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Distribution pattern of total organic carbon in soils of micro tidal mangrove ecosystem in west coast of Sri Lanka

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Abstract

Soil organic carbon represents a significant pool of carbon within the biosphere, which estimated over three times of carbon that found in the atmosphere. Mangroves play a important role in the accumulating higher soil organic carbon among the other wet lands and terrestrial ecosystems, due to its superior in primary productivity and extensive root system enhances the trapping of sediments suspended in the tidal and flooding water currents.

Study was focused on the stock of total organic carbon (TOC) and its horizontal and vertical distribution in mangrove soils of Negombo estuary, Sri Lanka. Two study sites, Kadolkele, a relatively undisturbed natural mangrove area and Wedikanda, a stand have been cultivated and sustainably utilized by fishermen to extract twigs and branches for "brush parks".

Highest TOC content (12.42 %) in its dry weight was recorded vertically at top soil layer (0-15 cm depth) and horizontally, between the zone 10- 30 m landwards from estuarine shoreline. Bulk density of mangrove soil ranged between 1.10 – 1.20 g cm^{-3} and lowest was recorded at upper layer and slightly increase with the depth. Highest amount of TOC was calculated, 204.93 t ha^{-1} at top soil layer (0 -15 cm) and observed decrease in vertically. TOC of 104.66 t ha^{-1} at 15 -30 cm depth and 68.58 t ha^{-1} at 30 - 45 cm depth respectively. A statically significant ($p<0.05$) positive correlation ($r^2 = 0.67$) was revealed between TOC in mangrove soil and stem density.

Introduction

Wetlands play a key role as sources of environmental services. Although wetlands cover about 5% of terrestrial surface, they are important carbon sinks, as they contain 40% of global soil organic carbon. (Mitsch and Gosselink, 2000). Estuarine wetlands in particular are reportedly have a higher capacity of carbon sequestration per unit area of approximately one order of magnitude greater than other types of wetlands. Mangroves occur in association about 75% of the coastlines on Earth, between latitudes 25 ^{0} N and 25 ^{0} S, and they are adapted to inter-tidal areas characterized by high temperature, fluctuating in salinity and anaerobic substrates resulted by inundation. Empirical evidence support that mangroves are important in balancing total organic carbon in the associated environment, including atmosphere (Ceron Breton *et al*, 2011).

Soil characteristics are one of the most important environmental factors directly affecting mangrove productivity and vegetation structure. It was noted that the type of soil and its chemical state are in turn affected by factors such as topography, tidal or riverine sedimentation pattern, climate, tidal range and long term sea level changes (Kevin, 1984). Chen and Twilley (1999), reported that mangrove soil formation is the combination of several ecological processes including organic matter production (above and below ground components), exportation, decomposition, burial and sedimentation of inorganic matter. The amount of organic carbon in soil is important in soil classification and chemical characterization. Many soil bacteria require organic carbon levels, exceeding 6%, which is conducive for better microbiological action than in mineral soils (Kevin, 1984). Organic matter dynamics are tightly coupled with biogeochemical cycles of nitrogen and phosphorus in mangrove soils through the processes of decomposition, mineralization and plant uptake (Chen and Twilley, 1999).

Approximately 1400-1600 Pg (1Pg=10^{15} g) of carbon is stored in soil in the form of organic matter, which is nearly three times that of the above ground biomass and approximately twice as much of the atmospheric carbon pool (Post *et al*., 1982; Eswarn *et al*., 1993; Zhag *et al*., 2007).

During the past few decades, strong evidence has emerged to signify the difference among the mangrove soils due to presence of different mangrove species. Nickerson & Thibodeau (1985); Thibodeau & Nickerson (1986), attributed these differences to the varying capacities of mangrove species in altering soil conditions adjacent to its root systems through specific physiological mechanisms such as releasing oxygen into the reducing soils.

Due to scanty records available on the carbon dynamics of micro tidal mangrove soils in Sri Lanka, the study was conducted with the objective of estimating the total organic carbon (TOC) content in different depths of mangrove soils in two mangrove areas, Kadolkele, and Wedikanda, located in the northern end of Negombo estuary, located on the west coast of Sri Lanka.

Two mangrove areas,i.e. Kadolkele, a relatively undisturbed natural mangrove stand and Wedikanda, a stand that has been cultivated and maintained by fishermen to extract twigs and branches to construct “Brush Parks”, a traditional fish aggregation device practiced in this estuary, were selected with the additional objective of understanding the impact of mangrove cultivation for economic purposes on total carbon retention capacity of these mangrove soils.

Materials and Methods

Study area

Negombo estuary is located on the west coast of Sri Lanka, that lies in the wet climatic zone where the annual rainfall is 2025 mm and the mean annual temperature is 27.0 ºC. The average tidal amplitude is less than 50 cm and therefore can be categorized micro-tidal. Total extent of mangrove forests are estimated to be 350 ha (Samarakoon and van Zon,1991). The two study sites, Kadolkele mangrove stand (7º11’50.48” N – 79º 50’47.50” E), extends over 13.5 ha and Wedikanda (7º 11’29.09” N – 79º 50’04.96” E), over 9 ha. (Figure.1).

Soil samples were collected from the two study sites, i.e. Kadolkele and Wedikanda in Negombo estuary. Belt transects of 10 m width were laid perpendicular to the shoreline across the environmental gradient in randomly selected representative locations in the study areas. Each transect was divided in to 10m x 10m sampling plots. Three transects with 40 plots ware used to take samples. Mangrove plants in the sampling plots were indentified and basic variables related to vegetation structure were measured using standard methods (Cintron and Novelli, 1984; Kathiresan and Khan, 2010).

Soil sampling and chemical analysis

Soil samples were collected with a split core sampler 77801 (2” x12’), from minimum of five randomly selected sites within each sampling plot (100 m^2). At each site soil samples were collected from three (3) depths, i.e. 0 – 15 cm, 15 – 30 cm and 30 – 45 cm.

Composite soil samples were prepared for each depth and they were air-dried and subsequently oven dried at 60º C to constant weight. Soil lumps were crushed with mortar and pestle and the soil was sieved through BS 1377 standard sieve with 150 µm mesh. Sieved soil samples were then analysed using standard wet chemical technique which adopts rapid dichromate oxidation of organic matter(Walkey-Black,1934, Anderson and Ingram,1998, Schumacher, 2002), for determining the percentage total organic carbon content (%TOC) in mangrove soil.

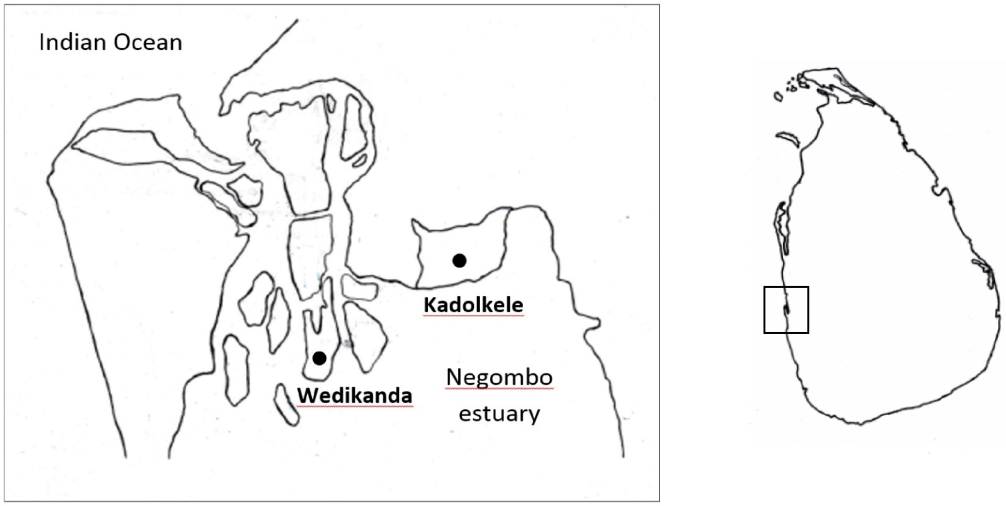

Figure1. Location of study sites in the mangrove areas of Negombo estuary, Sri Lanka

$K_2Cr_2O_7$ solution was used to oxidize the organic carbon in the soil samples under acid medium. The amount of oxidized carbon in the sample was measured by determining the amount of chromic ions produced during the oxidation. Colorimetric method was used to determine the chromic ion concentration. The colour intensity was determined by using UV-visible spectrophotometer (Spectro UV-VIS Double Beam UVD-3000) under 600 nm absorbance. Bulk density of mangrove soils at Kadolkele and Wedikanda were determined using standard procedures (Anderson and Ingram, 1998) and the weight of TOC in soil was calculated.

Results

Approximately similar mean percentages (12 %) of TOC were revealed to occur in the top soil layer (depth of 0-15 cm) in both the study sites (Kadolkele and Wedikanda) and it declined with depth and the lowest amounts of TOC were in 30-45 cm depth, in study sites. Percentage TOC in the sub-surface layers (15 -30 cm) varied between 2.5 – 7.8 at Kadolkele and 5.4 – 9.9 at Wedikanda. TOC content was revealed to vary with distance from estuarine shoreline (Figure.2).

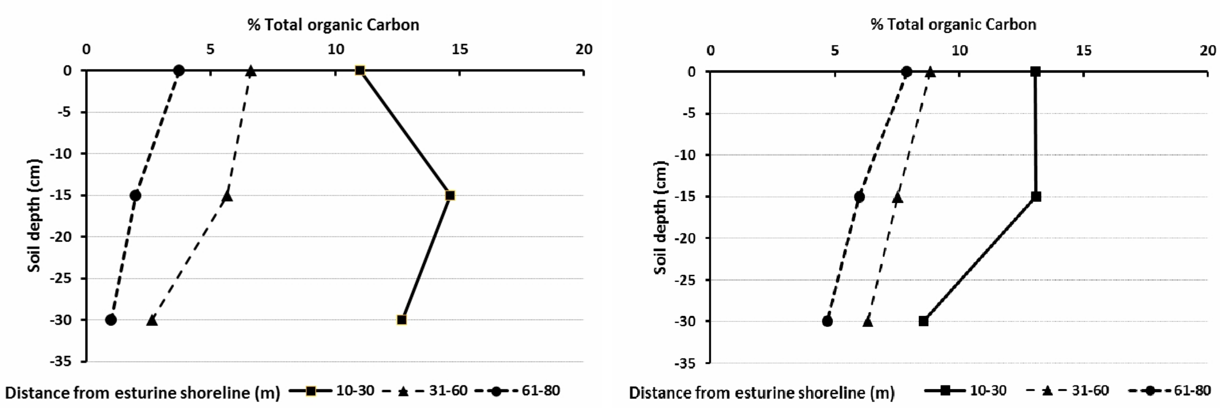

Figure2. Mean TOC in mangrove soils at varying distances from estuarine shoreline and with depth at Kadolkele and Wedikanda in Negombo estuary.

Mean TOC was calculated separating of three distance classes (10-30 m, 31-60 m and 61-80 m) from estuarine/lagoon shoreline to landwards. Highest TOC content was revealed within 10-30 m distance class and decline with landwards (Figure.3).

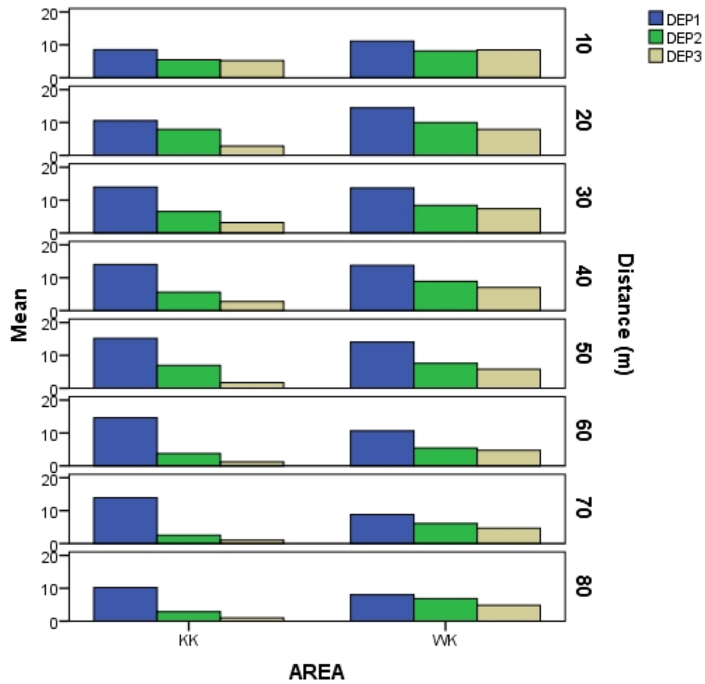

Figure3. Percentage TOC of soil (dry weight) at Kadolkele (KK) and Wedikanda (WK) at varying distances from estuarine shore line

A statistically significant ($p<0.05$) positive relationship was revealed between mangrove stem density and total organic carbon accumulated in soil (Figure.4).

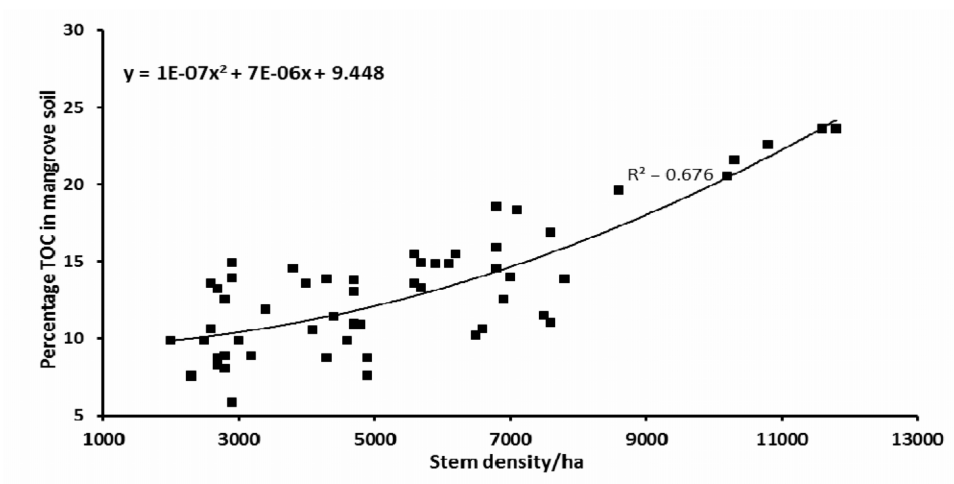

Figure4. Relationship between mangrove stem density and % total organic carbon (TOC) in mangrove soil

Mean bulk density of soil in the two study areas ranged from 1.1 to 1.3 g cm^3. Using the average % TOC in each layer of soil obtained from the two study sites (0-15, 15-30 and 30-45 cm), average amount/weight of TOC content embedded in mangrove soils in Negombo estuary was calculated (Table.1).

Table1. Mean %TOC, bulk density and amount of TOC in different depths of mangrove soil in Negombo estuary

Soil layer/ depth (cm)	Mean %TOC	Bulk density (gcm^3)	Amount of TOC ($t\ ha^{-1}$)
0-15 cm	12.42	1.10	204.93
15-30 cm	6.23	1.12	104.66
30-45 cm	3.81	1.20	68.58

Discussion

General trend observed on presence of total organic carbon (TOC) content in soils of tropical forests is a declining tendency with depth (Grace et al, 2006; Breton-Ceron et al, 2011) and a similar propensity was observed in the mangrove soils of the two study sites (Kadolkele and Wedikanda) in Negombo estuary, where TOC percentage decreased nearly by 50% from its surface to sub-surface layer at 15-30 cm depth and a similar decrease was observed in the soil layer further below at 30 – 45 cm depth (Table 1). The average % TOC content per unit dry weight of soil (12%) in the surface layer of three study sites in Negombo investigated by Pahalawattacrachchi (1995) and Priyadarshani et al (2008) have reported compatible results to that of the present study. TOC in soil shows a vast variability between different sites in the same vegetation. Bouillon et al, (2003) reported TOC content by percentage of soil dry weight, to range 0.6 -31.7 % from two mangrove areas at Godavari delta, in India and Pambala, Sri Lanka. This may be attributed to cumulative differences of physical factors, especially frequency and length of tidal inundation, elevation of the location, frequency and amounts of freshwater input that influences soil salinity and biotic factors such as stand density, mangrove plant, animal and microbial diversity as well as age of the stand.

TOC content in top soil layer at water front-areas (0 – 10 m) in general is lower than that was recorded for landward parts of the inter-tidal areas and this may be due to regular flushing of organic matter by tidal currents. Highest TOC content was revealed at 20 -50 m area from waterfront and it decreased towards inland at both Kadolkele and Wedikanda areas.

Kristensen (2008) reported that the percentage of buried carbon strongly depends on the environmental conditions specially the degree of tidal exchange and sedimentation of suspended matter. According to Breton-Ceron et al. (2011) the amount of carbon in soil differs greatly in different mangrove areas and it is largely influenced by forest age. As primary production increases with stand age, the efficiency of carbon burial in mangrove sediment too increases from 16% for a 5 year old forest to 27% for an 85 year old stand (Alongi et al., 2004).

TOC content of all three depths near the estuarine shoreline (10 – 30 m) recorded at Wedikanda was greater than at Kadolkele. This may be due to the relative location of the sites. Wedikanda is an island located close to the main channel of the estuary through which bulk of the tidal water moves in and out of the estuary and thus receives nutrients and organic matter transported with tidal currents. Besides, mature mangrove stems and branches are periodically harvested from mangrove areas of Wedikanda island to construct the fish aggregation devices locally known as “brush parks” and the cut stems and branches are left within the mangrove areas until all the leaves are fallen (and remain on the forest floor) and stems, twigs and branches are left behind. Frey and Basam (1978) reported the trapping of particulate materials by wetland plants is an important sedimentary and biogeochemical process in accreting wet lands. Sedimentation rates in wetlands have previously been measured by various methods and they were reported to range from 1.6 to 2.4 mm y^{-1} and it decreased in higher latitudes (Twilley, 1992). Higher rates of sedimentation have been observed in riverine mangroves than in basin mangroves. Twilley, (1992) revealed that accretion rates of fringe mangroves are the lowest with less than 1 mm y^{-1}, 1 – 2 mm y^{-1} in basin mangroves and the highest in riverine mangroves, which is more than 2 mm y^{-1}. Mangroves of Kadolkelle and Wedikanda in Negombo basin estuary are located away from the major freshwater inlet, i.e. Dandugam oya to the estuary and they can be categorized as fringing mangroves where accretion is minimal.

The statistically significant positive correlation that was revealed to occur between mangrove stem density and TOC in soil, may partly be due higher contribution of mangrove litterfall to TOC in soil and also by the contribution of extensive root system of mangrove trees that enhances the trapping process of sediment rich in organic matter suspended in the water column during the flooding/ tidal period. Furthermore, the aerial roots retard the forces of erosion along the shoreline, facilitating organic matter retention in the mangrove soils. Another source of organic carbon input to the soil is below ground production which is accounted mainly by dead roots of mangrove plants.

Amount of TOC in surface layer of mangrove soil was estimated to be 20.49 kg m^{-3} and it is acompatible with that of tropical moist and wet forests (6.5 – 21.0 kg m^{-3}) Post and Emanuel, (1982). Buringh (1984) reports that TOC content in prestine tropical forests that ranges 130- 375 t ha^{-1} which is higher than that of grass lands (90 – 160 t ha^{-1}), crop lands (60-130 t ha^{-1}) and secondary forests (140 - 200 t ha^{-1}). Present study revealed that TOC content in surface layer of mangrove soils in Negombo estuary (204.93 t ha^{-1}) is in a magnitude intermediate to that of soils in secondary forests and prestine tropical forests. Ahn Mi-Youn et al (2009) revealed that % TOC in wetland soils in Florida with a high percentage of clay content is proportionately high. Although the frequency and duration of inundation of Negombo estuarine mangrove areas by tide is limited, anaerobic conditions prevailing in mangrove soils, particularly the sub- surface layers, during the rainy period, when surface runoff floods these inter-tidal areas for relatively longer time, oxidation of organic matter due to exposure to atmosphere does not take place thus, decomposition rates decrease, leading to their accumulation in soil. Although the contribution of crabs in burying organic matter, especially through fallen leaves and propagules in burrows is not well investigated, abundance of crabs in these mangrove areas too may influence the carbon burial and thus the carbon sink function of these estuarine mangrove ecosystems.

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