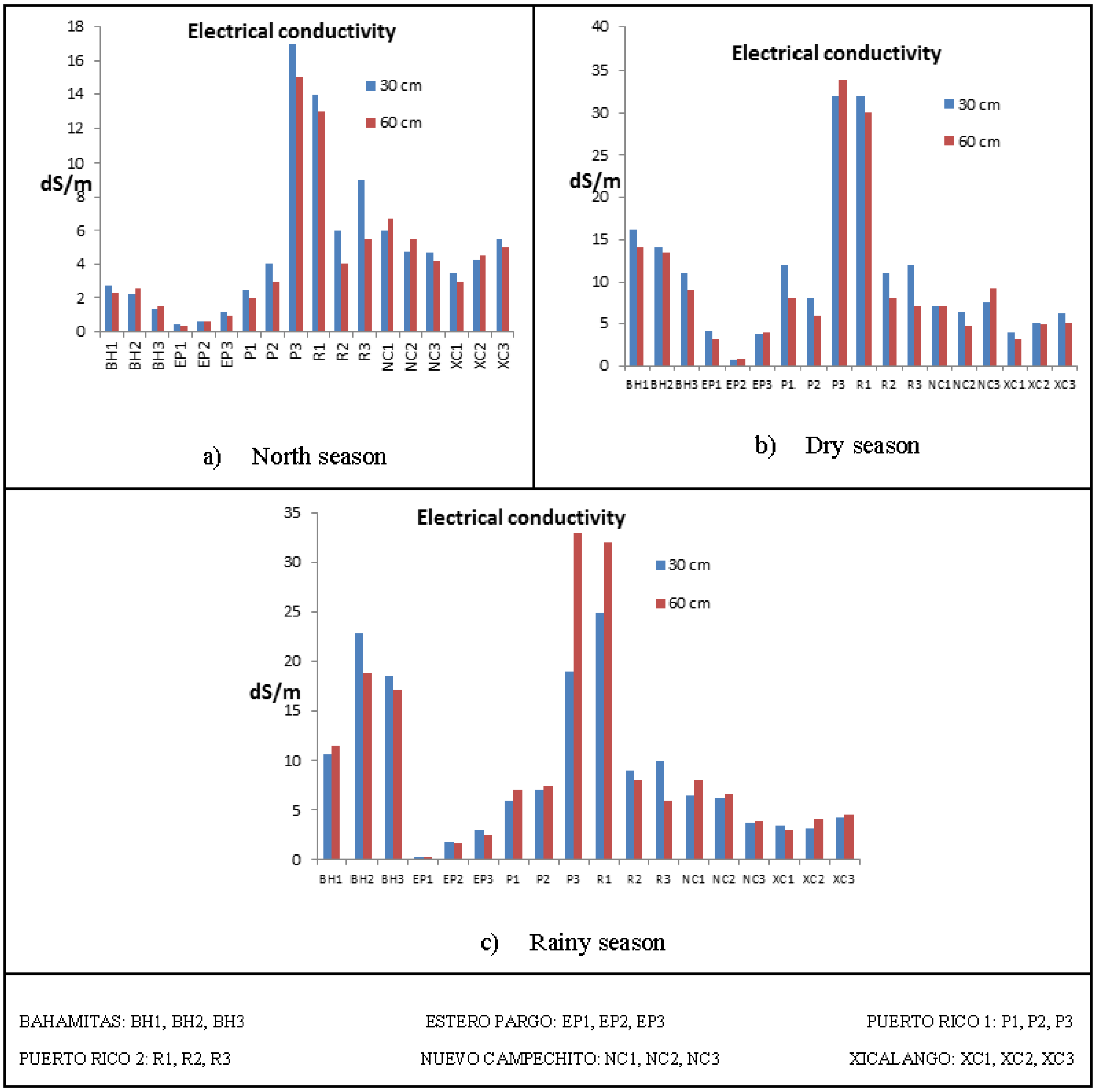
BAHAMITAS: BH1, BH2, BH3
ESTERO PARGO: EP1, EP2, EP3
PUERTO RICO 1: P1, P2, P3
PUERTO RICO 2: R1, R2, R3
NUEVO CAMPECHITO: NC1, NC2, NC3
XICALANGO: XC1, XC2, XC3

Figure 3. pH at 30 and 60 cm depth for all the sampling zones during north season (a), dry season (b) and rainy season (c).

pH variations in Puerto Rico were significant at the different depths and climatic periods (Tukey test, $P<0.05$). Soils in these sampling zones were more acidic at 30 cm depth, being more alkaline during the north season.

4.4. Organic carbon and organic matter content

The organic carbon concentrations for the three sampling zones in Bahamitas and Estero Pargo during the north, dry and rainy seasons are reported in Figures 5 a and 5b. The organic carbon (OC) content ranged from 4.76 to 15.73% for Bahamitas, and from 2.81 to 19.7% for Estero-Pargo. The mean carbon storage levels were 23.16 and 23.08 Kg C m-2 for Bahamitas and Estero-Pargo, respectively. Figures 6 a and 6b show the organic matter content (%) for the three sampling zones in Bahamitas and Estero Pargo during the north, dry and rainy seasons. In these sites, the long periods of tidal flooding (sites were flooded throughout the sampling



a) North season

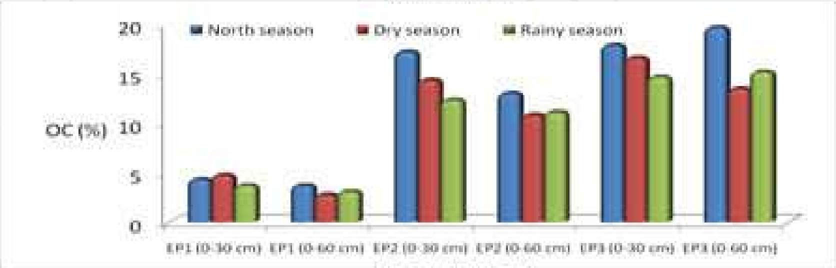
b) Dry season

c) Rainy season

Figure 4. Electrical conductivity at 30 and 60 cm depth for all the sampling zones during north season (a), dry season (b) and rainy season (c).

period) maintained anoxic conditions (below 10 cm of depth) and high organic matter and organic carbon contents. This explains why the highest values were found in the surface layer. This pattern is a general phenomenon observed in forests. The accumulation of organic matter is enhanced in sites with abundant rainfall or with deficient drainage. The highest values for organic matter, organic carbon and carbon storage were found during the north (when heavy rains occurred) and dry seasons. During the rainy season in these sites, accumulation of organic matter increases, but decomposition is slow and the accumulation remains until the north and dry seasons, resulting in values slightly lower during the rainy season in comparison with subsequent seasons. During the dry season, salts and dissolved organic carbon concentrate with increasing evaporation, whereas during the rainy season, pore waters were diluted with rain and runoff waters, resulting in lower organic carbon concentration.

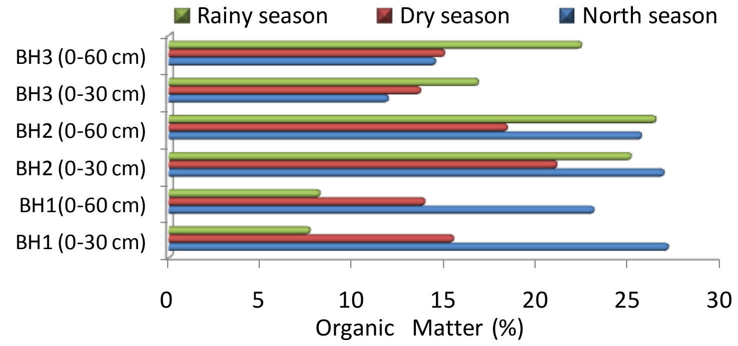
a) Bahamitas



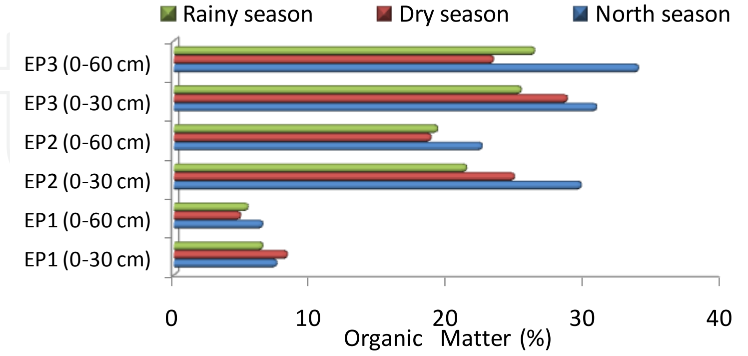
b) Estero Pargo

Bahamitas: BH1, BH2, BH3 Estero Pargo: EP1, EP2, EP3

Figure 5. Organic carbon content at 30 and 60 cm depth for all the sampling zones during the three climatic periods for a) Bahamitas and b) Estero Pargo.



a) Bahamitas

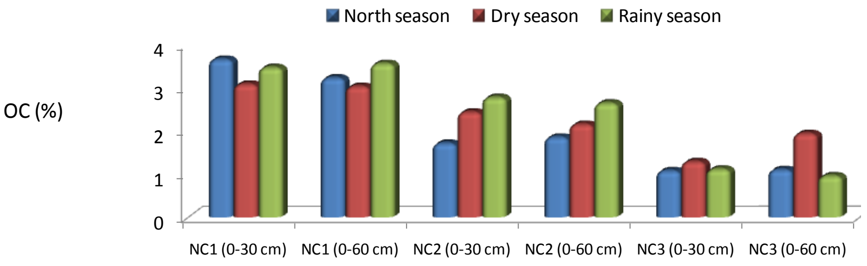


b) Estero Pargo

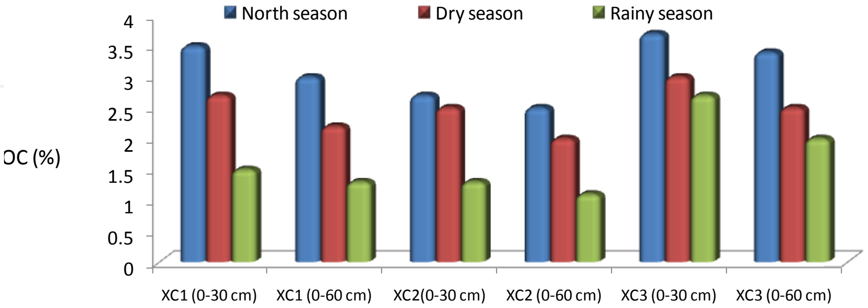
Bahamitas: BH1, BH2, BH3 Estero Pargo: EP1, EP2, EP3

Figure 6. Organic matter content (%) at 30 and 60 cm depth for all the sampling zones during the three climatic periods for a) Bahamitas and b) Estero Pargo.

The organic matter content for the three sampling zones in Nuevo Campechito and Xicalango during the north, dry and rainy seasons are shown in Figures 7a and 7b. The organic matter and organic carbon concentrations were higher at 30 cm depth. The same was observed for the organic matter content (%) for the three sampling zones in Nuevo Campechito and Xicalango during the north, dry and rainy seasons (Figures 8a and 8b). Organic matter ranged from 5.2 to 5.6% for Nuevo Campechito, and from 3.4 to 3.77% for Xicalango. The mean organic carbon contents were 72.78 Kg C m^{-2} for Nuevo Campechito and 79.29 Kg C m^{-2} for Xicalango. These high organic carbon contents were associated with the high productivity of the mangrove species that prevail in these sites, where litter accumulation causes high organic matter levels in the soils. In addition, the flooded conditions that prevailed during the sampling period maintained anoxic conditions that enhanced the carbon storage. Carbon storage was higher in live biomass in comparison with the soils. The forestry inventory revealed that most of the trees in these sites were younger than 7 years. Since it is well known that young trees store 30% more carbon than mature trees, this suggests that young individuals in growing stage in these sites store more carbon in live biomass than in soils. The organic matter and organic carbon contents were slightly higher in Nuevo Campechito than in Xicalango. Individuals of *Rhizophora mangle* with higher diameter and height were found in Nuevo Campechito in comparison with Xicalango. This species contributes a great quantity of organic matter due to litter falling on flooded soils, resulting in a low decomposition rate that increased the organic matter and carbon concentrations. On the other hand, in Xicalango there were zones where *Conocarpus erectus* was the prevailing species of mangrove, where litter was deposited on sandy soils with low moisture, resulting in a slower accumulation process.



a) Nuevo Campechito

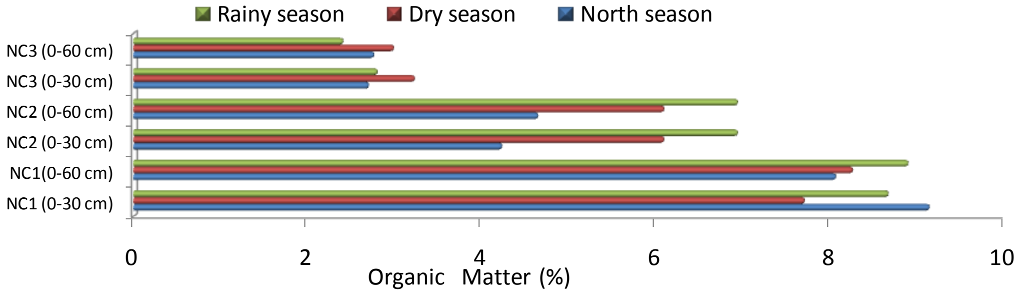


b) Xicalango

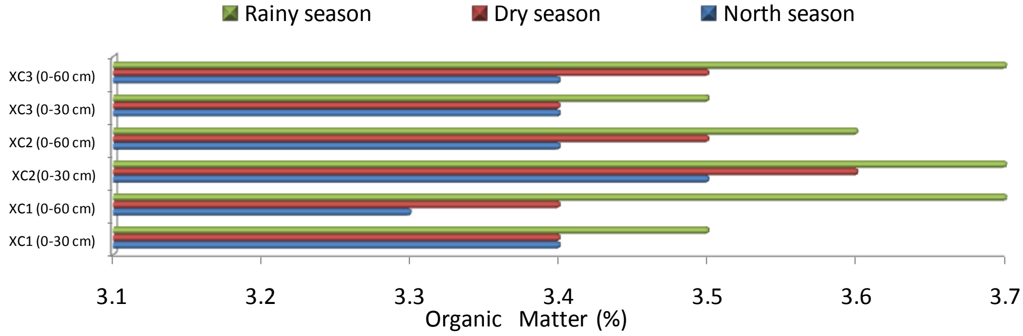
Nuevo Campechito: NC1, NC2, NC3 Xicalango: XC1, XC2, XC3

Figure 7. Organic carbon content at 30 and 60 cm depth for all the sampling zones during the three climatic periods for a) Nuevo Campechito and b) Xicalango.

Figures 9a and 9b show the result of the organic carbon content of the three sampling areas in Puerto Rico 1 and 2 in Puerto Rico for the north, dry and rainy seasons. In Puerto Rico, organic carbon ranged from 4.8 to 23.16% at 30 cm depth and from 2.99 to 18.61% at 60 cm depth for P1 and R1 sampling zones. Higher organic carbon concentrations were found in P3 and R1, reaching almost 14% of the content for the three climatic periods. P1, P2, R2 and R3 together accounted for almost 10% of the organic carbon content. The OC content diminished as the sampling depth decreased for all the sampling zones of this site. No significant differences were found for OC in the three climatic periods. These sites showed an organic carbon content between 7 and 11%, 0.2-0.35% of nitrogen, a C:N ratio from 41-47, CE and a carbon storage rate from 160 to 220 Kg C m^{-2}. The carbon storage rate decreased slightly with depth. Long periods of flooding maintained anoxic conditions. This could explain the finding of highest organic carbon and organic matter concentrations at 30 cm depth in this site.



a) Nuevo Campechito

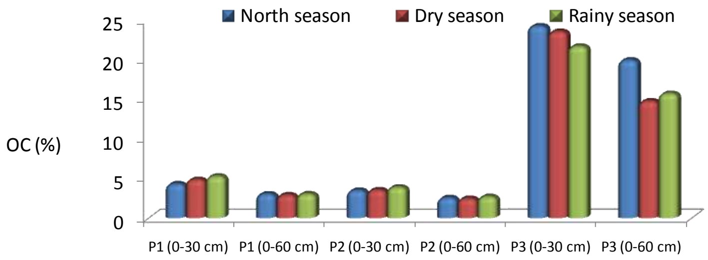


b) Xicalango

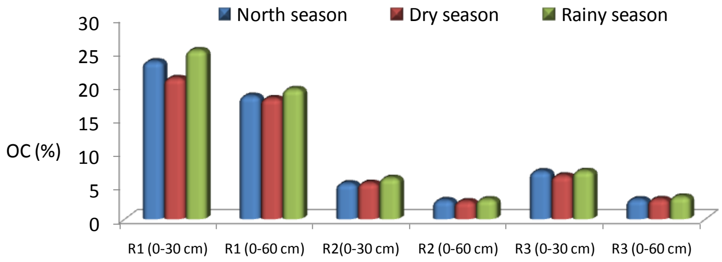
Nuevo Campechito: NC1, NC2, NC3 Xicalango: XC1, XC2, XC3

Figure 8. Organic matter content (%) at 30 and 60 cm depth for all the sampling zones during the three climatic periods for a) Nuevo Campechito and b) Xicalango.

The carbon storage in Bahamitas showed significant differences between the different climatic periods, with the highest values being found during the north season.The highest values found were for BH1 at 30 cm depth, for the three climatic periods, and for BH2 and BH3, during the dry season. However, for BH2 and BH3, the highest values found were at 60 cm depth during the north and rainy seasons. Carbon storage in Estero Pargo showed the highest values for EP2 and EP3, for the three climatic periods, where *Laguncularia racemosa* and *Rhizophora mangle* are the dominant species. the The lowest values for carbon storage for all three climatic periods were found in EP1, where the dominant species is *Conocarpus erectus*.



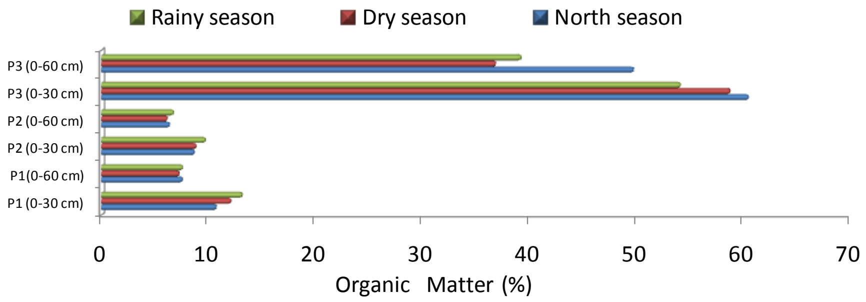
a) Puerto Rico 1



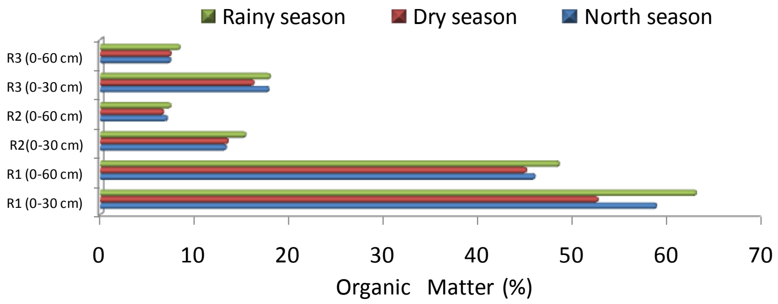
b) Puerto Rico 2

Puerto Rico 1: P1, P2, P3 Puerto Rico 2: R1, R2, R3

Figure 9. Organic carbon content at 30 and 60 cm depth for all the sampling zones during the three climatic periods for a) Puerto Rico 1 and b) Puerto Rico 2.



a) Puerto Rico 1



b) Puerto Rico 2

Puerto Rico 1: P1, P2, P3 Puerto Rico 2: R1, R2, R3

Figure 10. Organic matter content (%) at 30 and 60 cm depth for all the sampling zones during the three climatic periods for a) Puerto Rico 1 and b) Puerto Rico 2.

Site/Land Use	carbon storage (kg C m^{-2}).	Reference
Gahanna woods, Ohio, USA/isolated and forested wetland.	3.03	[22]
Old Woman Creek, Ohio, USA/riverine flow-through wetland.	2.77	
La Selva, Costa Rica/isolated and forested wetland.	0.43	
Earth University, Costa Rica/slow-flowing slough wetland.	1.67	
Palo Verde, Costa Rica/riverine flow-through wetland.	1.36	
Southern California, USA/coastal lagoon and wetland complex.	0.033	[30]
Okinawa Island, Japan/pioneer mangrove stand.	5.73	[31]
Tabasco, Mexico/ Red and white mangrove stand.	47.2-82.2	[9]
Southeast Australia/disturbed wetland soils.	6.61	[32]
Southeast Australia/undisturbed wetland soils.	11.19	
Sydney, Australia/coastal wetlands.	13.9	[33]
Tropical and subtropical China/marsh vegetation	40.0	[34]
Brazil/Oxisol.	12.0-24.0	[35]
Brazil/agricultural soils.	2.0-10.0	[36]
Bahamitas, Campeche, Mexico/neutral and sandy soils, perturbed mangrove forest.	23.16	This study
Estero Pargo, Campeche, Mexico/neutral and sandy soils, perturbed mangrove forest. Estero-Pargo.	23.08	
Nuevo Campechito, Campeche, Mexico/sandy clayloam, associations of *Rhizophora mangle-Lagunculariaracemosa-Conocarpuserectus*.	70.00	
Xicalango, Campeche, Mexico/sandy clay loam, associations of *Avicenniagerminans-Lagunculariaracemosa-Conocarpuserectus*	55.00	
Puerto Rico, Campeche, Mexico/sandy clayloam, associations of *Avicenniagerminans-Rhizophora mangle-Lagunculariaracemosa.*	190	

Table 1. Comparison of carbon storage rate found in this work with those obtained in other sites.

Conocarpus erectus and *Laguncularia racemosa* are the dominant species in NC3 and NC1. Carbon storage in soils of NC was lower in NC1 and NC2, which have associations of *Rhizophora mangle, Conocarpus erectus* and *Laguncularia racemosa*. In contrast, XC2 and XC3 did not show significant differences between each other. Carbon storage in soils of NC3 and XC1 were similar to those reported in forests with associations of *Rhizophora mangle-Avicennia germinans* (143.3 y 122.2 t C ha^{-1}) in French Guiana [29]. XC showed the highest values of carbon storage, ranging from 74.10±4.16 to 119.50±20.40 t C ha^{-1}, with significant differences ($p<0.05$) with NC. This behavior is due to the high productivity of species associated with this type of soil, resulting from defoliation and incorporation of high organic matter content in these soils.

There were significant differences for carbon storage in Puerto Rico 1 and Puerto Rico 2, showing the highest values in P3 and R2, with 325 and 320.50 t ha^{-1}, respectively, followed by R3 with 141.56 t ha^{-1} and finally P2 with 101.78 t ha^{-1}. In general, carbon storage in all sampling zones in the six studied sites showed significant differences regarding sampling depth.

In mangrove forests, the stand age is a determinant factor that influences the amount of organic carbon in the soil regardless of season. Comparing our results with carbon storage data obtained in other sites (Table 1), we can suggests that sandy and neutral soils as in our study area and associations of red and white mangrove have good potential of carbon sequestration, considering that our mangrove individuals were from young to mature in reproductive age. We can expect this potential to increase in the coming years.

5. Conclusions

Climatic season and soil type (vegetative community present and hydrogeomorfology) were the most important variables in this study. Concentrations of carbon in tropical soils tend to decrease with depth. This behavior indicates that a small fraction of carbon that is being introduced into the soil remains there, being typical of tropical forests where organic matter and nutrients do not accumulate because they are quickly used by biotic systems. It can be concluded that the accumulation of organic matter and carbon storage are determined by the rate of decay rather than the production rate of organic matter. The combination of anaerobic conditions on site and productivity of the system tends to cause the soils that remain flooded most of the time to be highly organic. High rates of carbon sequestration in this study indicate that conservation efforts to protect wetlands would have high benefits for the mitigation of global warming through the regulation of atmospheric carbon concentrations in this area.

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